

INVESTIGATION OF RECYCLED TIRE CHIPS FOR USE IN GDOT CONCRETE USED TO  
CONSTRUCT BARRIER WALLS AND OTHER APPLICATIONS

by

KATELYN STALLINGS

(Under the Direction of Stephan A. Durham)

ABSTRACT

This study investigates the use of recycled tire chips as a replacement for natural aggregates in concrete mixtures to improve the impact resistance of concrete barrier walls. The first phase of the project was used to replace large quantities of both coarse and fine aggregates to determine the maximum replacement proportions that could be achieved while maintaining adequate concrete strengths per GDOT standards. The second phase of the project was limited to replacing 20% of the volume of coarse aggregates with recycled tire chips and employed surface treatments to the rubber particles for better adhesion to the cement matrix. A full suite of tests on fresh and hardened concrete properties was performed and adequate strengths were achieved for a replacement up to 20% with recycled tire chips. The rubberized concrete mixtures showed an improved toughness and the ability to resist impact loads when compared to control mixtures.

INDEX WORDS: Recycled tire chips, Impact resistance, Rubberized concrete, Rubber aggregates, Concrete barrier walls

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## CHAPTER 1

### INTRODUCTION

#### **1.1 Use of Waste Materials in Concrete**

The incorporation of waste-stream materials in concrete mixtures has been an important contributor to concrete production for several decades. Materials such as fly ash, which require specialized landfills if disposed, are repurposed in concrete production while providing additional benefits to concrete properties. The use of these materials in concrete has obvious benefits, and therefore, instead of discarding this waste, it is sold thereby providing an additional economic value. The use of recycled tires in concrete production can provide many of the same life-cycle benefits that more traditional supplementary concrete materials offer. The major benefits of using recycled tire aggregates in concrete are not found in the direct economics of the material, but rather in its effect on concrete properties and its life cycle analysis. One major benefit of the use of recycled tire aggregates is the proximity of the manufacturers. Tire recycling facilities are located in and near major metropolitan areas, resulting in reduced transportation costs when compared to natural aggregates that may be trucked or railed in for use in urban concrete construction.

Discarded tires are often disposed in landfills or large stockpiles, resulting in an environmental hazard. Stockpiled tires can harbor water, creating an environment conducive to mosquito breeding and other pests. In the past, tires were burned to avoid this accumulation in stockpiles. The tire fires were difficult to extinguish and would release harmful chemicals into the environment resulting in regulations making it illegal to do so in many countries. With approximately 4,038 thousand tons of tires generated in 2015 in the United States alone, it is

critical to continue finding innovative ways to use this waste material [Rubber Manufacturers Association, 2016].

The use of waste tires in concrete mixtures has the potential to provide increased safety measures to drivers. Rubber modified concrete mixtures have long been discussed as having improved impact resistance and a heightened ability to absorb energy than ordinary portland cement concrete. This ideology could prove beneficial along highways and interstates travelled at high speeds, collisions with the concrete barrier could have fatal consequences. Construction of these walls or other applications involving impact could prove to be a more forgiving and ductile material thereby saving lives.

## **1.2 Study Objectives**

The objective of this research was to determine the impact resistance of rubber modified concrete mixtures for use in concrete barrier walls and other applications. In addition, chemical and mechanical methods to improve the bond between the rubber particles and the cement paste were studied. The toughness of the rubber modified concrete mixtures was a point of emphasis because of its relationship to impact resistance. Additionally, the relationship between the rubber quantity in a concrete mixture and its effect on various concrete properties was researched. The fresh concrete properties examined in this study were slump, air content, unit weight and temperature. The hardened concrete properties measured were compressive strength, split-tension strength, modulus of elasticity, modulus of rupture, absorption capacity, repeated drop-weight impact hammer test, and permeability.

The research was completed into two separate phases. In the first phase, mini-mixtures were designed and batched varying cement and rubber content to measure the influence increased rubber contents had concrete compressive strength. In addition, cement content coupled with

higher rubber contents were examined as well. Furthermore, a series of mixtures batched with crumb rubber were used to compare the effects of rubber particle size on concrete properties. Two additional mixtures including tire chips and crumb rubber in combination as a replacement for sand and rock in the mixtures were investigated.

The second phase of the research aimed at comprehensively studying the effects of tire chip content on hardened concrete properties. The toughness of the rubber modified concrete was of particular interest because of its relationship with energy absorption. Additionally, methods of improving the bond between the recycled tire chips and the cement paste were studied. Recycled tire chips were used to replace coarse aggregates at 10 and 20% by volume. An optimum amount of rubber aggregates to meet current GDOT specifications was determined, as well as the most effective rubber surface treatment to improve the hardened concrete properties.

This study aims at developing a rubber modified concrete mixture that exhibits improved toughness when compared to ordinary portland cement concrete mixtures. The diversion of this waste-stream material is an ancillary benefit to the utilization of this material in practice. The goal was to find the maximum replacement of coarse aggregate with tire chips that displays the greatest impact resistance while satisfying other important concrete characteristics. The use of surface treatments on the rubber particles was aimed at improving the mechanical performance of the rubber-modified concrete, allowing for higher rubber contents to be used in the mixtures while still meeting the requirements for barrier wall construction.

## CHAPTER 2

### LITERATURE REVIEW

#### **2.1 Overview**

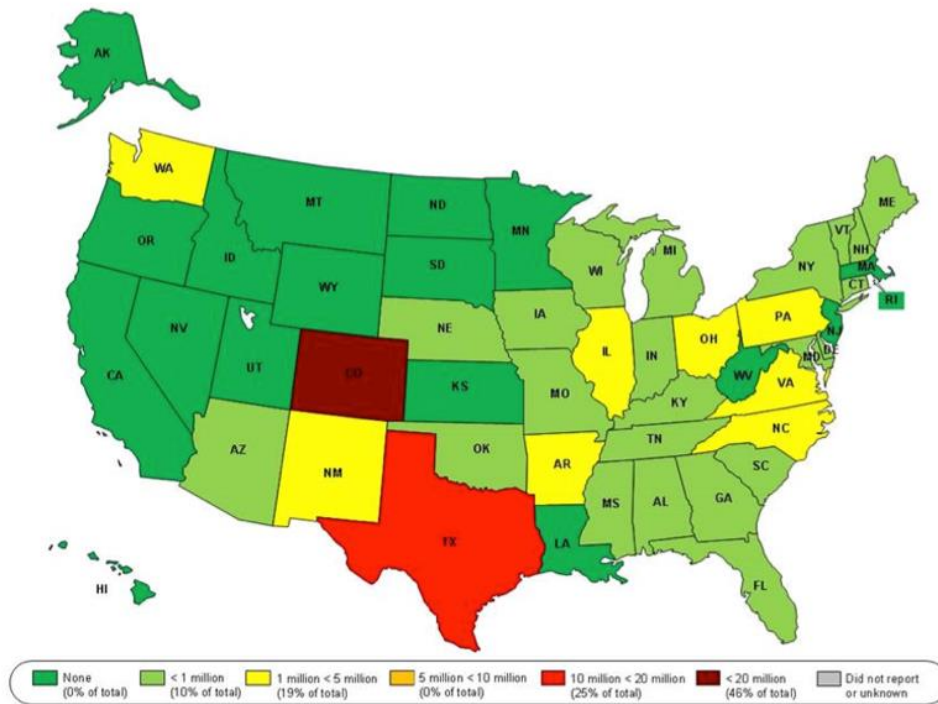
This literature review examines the past studies of concrete mixtures utilizing recycled rubber aggregates and the effects rubber has on concrete material properties. The review notes the trends that researchers of past studies on rubberized concrete have investigated and how these results have impacted rubberized concrete mixture design and enabled the use of rubberized concrete in civil engineering applications.

#### **2.2 Applications**

Organized recycling of scrap tires has existed for several decades, specifically between 1980 and 1990 when efforts were first made to mitigate the growing number of stockpiles. In 1990, an estimated 1 billion scrap tires were housed in stockpiles throughout the United States. While many states have reduced the number of tires stored in stockpiles below 1 million tires, Colorado and Texas far exceed the rest of the country, with more than 20 million and 10 million tires in stockpiles, respectively. Only 25 states have active stockpile cleanup programs working to actively resolve this issue. See Figure 2-1. With increasing numbers of disposed tires each year, new and innovative ways to repurpose this waste will serve the rubber industry well [Rubber Manufacturers Association, 2016].

In 2015, an estimated 4,038 thousand tons of tires were generated in the United States with about 67 million scrap tires remaining in stockpiles in the United States. These scrap tires are used in a variety of manners, including tire-derived fuel, ground rubber, and civil engineering applications. As shown in Figure 2-2, civil engineering applications utilized approximately 275

thousand tons of scrap tires in the United States in 2015, making up about 7% of the total tons of disposed tires. The usage is a 59.8% increase from 2013, where civil engineering applications represented only 172 thousand tons of the market. These recycled tires were used for road and landfill construction, septic tanks, and other construction applications [Rubber Manufacturers Association, 2016].

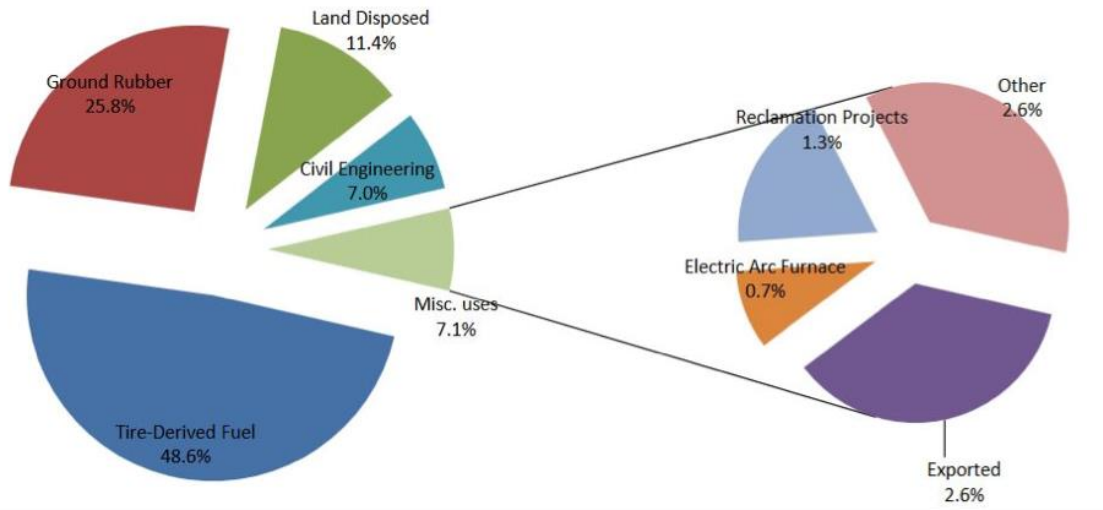


**Figure 2-1: Waste Tire Stockpiles in the United States [RMA, 2016]**

### 2.3 Materials

A comprehensive literature review was conducted prior to designing the concrete mixtures included in this study in order to determine the effects that utilizing recycled tire aggregates have on concrete fresh and hardened properties. Because of the varying applications for which recycled tires are used, the product is available in a number of different sizes. Research has been conducted on rubberized concrete mixtures using a variety of particle sizes, ranging from powdered rubber (<0.017in (0.425mm)) to rough shreds (1.97in (50mm)). The size and shape of the rubber particles

have significant effects on the behavior of the concrete mixtures. The sizes of the rubber aggregates used in most studies are dictated by the availability of products within the regional markets. ASTM D 6270 *Standard Practice for Use of Scrap Tires in Civil Engineering Application* defined many of the different sizes of recycled tire particles. These definitions are displayed in Table 2-1.



**Figure 2-2: Waste Tire Uses in 2015 [RMA, 2016]**

**Table 2-1: Terminology of Recycled Tire Products [ASTM D6270]**

Tire Product	Size Upper Limit, in (mm)	Size Lower Limit, in (mm)
Chopped tire	relatively large pieces of unspecified dimensions	
Rough shred	30 x 1.97 x 3.94 (762 x 50 x 100)	1.97 x 1.97 x 1.97 (50 x 50 x 50)
Tire shreds	12 (305)	1.97 (50)
Tire derived aggregate (TDA)	12 (305)	0.47 (12)
Tire chip	1.96 (50)	0.47 (12)
Granulated rubber	0.47 (2)	less than 0.017 (0.425)
Ground rubber	0.079 (2)	less than 0.017 (0.425)
Powdered rubber	less than 0.017 (0.425)	-

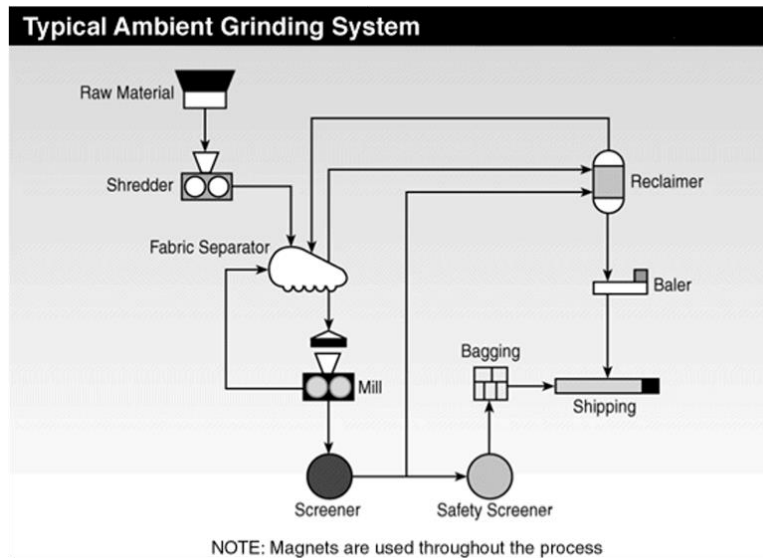
Several factors affect the material properties of the recycled tires used in past studies. The waste tire source was a determining factor in its material properties. Gesoğlu et al. noted that waste

truck tires are denser and stiffer than tires from passenger vehicles, and therefore produced stronger and stiffer concrete. Another finding stated a difference in the unit weight of crumb rubber than that of tire chips. Crumb rubber was found to have a unit weight of 51.82 lb/ft<sup>3</sup> (830 kg/m<sup>3</sup>), while tire chips had an increased unit weight of 63.68 lb/ft<sup>3</sup> (1020 kg/m<sup>3</sup>) [2007]. The density of tires is dependent on the age, manufacturer, and location of the tire.

The size and shape of the rubber particles dictates how the product was produced. Scrap tire rubber is primarily made of passenger car and truck tires, with a small percentage derived from off-road tires. Rubber properties such as strength and weight are affected by the original purpose of the tire and in return influence the manner in which the recycled tire particles are utilized. The production of crumb rubber particles is accomplished through numerous methods; however, the two most common are ambient grinding and cryogenic processing. Tires shredded using an ambient grinding method have a rough surface texture with a cut shape and similar dimensions. Smaller recycled tire products, such as crumb rubber, are often produced using cryogenic methods, which involve the use of liquid nitrogen or other chemicals to freeze the waste tires prior to reducing the material into smaller pieces [Scrap Tire News]. Another popular method used in the United States is a wet grind process, and it is used to produce crumb rubber with sizes ranging from 40 mesh to 200 mesh.

The ambient process, Figure 2-3, can be completed with the use of granulation or cracker mills. With this process, the material is stored at room temperature until they are processed. The granulation process usually requires three steps to separate the rubber, metal, and fabric from the waste tires. The first step shreds the tires into smaller tire chips, while the second machine removes the metal and fabric from the product. Large magnets are used to remove metals from the material, while air separators are used to remove the fabric from the rubber shreds. After each step is

complete, the material is sent through a sifter to gather any large pieces of rubber to send them back through the grinding process once more in order to ensure uniform sizing.

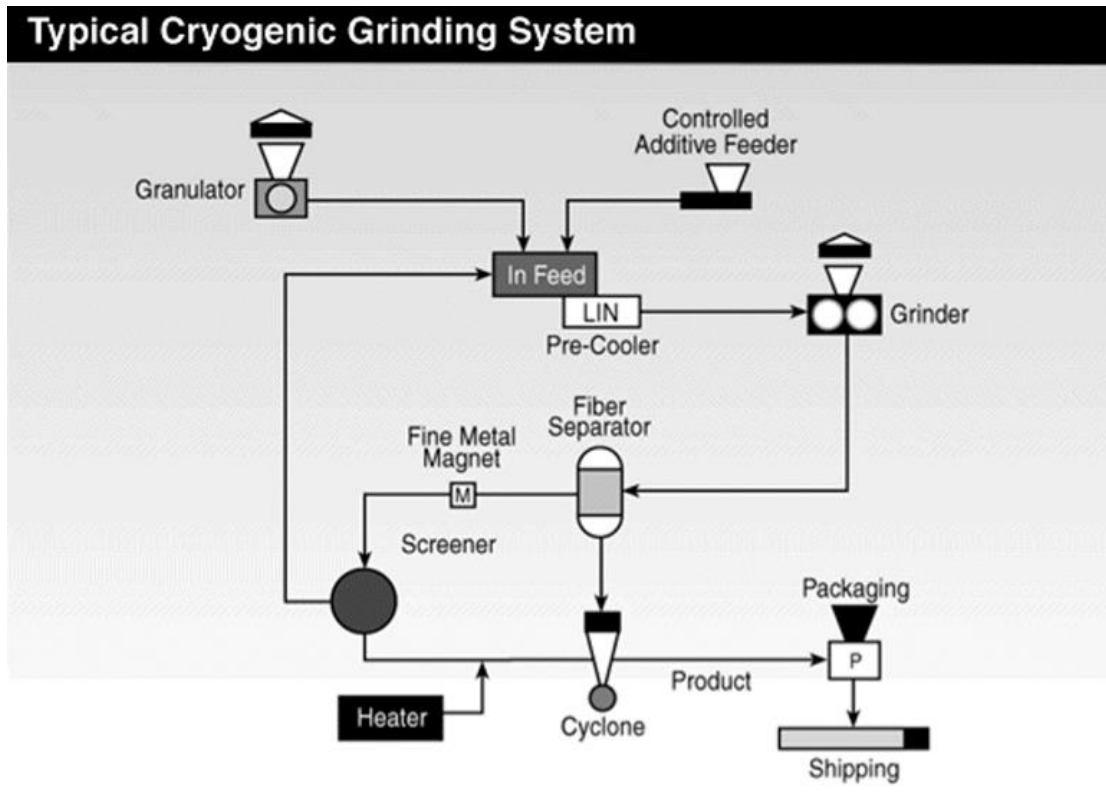


**Figure 2-3: Diagram of the Typical Ambient Shredding Process [Scrap Tire News]**

Once the rubber is grinded to an appropriate size and all of the extraneous materials are removed, the rubber is sent through a finishing mill to process the tire shreds into specified sizing. Cracker mills are very similar to this process. They usually involve two large rotating rollers with grooves cut in them to shred the tires. In this process, the size of the tire shreds is dictated by the distance between the rollers. The waste tires will pass through two or three of these cracker mills to attain the size necessary. Once this process is complete, the particles are sent through a screening system which sorts the tire pieces into different size categories. Particles that are deemed too large during this separate screening process are sent back through the cracker mills again. Shredded rubber products produced using the ambient method have rough surface texture with a cut shape and similar dimensions.

Methods of producing smaller rubber particle sizes usually involve a cryogenic process shown in Figure 2-4. This refers to the use of liquid nitrogen or other chemicals to freeze the waste

tires prior to reducing the material into smaller pieces. The rubber is subjected to temperatures as low as  $-112^{\circ}\text{F}$  ( $-80^{\circ}\text{C}$ ), at which the rubber material becomes glass-like. This process is generally used once the tires have been reduced to a 2 inch (5.08 cm) chip or smaller.



**Figure 2-4: Diagram of the Typical Cryogenic Process [Scrap Tire News]**

The material is cooled by immersion in a bath of liquid nitrogen, or sprayed with the chemical. Then the product is essentially smashed with a hammer, shattering the frozen rubber into small grinds. This impact typically reduces the rubber to sizes ranging from 1/4 inch (0.635 cm) to 30 mesh. This process has the capability to produce anywhere between 4,000 to 6,000 pounds (1,814 to 2,722 kg) of crumb rubber per hour. The production of smaller crumb rubber particles requires an additional grinding stage. To produce crumb rubber finer than 40 mesh, micro milling, or wet grinding is used. Crumb rubber is added to water, creating a slurry, where it

classified by size. When the correct sizes are separated, the slurry is dried, and the remaining rubber particles are ground in a process very similar to the ambient process. This process produces very clean rubber particles void of much debris that are mostly 60 mesh or finer [Scrap Tire News].

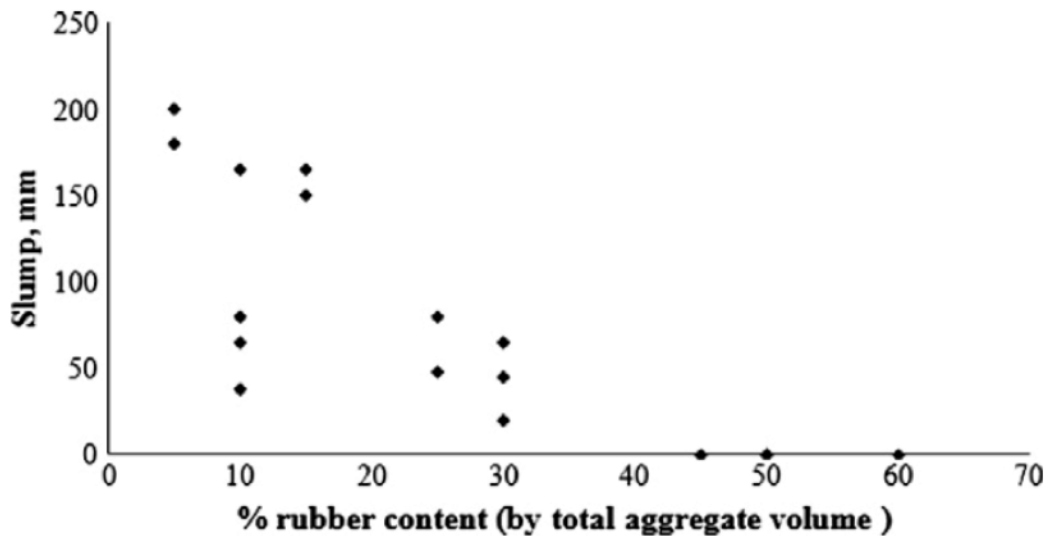
## **2.4 Fresh Properties of Rubberized Concrete**

Fresh concrete properties are an important indicator as to how the concrete mixture will ultimately behave in its hardened state. The initial properties impact the material's compressive strength, modulus of elasticity, durability, and likelihood of creep. The properties that are typically tested are slump, unit weight, temperature, and air content. The addition of other mixture constituents directly affects these properties, and ultimately, the long-term behavior of the material. In rubberized concrete, the size of the rubber particle added to the mixture also affects the concrete properties in different ways.

### **2.4.1 Slump**

Workability is an important measure of the concrete mixture that allows for it to be placed and finished without honeycombing or segregation. The slump test is a measure of concrete's workability and depends on the water-to-cementitious materials ratio (w/cm), water content, and air content of the concrete mixture. Rubberized concrete mixtures have been found to have lower slumps when compared to control mixtures. In one study, slump was reported to have decreased by more than 1/2 inch (1.27 cm) as compared to the control mixture when 25% of the coarse aggregate was replaced with rubber particles. The mixtures experienced even less slump as rubber content increased. This effect was mitigated with the use of plasticizer and air entraining admixture [Bing et. al., 2014]. Concrete mixtures that utilize silica fume as a cementitious material experienced even lower slump values [Antil, 2014]. Several studies have reported a slump of 0.0in (0.0mm) for mixtures which replaced 50% of the total aggregate volume with tire chips. Figure 2-

5 shows the slump change for concrete mixtures with increasing rubber content by total aggregate volume.



**Figure 2-5: Effect of Rubber Content on Slump Measurements [Najim et al., 2010]**

It is theorized that the decrease in slump with increasing rubber contents is due to friction created between the rubber and concrete mixture particles [Najim et al., 2010]. In addition, the reduction in workability may be a result of the fact that rubber particles create “an interlocking structure that resists the normal flow of concrete under its own weight” [Bing et al., 2014]. Despite the overwhelming majority of studies finding that slump decreases as rubber content increases in concrete mixtures, a few studies have reported the opposite effect. One study found that the maximum slump was more than 1.5 inches (3.81 cm) greater than the control mixture and occurred when 25% of both the coarse and fine aggregates were replaced with the same volume of rubber chips [Aiello et al., 2010]. Another study showing similar results found that tire derived aggregates increased the slump by an average of 1 inch when compared to the control mixture. In addition, the study found that silica fume in low quantities, 3 percent or less, further improved the workability of the mixture. Doses of silica fume greater than 5 percent, however, reduced the slump

[Siringi et al., 2015]. Another study showed that rubberized concrete mixtures that replaced 10% of the cement content with silica fume always had lower slump values than mixtures that were 100% cement [Gesoglu et al., 2007].

The shape and size of the rubber particles impact the workability of the rubberized concrete mixtures. Khatib and Bayomy found that rubberized concrete mixtures that replaced fine aggregates with crumb rubber experienced lower slump values when compared to mixtures that replaced coarse aggregate with tire chips and mixtures that replaced both coarse and fine aggregates at equal percentages. All rubberized concrete mixtures produced slump values less than the control mixture [1999].

#### **2.4.2 Air Content**

Agreement from several studies suggest the addition of rubber particles in concrete mixtures increases the air content of the sample even without the help of air entraining admixtures. One study found that increasing rubber aggregate content in 25% increments resulted in a quasi-linear relationship between the air content and rubber content of the mixture. The control mixture with a w/cm of 0.45 and no rubber aggregates had an air content of 2.5% while the rubberized concrete mixture consisting of a 100% replacement of coarse aggregates with tire chips had an air content of 6.0%. Similar to conventional concrete with only natural aggregates, the study showed an increase in air content with an increase in water content. The 100% aggregate replacement with tire chips mixture for the w/cm of 0.60 had an air content of 7.5% [Bing et al., 2014]. While this trend is evident in many studies, the size and shape of the rubber aggregates influences the air content of the rubberized concrete mixtures. Khatib and Bayomy found that concrete mixtures made with crumb rubber had greater air contents than those made with the same percent rubber content by total aggregate volume using tire chips [1999]. It is believed the rough surface of the

rubber aggregates is the cause of increased air contents in rubberized concrete mixtures. The non-polar nature of the rubber particles pushes away water molecules, while simultaneously trapping air on the surface of the rubber [Najim et. al., 2010].

### **2.4.3 Unit Weight**

Due to the increased air content of rubberized concrete samples and the replacement of dense aggregate with lighter rubber particles, the unit weight of rubberized concrete decreases as compared to conventional concrete as predicted. In one study, tests were completed replacing either coarse or fine aggregate by volume in 25% increments, with 75% replacement being the greatest. The unit weight decreased at approximately 2.9% for every 25% increase in coarse aggregate replacement. The results of this study are shown in Figure 2-6. The first grouping of mixtures in the figure include the control mixture, and mixtures replacing coarse aggregate with rubber particles at 25%, 50%, and 75%. The second grouping shows the unit weights and percent decrease for the control mixture and rubber replacing fine aggregate at 15%, 30%, 50%, and 75% by volume [Aiello et. al., 2010]. Güneyisi et al. found that at a 50% rubber content, the unit weight was only 75% of the normal concrete [2004]. In addition, studies have shown unit weight to be affected by how the rubber is ground prior to its inclusion in concrete mixtures. Rubber ground using a mechanical process will likely produce rubberized concrete with a higher air content due to its angular shape and thus lead to a decreased unit weight [Pedro et. al., 2013].

No.	Unit weight (kg/m <sup>3</sup> )	Decrease
C1	2372	–
RA1	2304	2.9
RB1	2234	5.8
RC1	2163	8.8
C2	2310	–
RA2	2254	2.4
RB2	2195	4.9
RC2	2170	6.0
RD2	2117	8.3

**Figure 2-6: Effect of Increasing Rubber Content on Unit Weight [Aiello et al., 2010]**

One study determined the bulk density of cement to be 63.74 lb/ft<sup>3</sup> (1,021 kg/m<sup>3</sup>), fine aggregate to be 90.58 lb/ft<sup>3</sup> (1,451 kg/m<sup>3</sup>), and rubber to be only 28.16 lb/ft<sup>3</sup> (451 kg/m<sup>3</sup>) [Pedro et al., 2013]. These measurements differ greatly from those found in another study, which observed the gravel with a unit weight of 103 lb/ft<sup>3</sup> (1,650 kg/m<sup>3</sup>), sand with a unit weight of 106.13 lb/ft<sup>3</sup> (1,700 kg/m<sup>3</sup>), and rubber particles with a unit weight of 71.79 lb/ft<sup>3</sup> (1,150 kg/m<sup>3</sup>) [Bing et al., 2014].

#### **2.4.4 Temperature**

While not widely reported in past research articles, temperature plays an important role in the strength development of concrete mixtures. Concrete temperature should range between 50 and 85°F (10 - 29°C) for proper cement hydration. Concrete with temperatures that exceed the 85°F (29°C) are at risk for plastic shrinkage, and ultimately internal cracking resulting from these stresses. Studies have shown that the addition of rubber aggregates did not cause the temperatures to exceed the allowable range [Kardos et al., 2015; Elchalakani, 2014].

It should be noted that it is important to utilize recycled rubber aggregates that have not been exposed to the sun for extensive periods of time. The black color of the tires will absorb heat, and could potentially speed up the hydration process of the rubberized concrete mixtures. The

acceleration of the hydration process could make mixtures much less workable and much more difficult to place and finish.

#### **2.4.5 Fresh Concrete Properties Summary**

In summary, past research on fresh rubberized concrete properties have shown the following trends:

- As rubber content increases, slump tends to decrease, becoming much less workable;
- At about 50% rubber content by total aggregate, slump nears 0 inches (0 cm);
- Air content of concrete increases as rubber content increases;
- Rubber particles are hydrophobic, allowing surface tension to trap air on its surface;
- Rubber does not affect concrete temperature; however, it is important to use rubber that has not been excessively exposed to the sun.

### **2.5 Properties of Hardened Rubberized Concrete**

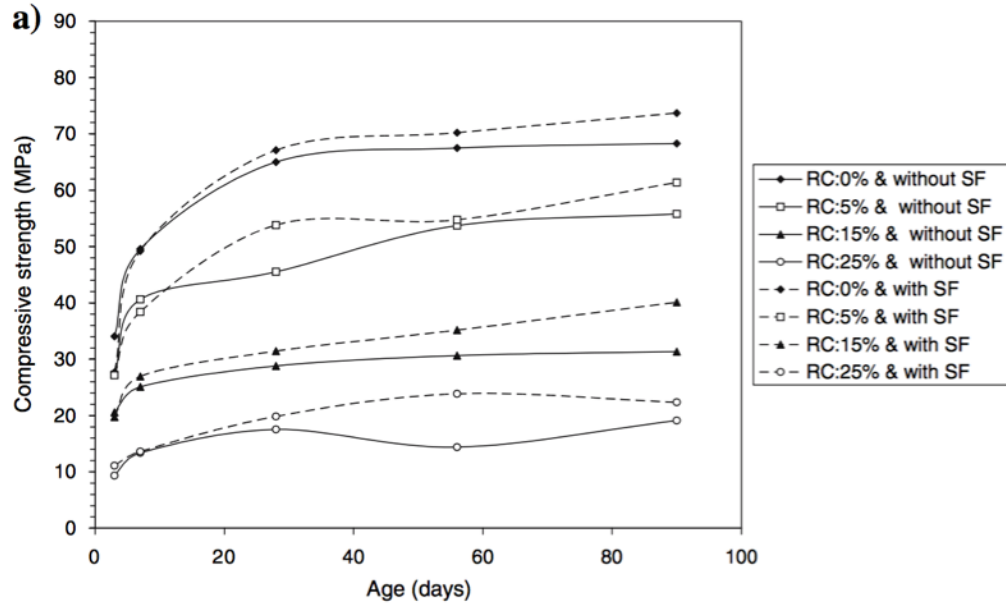
Rubber aggregates have been shown to have a significant impact on concrete's hardened properties. Concrete's compressive strength, split tensile strength, flexural strength, impact resistance, and resistance to chloride ion penetration is a direct function of the amount of rubber present in the mixture. As discussed in the following, the rubber particles size affects the hardened concrete properties.

#### **2.5.1 Compressive Strength**

Replacing aggregates with a more flexible, less dense material leads the concrete to have a reduced compressive strength. Rubber particle size and the material that is replaced has a strong influence on the effect of the replacement. In one study, coarse aggregates were replaced in increments of 25%, 50%, and 75% by total aggregate volume with recycled tire shreds. Cylinders

were created and tested for each of these mixtures, and the compressive strength of each sample decreased by 47.8%, 54.4%, and 61.9% respectively compared to the control mixture. The other group in this study replaced fine aggregates with rubber particles by volume in increments of 15%, 30%, 50%, and 75%. While each of the mixtures experienced a decrease in compressive strength compared to the control mixture, the 75% fine aggregate replacement mixture only showed a 37.1% decrease [Aiello et al., 2010]. This study suggests that replacing fine aggregates with crumb rubber particles has a less significant effect on the compressive strength than replacing coarse aggregates with tire chips. Another study agreed with this notion, noting that when all coarse aggregate was replaced with tire chips, the compressive strength experienced an 85% reduction, while only a 65% reduction in compressive strength was observed when 100% of the fine aggregates were replaced with crumb rubber particles [Siddique et al., 2004]. Siringi et al. found that a 17% replacement of coarse aggregate with 2" tire derived aggregate produced compressive strengths that were 45% lower than the control after 7 days and 40% lower at 28 days. When only 10% of coarse aggregate was replaced with 2 inch (5.08 cm) tire chips, compressive strength reduction was only 28.6% and 33.8% at 7 and 28 days, respectively [2015]. One study showed more promising results, with a 25% replacement of coarse aggregate experiencing a 26.5% reduction in compressive strength as compared to the control mixture with a w/cm of 0.40 [Bing et al., 2014].

The use of silica fume as a cementitious material replacement has proven to increase compressive strengths in both plain portland cement concrete and rubberized concrete mixtures [Gesoglu et al., 2007]. Figure 2-7 shows the change in compressive strength through 90 days of age for rubberized concretes with increasing rubber aggregates.



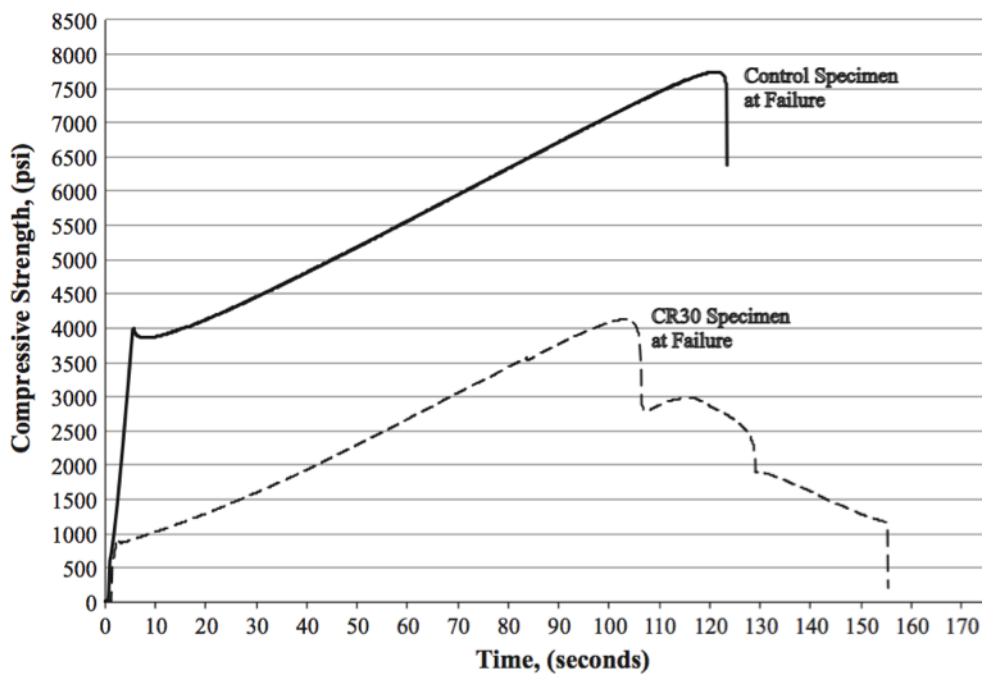
**Figure 2-7: Compressive Strength of Rubberized Concrete Mixtures With and Without Silica Fume Over 90-Day Period [Gesoğlu et al., 2007]**

While there is still a systematic decrease in compressive strength as more rubber is present in the mixture, replacing just 10% of cement with an equal weight of silica fume improves compressive strength. Another observation is that rubberized concrete mixtures have a high rate of strength gain in the first seven days after mixing, with the rate slowing down over a 90-day period [Gesoğlu et al., 2007]. Another study found that when fly ash made up 20% of the cementitious materials, the greatest compressive strengths occurred [Solanki et al., 2015].

Ganjian et al. attributes the loss in compressive strength to many contributing factors. One reason is that cement paste with rubber is softer than without, allowing for the development of cracks to form around rubber particles and expand during loading. In addition, poor bonding between cement and rubber particles leads to stresses being applied to the samples not uniformly. This causes cracks to occur between aggregates and the cement because they are responsible for a greater amount of the stress. Rubber aggregates are susceptible to movement toward the top of a sample when vibrated. This obviously leads to a non-uniform specimen with lower strength and

stiffness toward the top, where failure is more likely to occur. Finally, Ganjian et al. states that rubber is a much less stiff material than natural aggregates. This results in rubberized concrete mixtures having a much lower modulus of elasticity than conventional concrete mixtures [2008].

One observation worth noting is the failure behavior of rubberized concrete when subjected to flexural loadings. Kardos and Durham note that control mixtures with no rubber particles failed suddenly after the initiation of crack. The rubberized concrete specimens using crumb rubber particles were able to withstand one-quarter of its ultimate load after failure. This is explained by the crumb rubber pieces bridging the cracks in the concrete, much like how steel fiber reinforcement behaves [2015]. This ability to withstand residual loading is shown in Figure 2-8.



**Figure 2-8: Control Versus 30% CR Mixture [Kardos et al., 2015]**

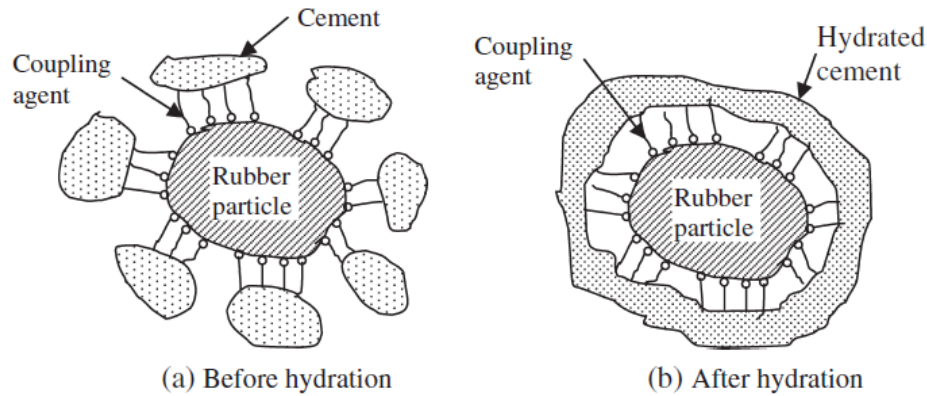
### **2.5.1.1 Surface Treatments of Recycled Rubber Particles**

Siddique et al. noted that there are several methods that have been studied to help diminish the loss in compressive strength of rubberized concrete mixtures. Some techniques include washing the rubber surface with water, acid etching, plasma pretreatment, and coupling agents. The purpose behind performing these pretreatments is to increase the surface roughness of the rubber particles, allowing for a better bond to form between the rubber and cement. Among the most effective of the treatments that have been studied, immersion in sodium hydroxide (NaOH) was found to be one of the most effective solutions [2004]. Segre et al. used saturated NaOH aqueous solutions to soak rubber particles in for 20 minutes, while the mixture was continuously stirred. The rubber particles were then removed, rinsed with water and dried at room temperature. The interface between the rubber and cement paste was studied using a Scanning Electron Microscope (SEM) and it was observed that the adhesion was improved when NaOH was used [2000]. Segre et al. notes that pretreatments with higher NaOH concentrations improved the adhesion more effectively. Segre et al. also stated that it is hypothesized that the NaOH “hydrolyzes the acidic and/or carboxyl groups” on the surface of the tire [2000]. Siddique et al. states that the NaOH pretreatment increases the strength of the rubberized concrete by imposing microscopic grooves in the rubber particles, increasing the surface area of the aggregates and increasing the bond strength between the cement matrix and the rubber particles [2004].

Rostami et al. [1993] found that simply soaking rubber particles in water resulted in compressive strengths 16% higher than those which were untreated. When carbon tetrachloride and water were used to pretreat rubber aggregates, the mixtures saw a 57% increase in compressive strength [Siddique et al., 2004].

Dong et al. performed a pretreatment in which the rubber particles used in the study were coated with a silane coupling agent. It was determined that the rubberized concrete mixtures that used silane coated particles performed much better under compression than the uncoated rubber modified concrete did. At the 28-day sample, the 30% coated rubber mix exhibited strengths that were 25% greater than the 30% uncoated rubberized did. The coating also prevented the concretes from losing as much strength when compared to the control mixture. At 28-days, the 15% coated rubber mixture lost only 10% of the compressive strength when compared to the control mixture, while the 30% coated rubber mixture lost only 23%. In comparison, the uncoated rubber mixtures lost 32% and 38% of the compressive strength, respectively [2013].

Dong et al. chemically bonded cement particles to the surface of rubber particles. The procedure to coat the rubber particles first began with creating an ethyl alcohol aqueous solution at a predetermined concentration and adding silane and stirring for a duration of 10 minutes with the use of a magnetic stirrer. Once this was complete, the rubber particles were added and stirred for 20 minutes. The rubber-silane-ethyl alcohol concoction was then heated to 80°C and refluxed for 30 minutes and cooled to room temperature. Once this was complete, the rubber was rinsed with alcohol by filtration and dried in an oven at 110°C for 12 hours. The result is an improved rubber particle that will bond with cement particles as displayed in Figure 2-9. The use of this method produced compressive and split tensile strengths that were 10-20% higher than the untreated rubberized concrete mixtures. Another notable finding was that the silane coated rubber particle mixtures experienced an improvement in energy absorptivity when compared to the untreated rubberized concrete mixtures [2013].



**Figure 2-9: Silane Pretreated and Cement Coated Rubber Particles [Dong et al., 2013]**

Huang et al. studied a two-staged pretreatment of rubber particles for bond improvement. In the first stage, a silane coupling agent was used to coat the particles. This method was used because of ability of the silane solution to attach to organic materials like rubber, allowing the surface of the rubber particles to better attach to the cement paste. The particles were then treated with cement to coat the silane layer. This provided a hard shell around the rubber and improved the bond to the rest of the concrete matrix. The compressive strengths of the concrete mixes made with this two-stage method saw substantial improvements when compared to as-received rubber modified concretes. Rubber contents of 5, 10, 15, 20, and 25% were tested, and saw 24, 9, 18, 14, and 22% increases in strengths between the two groups [2012].

### **2.5.2 Flexural Strength and Modulus of Rupture**

Much like the compressive strength results, as more rubber aggregates are incorporated into concrete mixtures, flexural strength decreases. This result is expected, because flexural strength is a function of a material's compressive strength. One study replaced coarse aggregate with rubber chips having a maximum nominal size of 0.79 inch (20 mm) by volume in 3% increments. The control mixture had an average flexural strength of 707.78 psi (4.88 MPa), while the mixture with just 12% rubber aggregates was only 362.59 psi (2.50 MPa). The mixture with

3% rubber aggregate lost 6.76% of its flexural strength after 28 days [Shah et al., 2014]. Similarly, a study which used a combination of crumb rubber and fine rubber powder to replace fine aggregates found that when 40% of the aggregate was replaced, the rubberized concrete lost 72% of its flexural strength. When only 10% of rubber was added, the rubberized concrete lost 37.9% of its flexural strength as compared to the control mixture. The study compared the results of these mixtures to similar mixtures containing 10% silica fume and found that the mixture containing 40% fine rubber aggregates lost 68.9% of its flexural strength. The mixture containing silica fume only lost 23.7% of its flexural strength with 10% rubber aggregates [Elchalakani, 2014].

### **2.5.3 Split Tension Strength**

Split tension strength has been shown in many studies to decrease with the addition of rubber into the concrete matrix. One study tested the indirect tensile strength of cylinders with varying amounts of tire screenings, tire chips, and fly ash. When no tire screenings were added to the mixture, the sample that had 40% fly ash had the greatest tensile strength, measuring at 831 psi (5.73 MPa). However, when the mixture had 40% tire aggregates replacing the fine aggregates, and 40% fly ash, the mixture had the least amount of tensile strength, at only 22 psi (0.15 MPa). With increasing amounts of tire screenings, the tensile strength decreased, with no apparent relationship to the amount of fly ash. When coarse aggregates were replaced with tire chips, the same trends occurred, except the tensile strengths were noticeably greater for the samples with tire chips [Solanki et al., 2015]. Another study found an interesting trend. While all mixtures showed tensile strengths less than the control mixture, Ganjian et al. found that ground rubber particles substituted for cement had greater tensile strength than chipped rubber replacing coarse aggregates for all replacement percentages by weight [2009].

Studies have shown that the interesting and noteworthy observation discovered while performing the split tension test is the manner by which the specimens failed. While the study found that the tensile strength decreased with increasing rubber content, cylinders that contained crumb rubber particles showed a crushing effect before failure. Cylinders with no rubber aggregates simply crack suddenly in half. The rubberized concrete cylinders showed flattened out bearing surfaces from where the load was applied, and crumbled under the stress [Kardos et al., 2015].

#### **2.5.4 Modulus of Elasticity**

The modulus of elasticity is a measure of a material's stiffness and is a ratio of stress to strain. One study found that samples with a 7.5% replacement of coarse aggregates with tire chips saw a 20% decrease in the modulus of elasticity [Siringi et al., 2015]. Güneyisi et al. also found that increasing the rubber content decreased the modulus of elasticity of the rubberized concrete sample. For a w/cm of 0.60, the control mixture had a modulus of elasticity of 4,786 ksi (33 GPa), while the sample with a w/cm of 0.40 had a modulus of elasticity of 6,672 ksi (46 GPa). A sample with a 50% rubber content of the total aggregate volume experienced a modulus of elasticity of 943 and 1160 ksi (6.5 and 8.0 GPa) for w/cm of 0.60 and 0.40 respectively. For this study, the concrete experienced an 83% decrease in the modulus of elasticity for all rubberized concretes. The addition of silica fume improved the modulus of elasticity slightly, increasing the value up to 15% [2004]. One journal explains that the modulus of elasticity of the rubberized concrete experiences the decrease compared to the control mixture because it is directly dependent on the stiffness of the constituents in the mixture. In their experiment, they saw the effect that the w/cm had on the modulus of elasticity as well. In Series I, a w/cm content of 0.40 was used while Series II used 0.60. For replacement percentages of 25, 50, 75 and 100% of coarse aggregate with rubber

particles, the mixtures for Series I saw a decrease in the modulus of elasticity of 13, 36, 44, and 57% respectively. The same percent replacements for Series II saw decreases in the modulus of elasticity of 30, 40, 54.6 and 69.5% respectively [Bing et al., 2014]. A study completed by Ganjian et al. compared the effect of crumb rubber versus rubber chips on the reduction in the modulus of elasticity. With a 5-10% replacement of aggregate with rubber, chipped rubber saw a 17-25% reduction in the modulus of elasticity while powdered rubber experienced an 18-36% reduction [Thomas et al., 2015].

### **2.5.5 Energy Absorption**

Rubberized concrete is often considered a quality option for lightweight concrete where strength is not the most important defining characteristic. Studies have shown that rubber aggregates provide concrete with increased toughness and the ability to sustain loading after failure. Pedro et al. performed an impact test where a 1 kg (2.20 lb) mass was dropped at increasing heights onto rubberized concrete samples. The results showed that the rubberized samples had between 2 and 2.5 cm (0.79 and 0.98 in) diameter dents, while the control mixture had dents ranging from 1 and 1.5 cm (0.39 and 0.59 in). In addition, the authors found that mixtures with higher rubber contents were able to sustain drops from greater heights without cracking compared to the control mixture. Crack widths also decreased with the inclusion of rubber particles. It was concluded that introducing rubber into the concrete matrix improved the concrete's response to impact and could withstand "higher energy without rupture" [2013]. Najim et al. found that rubberized concrete's toughness increased up to a rubber content of 25% volumetric replacement. Further, it was found that rubberized concrete exhibits improved fracture toughness, where a 75% replacement had a 350% improvement over the control mixture. While the introduction of rubber chips improves the impact resistance, it was found that "crack width and propagation is greater in comparison with

natural aggregate content.” This phenomenon is thought to be due to the higher strain rate rubberized concrete experience. Because of this fact, rubberized concrete is able to absorb more energy when compared to traditional concrete mixtures [2010].

Tantala et al. [1996] found that the toughness of concrete mixtures with 5% and 10% rubber by volume of the coarse aggregate content was greater than that of the control mixture. The mixture with only 5% rubber content had greater toughness than the 10% mixture as a result of a more substantial decrease in compressive strength for the mixture with the greater rubber content. Raghvan et al. [1998] found that rubberized concrete mixtures made with rubber shreds were able to withstand additional loading after the peak load. This was due to the rubber particles bridging the cracks in the concrete. Rubberized concrete mixtures made with shredded rubber pieces were not broken entirely in half during this experiment, while mixtures made with crumb rubber pieces broke into halves after peak load. It was concluded that post-cracking strength was “enhanced when rubber shreds are used instead of granular rubber” [Siddique et al., 2004].

Elchalakani notes that not much previous work has been done on the use of rubberized concrete in barrier wall construction. Rubber modified concrete mixtures are generally regarded as useful in situations where strength is not important. Many suggested uses of the composite material are for sound barriers or vibration absorptive infrastructure for use in agriculture. Previous studies on the use of rubberized concrete in barrier walls found that increased rubber content reduced vehicular deceleration forces significantly. The drop tests for this study found that rubberized concretes are more resilient, and able to endure high impact load “without inducing a stress more than the plastic limit” [2014].

### 2.5.6 Resistance to Chloride Ion Penetration (Permeability)

A concrete's resistance to chloride ion penetration is an indication of the concrete's permeability. Less permeable concrete is more likely to have a longer life, because water is not allowed to seep into the concrete and form internal stresses. In a study conducted by Gesoğlu et al., it was observed that the depth of chloride penetration increases with the increase in rubber content. This effect was magnified with a higher w/cm. The effects varied with increased moist curing times. Longer moist curing times decreased the chloride penetration depth in all samples [2007]. These effects are evident in the Figure 2-10. The first graph shows the chloride penetration depth for concrete with a w/cm of 0.40 while the second is a ratio of 0.60. For the concrete with a 0.40 w/cm, the chloride penetration depth varied 27-59% from the control mixture, while the 0.60 w/cm concrete varied about 6-40%. The chloride penetration depth significantly decreases with 28 days of moist curing. In addition, the inclusion of silica fume, at dosages of 10% by mass, greatly improves the resistance to chloride penetration.

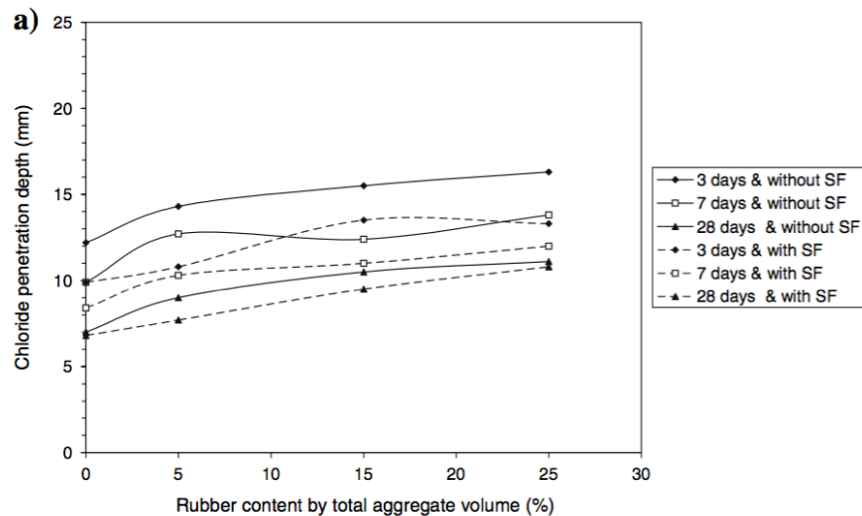


Figure 2-10: Effects of Rubber Content on Permeability [Gesoğlu et al., 2007]

### **2.5.7 Hardened Concrete Properties Summary**

In summary, past research on hardened rubberized concrete properties have shown the following trends:

- As rubber is added to concrete mixtures, compressive strength decreases significantly;
- When cement is replaced with 10% silica fume in rubberized concrete mixtures, better compressive strengths are reported;
- Flexural strength decreases with increased rubber content; however, rubberized concretes are able to withstand residual loads after failure;
- Rubberized concretes show improved resistance to impact loads, often cracking less than the control mixtures;
- Concrete is more permeable with increased rubber contents;
- Permeability decreases when silica fume is present in the mixture at equal rubber contents;
- Rubberized concrete mixtures show a less brittle, more elastic failure mechanism than traditional concrete cylinders.

### **2.5.8 Literature Review Rubberized Concrete Properties Summary**

A thorough literature review was completed on the use of recycled rubber aggregates in concrete and their effects on concrete properties. A brief summary of these properties are shown in Table 2-2.

**Table 2-2: Summary of Literature Review**

Slump & Workability	Decrease	(Bing et. al., 2014)
		(Antil, 2014)
		(Najim et. al., 2010)
		(Siringi, et. al., 2015)
		(Gesoglu, et. al., 2007)
	Increase	(Khatib, et. al., 1999)
	Increase	(Aiello, et. al., 2010)
Air Content	Increase	(Bing et. al., 2014)
		(Najim et. al., 2010)
		(Khatib, et. al., 1999)
Unit Weight	Decrease	(Guneyisi et. al., 2004)
		(Pedro, et. al., 2013)
		(Aiello, et. al., 2010)
		(Bing, et. al., 2014)
Compressive Strength	Decrease	(Aiello, et. al., 2010)
		(Siddique, et. al., 2004)
		(Siringi, et. al., 2015)
		(Bing, et. al., 2014)
		(Ganjian, et. al., 2009)
Flexural Strength	Decrease	(Shah, et. al., 2014)
		(Elchalakani, 2014)
		(Kardos and Durham, 2015)
Splitting Tension	Decrease	(Solanki, et. al., 2015)
		(Kardos and Durham, 2015)
Modulus of Elasticity	Decrease	(Siringi, et. al., 2015)
		(Guneyisi, et. al., 2004)
		(Bing, et. al., 2014)
		Thomas, et. al., 2015)
Permeability	Decrease	(Gesoglu, et. al., 2007)
Energy Absorption	Increase	(Pedro, et. al., 2013)
		(Najim, et. al., 2010)
		(Tantala, et. al, 1996)
		(Raghvan, et. al., 1998)
		(Siddique, et. al., 2004)

## CHAPTER 3

### PROBLEM STATEMENT

In recent decades, tires have been recycled in numerous ways across the United States. However, as the population continues to grow, it is important to continue investigating new and innovative ways to repurpose this waste material. Georgia lawmakers passed legislation in the early 1990s which outlined specific guidelines to follow for disposing of waste tires throughout the state. The Department of Natural Resources Environmental Protection Division is responsible for overseeing the proper disposal of these waste tires. This agency requires that all scrap tires receive an identification number and be tracked to its final end user or disposal facility. Permits are assigned to approved disposal facilities as well as any individual transporting the scrap tires. Additionally, there exists strict requirements for processing plants intended to recycle these waste tires.

In 2013, GDOT constructed more than 42,000 LF of concrete barrier utilizing a Class A concrete mixture design (3000 psi). There may be potential for the beneficial utilization of recycled tire chips in concrete barrier applications which can possibly lead to improved safety for vehicle occupants as well as reduce disposed rubber from going to landfills or stockpiles, and potentially saving materials cost for GDOT. Additionally, there may be other applications requiring less compressive strength, Class B – 2200 psi, where rubberized concrete could be advantageous. Concrete safety barriers are one of the widely used impact attenuators that are intended to either decelerate vehicles to a safe stop or redirect them away from a fixed object. However, concrete exhibits little plastic deformation when impacted by a vehicle and thus an

undesirable trait for safety barriers. GDOT has not studied recycled rubber tires for concrete barriers or other concrete related applications despite the potential for safety, environmental, and economic benefits.

The overall objective of this study was to create rubber-modified concrete that exhibits improved toughness for impact resistance when compared to concrete mixtures without rubber aggregates. More ductile barrier walls and other concrete infrastructure will provide a safer, more durable and energy absorptive surface in the case of car collisions. An ancillary benefit of the use of this waste material is that it provides another destination for recycled tire chips. The use of this material in concrete barrier walls will aid in the management of waste produced by increasing urbanization. To accomplish this, GDOT Class A (3,000 psi, 20.68 MPa) concrete design requirements will be abided by for the rubberized concrete mixtures developed in this study. Additional recommendations will be made for use in GDOT Class B concrete (2,200 psi, 15.17 MPa).

Ultimately, the study purpose is to assess the potential for recycled tire particles for use as a virgin aggregate replacement in concrete production in Georgia. In particular, the effect of the replacement of coarse aggregate with recycled tire chips and fine aggregate with crumb rubber particles on various fresh and hardened concrete properties were determined. In each instance, the virgin aggregates were replaced volumetrically in 10% increments up to the maximum of 50%. In the first phase of the project, the effects of the replacement with rubber on the concrete's compressive strength along with slump, air content, temperature, and unit weight was determined. In the second phase of the project, additional tests to determine more extensive hardened concrete properties were explored. These tests include: split-tension strength, modulus of elasticity, modulus of rupture, energy absorption, repeated drop-weight impact hammer test, and resistance

to chloride ion penetration (permeability). The primary objective of this study was to determine an optimized rubber content and surface treatment for concrete mixtures exhibiting improved toughness and resistance to impact. Recommendations for inclusion of rubber tire chips for concrete applications are included within this report.

## CHAPTER 4

### CONCRETE MATERIALS

#### **4.1 Research Study Purpose**

This study aimed at designing and testing modified concrete incorporating recycled waste tires to improve the toughness and energy absorption when subjected to impact. To ensure the fresh and hardened concrete material properties are deemed correct, the individual material constituents and properties must first be gathered or determined. These properties include the physical and chemical properties of the cement, the gradation, specific gravity, and absorption capacity of the fine aggregates, and correct dosage rates for chemical admixtures. Details of each are presented in the following sections of this report.

#### **4.2 Cementitious Materials**

A Type I-II cement was used for this study. No additional cementitious materials were used in place of cement. The cement used had a specific gravity of 3.16. The complete chemical and physical properties analysis of the cement is shown in Table 4-1.

#### **4.3 Virgin and Recycled Tire Aggregate Materials**

Both the virgin coarse and fine aggregates used in this study were obtained from quarries local to Athens, Georgia. The aggregate properties as well as the sieve analyses were provided by the supplier and confirmed through laboratory testing. The coarse aggregate used in the study was an ASTM C33 size #57 stone. In addition, the fine aggregate satisfied the requirements of ASTM C33. The material properties of the natural coarse and fine aggregates were verified using the test procedures described in ASTM C127 and ASTM C128, respectively.

**Table 4-1: Chemical and Physical Test Data for Type I/II Cement**

Chemical and Physical Properties		Test Results	ASTM C 150 Specifications
SiO <sub>2</sub>	(%)	19.7	-----
Al <sub>2</sub> O <sub>3</sub>	(%)	4.7	6.0 max
Fe <sub>2</sub> O <sub>3</sub>	(%)	3	6.0 max
CaO	(%)	63.3	-----
MgO	(%)	3.1	6.0 max
SO <sub>3</sub>	(%)	3.2	3.0 max
CO <sub>2</sub>	(%)	1.7	-----
Limestone	(%)	4	5.0 max
CaCO <sub>3</sub> in Limestone	(%)	98	70 min
C <sub>3</sub> S	(%)	54	-----
C <sub>2</sub> S	(%)	15	-----
C <sub>3</sub> A	(%)	7	8 max
C <sub>4</sub> AF	(%)	9	-----
C <sub>3</sub> S + 4.75 C <sub>3</sub> A	(%)	89	100 max
Loss of Ignition	(%)	2.7	3.0 max
Blaine Fineness	cm <sup>2</sup> /g	387	260 - 430
Air Content of PC Mortar	(%)	8	12 max
Specific Gravity		3.16	-----

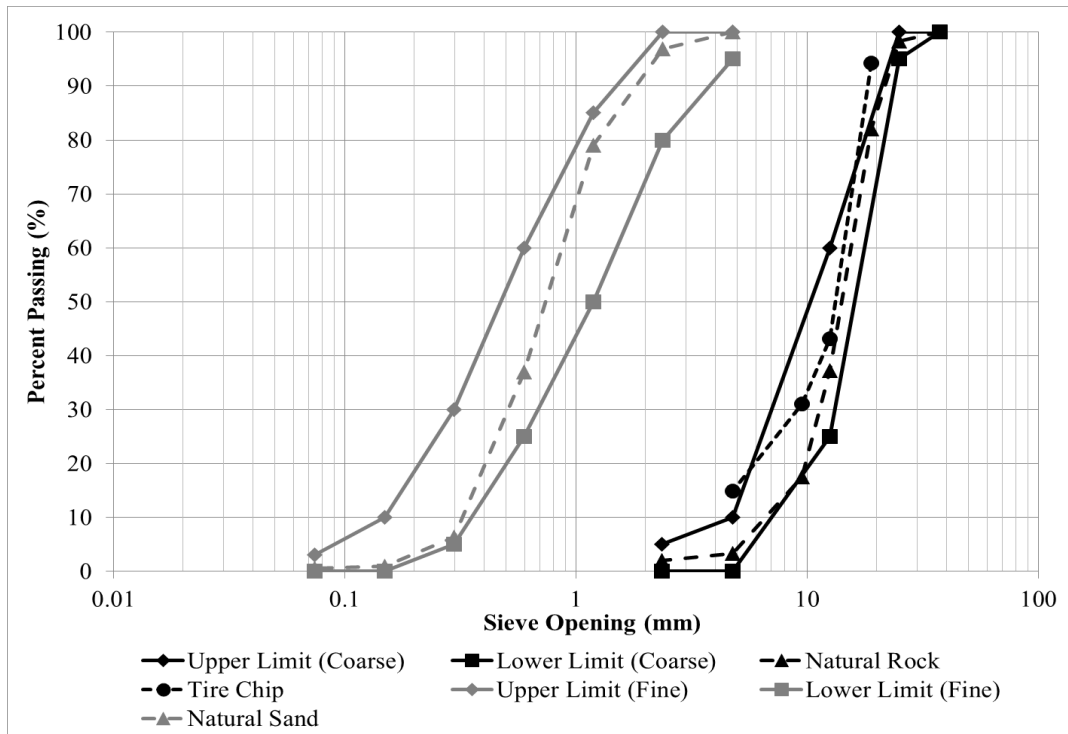
This project aimed to replace coarse aggregate with tire chips ranging in between 3/4" and 1-1/2" in size and a crumb rubber similar to ASTM C33 fine aggregate. Figure 4-1 shows the tire chips utilized for this study along with the virgin coarse aggregate. While some of the tire chips are longer than the coarse aggregate, the materials are very similar in size. Figure 4-2 shows the crumb rubber selected for the study in comparison to the standard concrete sand. Material properties tests were conducted on the tire chip and crumb rubber aggregates used in this study. It was important to obtain tire chip and crumb rubber products that were similar in size to the virgin aggregates that were being replaced. A sieve analysis was performed using ASTM C136 on each recycled aggregate. The gradation results of the sieve analyses of both the tire chip and crumb rubber combined with the natural aggregates, and ASTM C33 upper and lower limits are shown in Figure 4-3.



**Figure 4-1: Tire Chip and Virgin Coarse Aggregate Comparison**

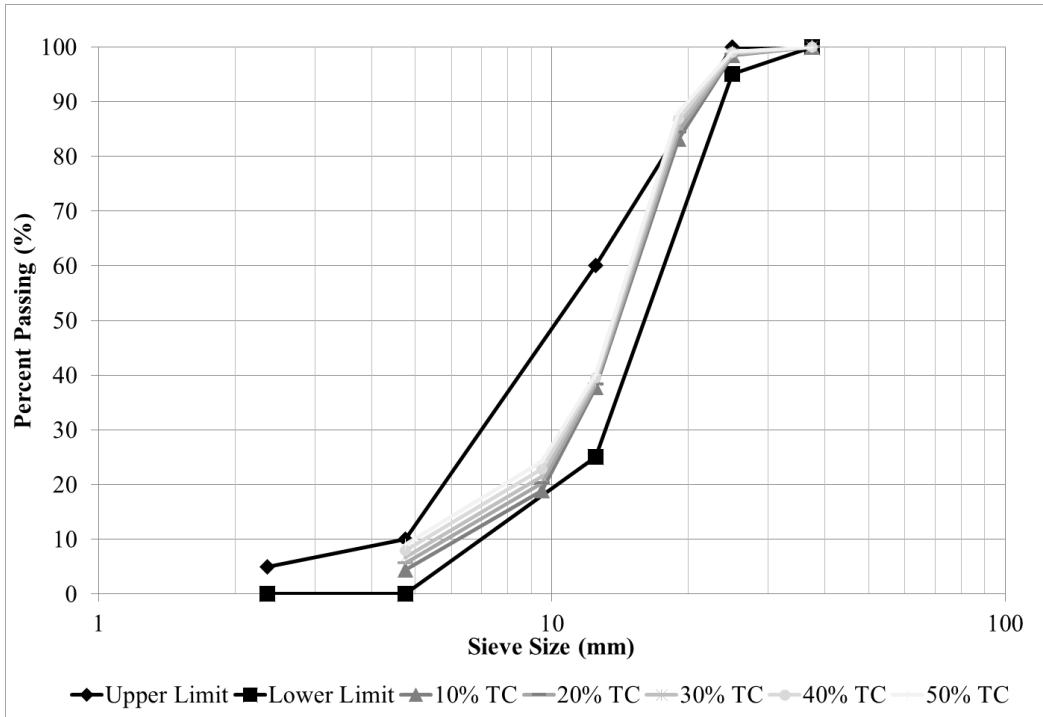


**Figure 4-2: Crumb Rubber and Virgin Fine Aggregate Comparison**

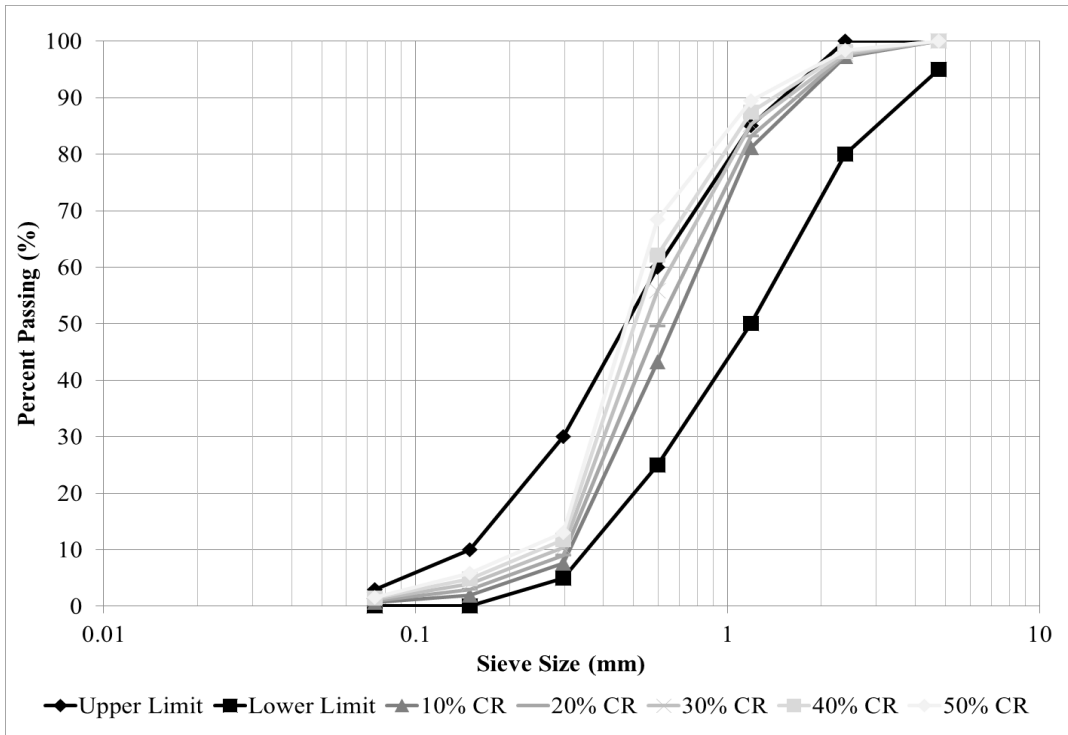


**Figure 4-3: Sieve Analysis for Natural and Recycled Rubber Coarse and Fine Aggregates**

While the gradation curve of the tire chip falls outside of the ASTM limits for a No. 57 aggregate, it is clear that the rubber coarse aggregate is similar in size to the virgin rock. Similarly, the crumb rubber is comparable in size to the fine aggregate, but falls outside the limits because of its more uniform size. Although the recycled rubber aggregates fell outside the upper and lower limits of ASTM C33, the authors felt they were acceptable for inclusion in the study mixtures as a result of the blended natural/recycled aggregate composites satisfying the gradation requirements. The blended aggregate gradations are illustrated for the coarse and fine aggregates in Figures 4-4 and 4-5, respectively. As shown, the blended coarse aggregate satisfies the ASTM C33 requirements for Size #57 stone at coarse aggregate replacement with tire chip up to 50%. However, the blended fine aggregate only satisfied ASTM C33 grading requirements up to 30% of fine aggregate replacement with crumb rubber.



**Figure 4-4: Gradations of Natural Rock and TC Aggregates at Various Replacement Levels**



**Figure 4-5: Gradations of Natural Sand and CR Aggregates at Various Replacement Levels**

Depending on the type of tire and what it was used for during its service life, the physical properties of the rubber can differentiate. In many research articles that were reviewed, the specific gravity of the tire particles reported were in a large range of values. Determining the specific gravity of the rubber aggregates was a key step in the initial stages of the study. Because the absolute volume method was used to replace the virgin aggregates with tire chip and crumb rubber, it was important to determine an accurate ratio of the specific gravities between the materials in order to properly proportion the mixtures. *ASTM C-127 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate* was adapted and used to determine these properties of the rubber aggregates for this study. Because some of the tire chips floated during the test, the tire chips were manually agitated until the rubber particles sunk to the bottom of water. The tire chip and crumb rubber aggregates were found to have a SG of 1.12, which is less than half the virgin coarse and fine aggregates reported as both being 2.65. The absorption capacity of the rubber particles was found to be 0.3%

#### **4.4 Chemical Admixtures**

In this study, an air-entraining admixture (AEA) was used to maintain adequate air contents as defined by GDOT. Additionally, a high-range water-reducing admixture (HRWRA) and a viscosity modifying admixture (VMA) were used to ensure good consistency of the fresh concrete. The VMA was introduced during the 705 lb/yd<sup>3</sup> series due to some of the tire chips floating to the surface of the concrete cylinders after finishing. The VMA was able to suspend the rubber particles within the concrete matrix more effectively.

The typical dosages for these admixtures was 5-8 fl oz/cwt (326-522 mL/100 kg), 3-6 fl oz/cwt (196-391 mL/100 kg), and 0.5-5 fl oz/cwt (33-326 mL/100 kg) for the VMA, HRWRA, and AEA, respectively. This study served as a preliminary investigation into a larger study, thus

the admixture dosages were altered throughout the process to ensure consistent fresh properties later on. Typically, 1.25 fl oz/cwt (81 mL/100 kg) of AEA, 8 fl oz/cwt (522 mL/100 kg) of VMA, and 4-6 fl oz/cwt (261-391 mL/100kg) of HRWRA was used in these mixtures. More HRWRA was used for mixtures with greater rubber contents because rubber reduces the workability of the concrete.

## CHAPTER 5

### EXPERIMENTAL DESIGN

#### **5.1 Design Plan**

The primary objective of this research study was to find an optimized mixture utilizing recycled rubber aggregates from waste tires as a substitute for coarse aggregates in the construction of concrete barrier walls and other applications. The addition of rubber was intended to create a concrete mixture capable of absorbing greater impact loading than traditional concretes. The optimized concrete mixture satisfies the requirements of GDOT Class A fresh and hardened concrete properties. In addition, concrete mixtures will be compared with the GDOT Class B specification as to allow for other potential uses for the rubber-modified concrete. Previous research studies examining similar concepts uncovered the potential applications of this study where energy absorptivity would be advantageous. Though there is limited literature on the use of rubber modified concrete in barrier wall construction, the increase in toughness of the composite material is well documented. These studies assisted in the development of trial concrete mixtures and ultimately a recommended optimized mixture design.

#### **5.2 Batching of Concrete Mixtures**

Rubberized concrete mixtures using tire chips and crumb rubber particles were batched and completed through trial mixture design and testing. The same mixture design process was used for all mixtures that were produced through this study. The procedures specified by ASTM C-192 *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory* dictated the processes followed for the mixtures batched during this study with few variations. The procedures

were deviated from the standard when treatments were applied to the surface of the rubber particles in order to improve the bond between the rubber particles and the concrete paste.

### **5.2.1 Batching Procedure for Each Mixture**

The materials used for each mixture were weighed and stored in five gallon buckets sealed with lids prior to batching. These materials remained sealed in storage until mixing commenced. The cement was set aside in the laboratory along with the mixing water and stored to maintain temperatures in accordance with ASTM C-511. Extra water was set aside to account for fluctuations in moisture contents of the coarse and fine aggregates. Storing the aggregates beforehand in this manner was performed to ensure moisture contents of the materials would remain constant before mixing could take place.

### **5.2.2 Preparation the Day before Batching Concrete Mixtures**

Approximately 24 hours before batching of the mixtures, samples of both coarse and fine aggregate were weighed and oven dried in order to calculate the moisture content of the constituents. The samples were taken from the center of the aggregate buckets in order to measure an average aggregate moisture content. The drying process followed the procedures required by *ASTM C-566 Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying*. Once the moisture content was calculated, the oven-dried aggregates were returned to their respective buckets for use in the mixing process.

All of the necessary tools and equipment required to test the fresh concrete properties were gathered and prepared for testing the concrete mixtures. Additionally, any molds needed to prepare specimens for hardened concrete property tests at later ages were gathered and placed with the materials for the following day.

### **5.2.3 Mixture Process**

The procedures followed during the mixing process for this study met the guidelines set by ASTM C-192 *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*. Instead of “buttering” the mixer, the mixer was simply rinsed with water prior to batching. Once the water was drained from the mixer, the coarse and fine aggregates along with any recycled rubber aggregates were added to the mixer and allowed to blend for a total of ten minutes prior to the addition of any other components. The rubber was added with the virgin aggregates and allowed to mix in order to mechanically roughen the surface of the particles in an attempt to improve the adhesion between the rubber and the concrete materials. Before adding the mixing water to the mixture, admixtures were combined into the water and stirred. Upon completing the initial ten minutes of aggregate mixing, the cement was added to the mixer and allowed to blend with the aggregates. The purpose of this was to separate any large pieces of cement present in the bucket and prevent additional clumping of the mixture. This practice helped to prevent the cementitious materials from clumping and sticking to the sides of the mixer during the mixing process. Finally, the mixing water containing the admixtures used for the experiment was added to the other constituents. The concrete was allowed to mix for an additional five minutes. The total mixing time for each mixture was approximately fifteen minutes.

Once the mixing process was completed, the batch was discharged from the mixer into a dampened wheelbarrow to begin performing fresh properties tests on the concrete. Additionally, the concrete was cast into molds for hardened properties tests at later ages.

### **5.3 Curing Concrete Specimens**

Water tanks located in the materials testing laboratory include heaters and circulating pumps. The temperature in the water tanks is controlled and maintained within the limits of *ASTM*

*C-511 Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes.* The storage tanks used for curing the concrete samples were maintained at a temperature ranging between 69.8°F and 77°F (21°C and 25°C). The tanks were not equipped with temperature recording or sensing devices; however, were checked manually on a daily basis to ensure compliance. The heating elements were managed manually to ensure that the temperature of the baths were within proper limits. Additionally, the water in the storage tanks were saturated with calcium hydroxide. The purpose of this is to prevent leaching of this chemical from the concrete specimens during the curing period. The water in the baths was constantly circulated using a pump, and the water stirred at least once a month to ensure that the lime was still effective. The specimens were added to the water tanks 24 hours after mixing, and remained in the tank until time of testing.

## **5.4 Testing for Concrete Properties**

The testing of the concrete specimens took place at two different times. The fresh concrete properties were tested and recorded in the concrete's fresh, or plastic state, while the hardened properties were measured after the concrete specimens solidified and gained strength. The hardened concrete properties were measured at time intervals specified by ASTM.

### **5.4.1 Fresh Concrete Property Tests**

Notable fresh concrete properties were tested and recorded for each mixture. The properties tested after mixing each sample included slump, air content, unit weight, and temperature. Fresh concrete properties are important because they are often indicators for concrete workability, fluidity, durability, and density. Table 5-1 provides the testing standard procedure followed for the testing of each fresh concrete property.

**Table 5-1: Fresh Concrete Properties Tests**

<b>Fresh Concrete Tests</b>	<b>Standard Identification</b>	<b>Testing Day</b>
Slump	<i>ASTM C-143</i> , AASHTO T 119	Batching Day
Temperature	<i>ASTM C-1064</i> , AASHTO T 309	Batching Day
Pressure Meter Air Content	<i>ASTM C-231</i> , AASHTO T 152	Batching Day
Unit Weight	<i>ASTM C-138</i> , AASHTO T 121	Batching Day

#### **5.4.2 Hardened Concrete Property Tests**

The hardened concrete properties tests were completed in accordance with ASTM standards. In the first phase of the study, only concrete compressive strength tests were completed on the specimens. During the second phase of the research, additional tests were conducted to measure the mechanical and impact performance of each mixture. The tests completed during the second phase of the study include: compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, rapid chloride ion permeability, force-displacement (static energy dissipation capacity), and repeated drop-weight impact hammer test. Table 5-2 shows the standard identification and testing time for each hardened concrete test.

#### **5.5 Mixture Design Proportioning**

The GDOT specifies minimum and maximum quantities and values for its Class A concrete. The minimum amount of cement was listed as 611 lb/yd<sup>3</sup>, while the maximum water/cement ratio was 0.49. In addition, GDOT requires the use of either Size No. 56, 57, or 67 coarse aggregates. Furthermore, the minimum compressive strength for Class A concrete is listed as 3,000 psi (20.7 MPa), which served as the baseline strength for all mixtures. GDOT provides a range of 2 to 4 inches (50.8 mm to 101.6 mm) for slump and an entrained air content between 2.5 and 6%.

**Table 5-2: Hardened Concrete Properties Tests**

<b>Hardened Concrete Tests</b>	<b>Standard Identification</b>	<b>Testing Day</b>
Compressive Strength	<i>ASTM C-39</i> , AASHTO T 22	1, 7, 28, 56 Days
Flexural Strength	<i>ASTM C-78</i> , AASHTO T 97	28, 56 Days
Splitting Tensile Strength	<i>ASTM C-496</i> , AASHTO T 198	28, 56 Days
Modulus of Elasticity	<i>ASTM C-469</i>	28, 56 Days
Permeability	<i>ASTM C-1202</i> , AASHTO T 227	28, 56 Days
Coefficient of Thermal Expansion	<i>AASHTO T 336</i>	28 Days
Force-Displacement	None	28 Days
Impact Hammer Test	None	28 Days

The strategy for proportioning the mixture designs for this study was to maintain consistent batch sizes when the virgin aggregates were replaced with the recycled rubber aggregates. In order to accomplish this, the absolute volume method was utilized. Because of the use of the rubber aggregates, it was difficult to predict the hardened characteristics of the concrete mixtures. Mini-mixtures were designed, batched, and tested in order to establish a baseline for concrete strength characteristics as a function of cement and rubber content. The study began with twenty-four concrete mixture designs followed by seven additional mixtures that were analyzed and tested extensively. From the second phase of the study, adequate knowledge was gained such that recommendations regarding the use of recycled rubber in concrete mixtures for barrier wall and other concrete applications.

### **5.5.1 Phase I - Trial Proportioned Research Mixtures**

The first phase of the study began with a total of twenty-four trial mixtures. This phase included varying cement content as well as increasing the rubber content. Additionally, one series was used to examine the differences in concrete performance when using crumb rubber as compared to tire chips. Two additional mixtures were completed combining the use of crumb rubber and tire chips. Table 5-3 outlines the mixtures completed in the first phase of this study.

The effect of cementitious content was evaluated by selecting three different quantities of cement when using recycled tire chip as the coarse aggregate replacement for this study: 611, 660, and 705 lb/yd<sup>3</sup> (362, 392, and 418 kg/m<sup>3</sup>). The series of mixtures that investigated the use of crumb rubber as a sand replacement used only 660 lb/yd<sup>3</sup> (392 kg/m<sup>3</sup>) of cement. Additionally, the mixtures that included a combination of crumb rubber and tire chips contained 660 lb/yd<sup>3</sup> (392 kg/m<sup>3</sup>) of cement. Each mixture in the study maintained a constant w/c of 0.42. The target air content for each mixture was 5%, while the target slump was 3 inches (76.2mm). Chemical admixtures were utilized in attempt to achieve the ranges specified by GDOT. The quantities of each constituent is provided in Table 5-4

The knowledge and experience gained from producing these trial mixtures guided the design and batching for the second phase. The second phase included an extensive examination into the hardened concrete properties through the testing of seven rubberized concrete mixtures. Tire chips were solely utilized as a coarse aggregate replacement in percentages up to 20% in 10% increments using three different surface treatments designed to improve bonding between the rubber particles and cement paste.

**Table 5-3: First Phase Trial Mixture Design Matrix**

Mixture ID	w/cm	Cementitious Content, lbs (kg)	% Sand Volume	% Crumb Rubber Volume	% Tire Chip Volume	% Coarse Aggregate
.42/611/100CA/0TC	0.42	611 (277)	100	0	0	100
.42/611/90CA/10TC	0.42	611 (277)	100	0	10	90
.42/611/80CA/20TC	0.42	611 (277)	100	0	20	80
.42/611/70CA/30TC	0.42	611 (277)	100	0	30	70
.42/611/60CA/40TC	0.42	611 (277)	100	0	40	60
.42/611/50CA/50TC	0.42	611 (277)	100	0	50	50
.42/660/100CA/0TC	0.42	660 (299)	100	0	0	100
.42/660/90CA/10TC	0.42	660 (299)	100	0	10	90
.42/660/80CA/20TC	0.42	660 (299)	100	0	20	80
.42/660/70CA/30TC	0.42	660 (299)	100	0	30	70
.42/660/60CA/40TC	0.42	660 (299)	100	0	40	60
.42/660/50CA/50TC	0.42	660 (299)	100	0	50	50

.42/705/100CA/0TC	0.42	705 (320)	100	0	0	100
.42/705/90CA/10TC	0.42	705 (320)	100	0	10	90
.42/705/80CA/20TC	0.42	705 (320)	100	0	20	80
.42/705/70CA/30TC	0.42	705 (320)	100	0	30	70
.42/705/60CA/40TC	0.42	705 (320)	100	0	40	60
.42/705/50CA/50TC	0.42	705 (320)	100	0	50	50
.42/660/90FA/10CR	0.42	660 (299)	90	10	0	100
.42/660/80FA/20CR	0.42	660 (299)	80	20	0	100
.42/660/70FA/30CR	0.42	660 (299)	70	30	0	100
.42/660/60FA/40CR	0.42	660 (299)	60	40	0	100
.42/660/90FA/10CR/95CA/5TC	0.42	660 (299)	90	10	5	95
.42/660/80FA/20CR/90CA/10TC	0.42	660 (299)	80	20	10	90

Key: w-cm/cement content/coarse aggregate content/tire chip content

### 5.5.2 Mixture Design Identification

The mixture identification numbers for each of the specimens represents all of the relevant information regarding each mixture. For example, the first number (.42/611/100CA/0TC) represents the w/cm of the mixture. For the purposes of this study, the w/cm for all of the mixtures remained constant at 0.42. The second number in the identification number represents the cement content. For the example mixture, this number incorporates 611 lb/yd<sup>3</sup> (362.5 kg/m<sup>3</sup>) of cement. The third number indicates the percentage of coarse aggregate or fine aggregate present in the sample. The letters “CA” indicate the number is referring to coarse aggregate, while the letters “FA” refer to the amount of fine aggregate in the mixture. Finally, the last number in the identification number refers to the percentage of tire chips or crumb rubber in the mixture.

The letters “TC” refers to tire chips while “CR” indicates that crumb rubber is used in the mixture. The final two mixtures in the trial mixture list have longer identification numbers resulting from the mixtures including rubber aggregates for both coarse and fine aggregate.

### **5.5.3 Phase II – Research Mixture Designs**

Because of environmental and economic factors, it was proposed that a cement content of 611 lb/yd<sup>3</sup> (362.5 kg/m<sup>3</sup>) be used for the second phase large-scale mixtures. Cement is the most economically and environmentally taxing ingredient in concrete, thus it was important to limit these factors as much as possible. In addition, tire chips were selected as the only rubber aggregate used in the second phase of this study as a result of the tire chips being more cost effective to produce and purchase when compared to crumb rubber. Based on the first phase results, up to 20% replacement of coarse aggregate with tire chips was studied during the second phase of the project. Additionally, three surface treatments were utilized to study the bond between the rubber aggregates and the cement paste. The surface treatments that were examined included a mechanical roughening, sodium hydroxide and silane coupling agent to treat the surface of the rubber. The mixture design matrix is shown in Table 5-5.

**Table 5-4. Trial Mixture Quantities**

Mixture Identification	w/c	*Cement	*Coarse Aggregate	*Fine Aggregate	*Tire Chips	*Crumb Rubber	**AEA	**HRWRA	**VMA
.42/611/100CA/0TC	0.42	611 (362)	1800 (816)	952 (432)	0	0	0	3 (196)	0
.42/611/90CA/10TC	0.42	611 (362)	1620 (735)	952 (432)	76 (34)	0	0	3.5 (228)	0
.42/611/80CA/20TC	0.42	611 (362)	1440 (653)	952 (432)	152 (69)	0	0	3.5 (228)	0
.42/611/70CA/30TC	0.42	611 (362)	1260 (572)	952 (432)	228 (103)	0	0	5.5 (359)	0
.42/611/60CA/40TC	0.42	611 (362)	1080 (490)	952 (432)	304 (138)	0	0	7 (756)	0
.42/611/50CA/50TC	0.42	611 (362)	900 (408)	952 (432)	380 (172)	0	0	7 (756)	0
.42/660/100CA/0TC	0.42	660 (392)	1800 (816)	952 (432)	0	0	0	7 (756)	0
.42/660/90CA/10TC	0.42	660 (392)	1620 (735)	952 (432)	76 (34)	0	0	7 (756)	0
.42/660/80CA/20TC	0.42	660 (392)	1440 (653)	952 (432)	152 (69)	0	0	7 (756)	0
.42/660/70CA/30TC	0.42	660 (392)	1260 (572)	952 (432)	228 (103)	0	0	7 (756)	0
.42/660/60CA/40TC	0.42	660 (392)	1080 (490)	952 (432)	304 (138)	0	0	7 (756)	0
.42/660/50CA/50TC	0.42	660 (392)	900 (408)	952 (432)	380 (172)	0	0	7 (756)	0
.42/705/100CA/0TC	0.42	705 (418)	1800 (816)	952 (432)	0	0	1 (65)	8 (522)	8 (522)
.42/705/90CA/10TC	0.42	705 (418)	1620 (735)	952 (432)	76 (34)	0	1 (65)	7 (756)	8 (522)
.42/705/80CA/20TC	0.42	705 (418)	1440 (653)	952 (432)	152 (69)	0	1.25 (81)	4.5 (293)	8 (522)
.42/705/70CA/30TC	0.42	705 (418)	1260 (572)	952 (432)	228 (103)	0	1.25 (81)	4 (261)	8 (522)
.42/705/60CA/40TC	0.42	705 (418)	1080 (490)	952 (432)	304 (138)	0	1.25 (81)	5 (326)	8 (522)
.42/705/50CA/50TC	0.42	705 (418)	900 (408)	952 (432)	380 (172)	0	1.25 (81)	5.5 (359)	8 (522)
.42/660/90FA/10CR	0.42	660 (392)	1800 (816)	936 (425)	0	44 (20)	1.25 (81)	4 (261)	8 (522)
.42/660/80FA/20CR	0.42	660 (392)	1800 (816)	832 (378)	0	88 (40)	1.25 (81)	4 (261)	8 (522)
.42/660/70FA/30CR	0.42	660 (392)	1800 (816)	728 (330)	0	132 (60)	1.25 (81)	4 (261)	8 (522)
.42/660/60FA/40CR	0.42	660 (392)	1800 (816)	624 (283)	0	176 (80)	1.25 (81)	4 (261)	8 (522)
.42/660/90FA/10CR/95CA/5TC	0.42	660 (392)	1710 (776)	936 (425)	38 (17)	44 (20)	1.25 (81)	4 (261)	8 (522)
.42/660/80FA/20CR/90CA/10TC	0.42	660 (392)	1620 (735)	832 (378)	76 (34)	88 (40)	1.25 (81)	4 (261)	8 (522)

\* lb/yd<sup>3</sup> (kg/m<sup>3</sup>)

\*\* fl. oz/cwt (mL/100 kg)

**Table 5-5: Second Phase Research Mixtures**

Surface Treatment	Mixture ID	w/cm	Cementitious Content, lbs (kg)	% Tire Chip Volume	% Coarse Aggregate
None	.42/611/100CA/0TC	0.42	611 (277)	0	100
Mechanical	.42/611/90CA/10TC/M	0.42	611 (277)	10	90
Mechanical	.42/611/80CA/20TC/M	0.42	611 (277)	20	80
Sodium Hydroxide	.42/611/90CA/10TC/NaOH	0.42	611 (277)	10	90
Sodium Hydroxide	.42/611/80CA/20TC/NaOH	0.42	611 (277)	20	80
Silane Coating	.42/611/90CA/10TC/S	0.42	611 (277)	10	90
Silane Coating	.42/611/80CA/20TC/S	0.42	611 (277)	20	80

To perform the NaOH surface treatment, the tire chips were placed in a saturated bath of the chemical, and allowed to rest there for 20 minutes. After this duration, the tire chips were removed from the bath and rinsed with water and dried to room temperature. A similar procedure was used with the silane coupling agent; however, drying was performed through the use of a standard laboratory oven. Appropriate laboratory personal protection equipment was used when handling the solvents. The surface treatments were used on the rubber-modified concrete mixtures for replacement levels of 10% and 20% in order to determine the effect of the treatment on the bond between the rubber and concrete. The mixture proportions are presented in Table 5-6.

### 5.5.3.1 Mechanical Abrasion Surface Treatment

The mechanical abrasion surface treatment of the recycled tire chips was completed at the time of mixing. Once all of the materials were weighed out and the mixing process was ongoing, the coarse and fine aggregates along with the recycled tire chips were added to the concrete mixer. All of the materials were mixed continuously for ten minutes before the addition of any other materials. The idea behind this surface treatment was that the friction between the natural aggregates and the tire

chips would roughen the surface of the recycled tire chips, giving the rubber more surface area for the concrete mixture to bond to. Past research has indicated that the Interfacial Transition Zone (ITZ) between the cement matrix and the tire chips is the main point of weakness for rubberized concrete mixtures, therefore theoretically increasing the surface area of the ITZ will give the cement more area to bond to, improving the strength of the bond between the rubber and the concrete matrix.

### **5.5.3.3 Silane Coupling Agent Surface Treatment**

Silane coupling agents are used to bond inorganic and organic materials together through strong chemical bonds. They are silicon-based chemicals that contain inorganic and organic reactivity within the same molecule. The agent acts as an interface between an inorganic substrate, like glass or metal, and an organic material such as an organic polymer, coating, or adhesive. The general structure of the silane coupling agent molecule is  $(\text{RO})_3\text{SiCH}_2\text{CH}_2\text{CH}_2\text{-X}$  where “RO is a hydrolyzable group, such as methoxy, ethoxy, or acetoxy, and X is an organofunction group, such as amino, methacryloxy, epoxy, etc.” [A Guide to Silane Solutions, 2009]. A silane can be a very diverse molecule, but the common denominator is the existence of a central silicon atom with four attachments. The combinations of these attachments give the chemical its defining characteristics, making the groups nonreactive, inorganically reactive, or organically reactive. Silanes are small molecules, which allows for the chemical to penetrate the substrates and create strong bonds [Limitless Silanes, 2017].

**Table 5-6. Research Mixture Quantities**

Mixture Identification	w/c	*Cement	*Coarse Aggregate	*Fine Aggregate	*Tire Chips	**AEA	**HRWRA	**VMA	Rubber Treatment
.42/611/100CA/0TC	0.42	611 (362)	1800 (816)	952 (432)	0	1.25 (81)	7 (756)	8 (522)	None
.42/611/90CA/10TC/M	0.42	611 (362)	1620 (735)	952 (432)	76 (34)	1.25 (81)	7 (756)	8 (522)	Mechanical
.42/611/80CA/20TC/M	0.42	611 (362)	1440 (653)	952 (432)	152 (69)	1.25 (81)	7 (756)	8 (522)	Mechanical
.42/611/90CA/10TC/NaOH	0.42	611 (362)	1620 (735)	952 (432)	76 (34)	1.25 (81)	7 (756)	8 (522)	Sodium Hydroxide
.42/611/80CA/20TC/NaOH	0.42	611 (362)	1440 (653)	952 (432)	152 (69)	1.25 (81)	7 (756)	8 (522)	Sodium Hydroxide
.42/611/90CA/10TC/S	0.42	611 (362)	1620 (735)	952 (432)	76 (34)	1.25 (81)	7 (756)	8 (522)	Silane Coating
.42/611/80CA/20TC/S	0.42	611 (362)	1440 (653)	952 (432)	152 (69)	1.25 (81)	7 (756)	8 (522)	Silane Coating

\* lb/yd<sup>3</sup> (kg/m<sup>3</sup>)

\*\* fl. oz/cwt (mL/100 kg)

The silane coupling agents that were used in this study were XIAMETER OFS-6020 Silane and XIAMETER OFS-6040 Silane. The material properties of each are presented in Tables 5-7 and 5-8, respectively. Both of these solutions can be used as either a primer or an additive to promote adhesion. It is recommended that when these substances are used as a primer, that they be diluted down to a concentration of 1.0%. If they are being used as an additive, the typical concentration should be 0.5-2.0% for the OFS-6020 and 0.05-3.0% for the OFS-6040. Both of the solutions can be diluted in alcohols and water [Coatings & Inks Additive Selection Guide, 2017]. The benefits of using these products are that they improve adhesion, and compressive, tensile, and flexural strengths [msds for 6040 and 6020, 2017].

To apply the silane coupling agent surface treatments, both products were completely mixed together at a 1:1 ratio by weight. This solution was then diluted in an aqueous solution by adjusting the pH of water to 4.5 using acetic acid and adding the silane at a concentration of 1.0%. This new aqueous solution was then mixed for a duration of 15 minutes to ensure a homogenous substance. It is imperative that this diluted solution be used within 24 hours of being prepared because the XIAMETER OFS-6040 is not indefinitely stable in water and older solutions will begin to show a slight haze.

Once this diluted silane solution was created, the previously weighed tire chips for the mixture were added to the solution and stirred for 20 minutes to completely coat the surface of the tire chips. Once this was completed, the tire chips were removed from the solution and dried in a standard laboratory oven heated to a temperature between 221° and 248°F (105° and 120°C) for 12 hours. This drying process completes the condensation of the silanol groups at the surface of the rubber while also removing any moisture that may be present on the rubber aggregates. After

the drying is completed, the tire chips are added to the mixer at time of batching and the mixing process continues using normal procedures.

**Table 5-7: Material Properties of XIAMETER OFS-6040 Silane**

Test	Unit	Value
Appearance		Clear liquid
Color	APHA	50
Viscosity	cst	3
Specific gravity at 25°C (77°F)		1.07
Refractive index		1.428
Flash point-closed cup	°C (°F)	>101 (>213)
Purity by GC	%	>98.5
Chloride	ppm	<10
Molecular weight	g/mol	236.34
CAS #		2530-83-8

**Table 5-8: Material Properties of XIAMETER OFS-6020 Silane**

Test	Unit	Value
Appearance		Clear liquid
Flash point-closed cup	°C (°F)	85 (185)
Specific gravity at 25°C (77°F)	°C (°F)	1.03
Refractive index		1.445
Neutral equivalents	g/eq	115
Color		Light straw
Viscosity	mm <sup>2</sup> /s	5

Similar to when performing the NaOH surface treatment, it is important to adhere to proper safety precautions when handling both of these silane coupling agents. When using both of these products, it is necessary to wear eye and face protection, because the products have the danger of causing serious eye damage. Additionally, XIAMETER OFS-6020 Silane is a combustible liquid, can potentially cause skin irritation, and could be harmful to inhale. While performing this surface treatment, long sleeves, gloves, safety glasses, and a face shield were always used. Additionally, it was important to either handle these chemicals outside, or in a well ventilated area. If these

conditions are not possible, respiratory protection should be used. Additionally, these chemicals should be kept away from any sort of fire hazard.

## **5.6 Data Analysis and Design Summary**

The experimental design for this study allowed for the researchers to investigate the effect of cement content and rubber particle size on the fresh concrete properties and compressive strength of rubber-modified concrete mixtures. Further investigation was performed to more comprehensively understand the mechanical performance of the rubberized concrete when subjected to other forms of loading, specifically impact. The test results from the first phase of this study were compared to previous work performed on this topic to see if trends were predominantly similar. Ultimately, results from the second phase of the study are used to provide recommendations to GDOT regarding the use of rubberized concrete mixtures for barrier wall construction in Georgia. Additionally, the results from this study may be used to provide recommendations regarding the use of tire chips and/or crumb rubber for use in alternative concrete construction.

## CHAPTER 6

### EXPERIMENTAL RESULTS

#### 6.1 Trial Mixtures

##### 6.1.1 Batching of Trial Mixtures

The batching of trial mixtures with rubber contents ranging up to 50% were completed as the initial investigation of this study. This process was completed for mixtures with 611, 660, and 705 lb/yd<sup>3</sup> (362, 392, and 418 kg/m<sup>3</sup>) of cement. Additionally, a series of mixtures with 660 lb/yd<sup>3</sup> (391.6 kg/m<sup>3</sup>) of cement was completed that included a fine aggregate replacement with crumb rubber. Further, two mixtures with a combination of crumb rubber and tire chips were batched in the preliminary investigation. Because the w/cm remained constant throughout the study, the mixtures will be referred to as its shorthand mixture identification name throughout the remainder of the report. For instance, 660TC20 will be used to refer to the mixture with 660 lb/yd<sup>3</sup> (391.6 kg/m<sup>3</sup>) of cement and 20% tire chip replacement.

##### 6.1.2 Fresh Concrete Properties of Trial Mixtures

The primary objectives of designing and testing the trial batches was to determine the appropriate dosages needed for the design of the larger scale rubberized concrete mixtures as well as to establish the limits of aggregate replacement with rubber and meet the GDOT specifications. The concrete properties measured included slump, air content, unit weight, and temperature. Table 6-1 provides the fresh concrete properties results from the trial mixtures.

A Viscosity Modifying Admixture (VMA) was used during later mixtures included in the trial batching sequence as a result of the tire chips floating to the top of the concrete specimens

after fabrication. This phenomenon resulted in the cylinder tops being uneven and creating a level of difficulty when testing specimens for compressive strength. The VMA improved the mixtures by helping to suspend the rubber particles within the specimens and prevented the tire chips from floating to the tops of the cylinders. Further, the HRWRA dosages increased with the increased amounts of rubber particles because of the recycled aggregate's effect on the workability. As the literature suggested, increasing rubber content reduces the workability of concrete mixtures. This was accounted for when specifying dosages for HRWRA in the second phase of the study. Additionally, the brand of HRWRA that was used for early trial mixing was switched for later mixtures because of a consequential effect of entraining air without the use of an AEA.

#### **6.1.2.1 Slump**

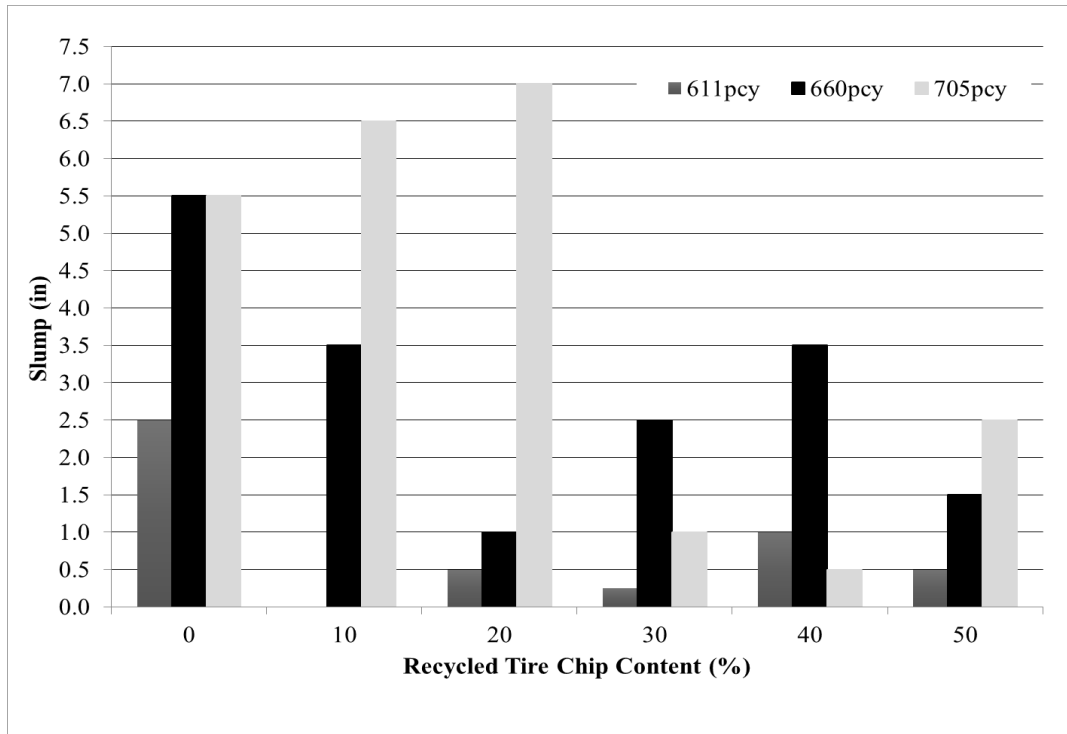
The target slump for all mixtures was between 2 and 4 in (50.8 mm to 101.6 mm), per GDOT requirements. Because these mixtures were used as small-scale trial batches for the large-scale study, the admixture dosages were adjusted accordingly to approach the acceptable range per these standards. Previous literature indicated that higher rubber contents resulted in lower workability, and thus HRWRA dosages were adjusted in order to combat this issue. Figure 6-1 shows the slump results for each of the mixtures performed for this study.

While the slump results were outside the target slump range for some mixtures, the more important concern was a consistent and consolidated concrete mixture that could be placed with relative ease. Even though the slump measurement was low for several mixtures, especially mixtures with 20% replacement of coarse aggregate with tire chips, the problem could be easily overcome with a higher HRWRA dosage.

**Table 6-1: Fresh Concrete Properties in Trial Mixtures**

Mix Name	Slump, in (mm)	Unit Weight, lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	Air Content, %
611TC0	2.50 (63.5)	144.6 (2,316)	4.9
611TC10	0.00 (0.0)	140.0 (2,242)	3.8
611TC20	0.50(12.7)	137.6 (2,204)	4.2
611TC30	0.25 (6.4)	134.0 (2,147)	4.9
611TC40	1.00 (25.4)	129.8 (2,079)	4.5
611TC50	0.50 (12.7)	125.6 (2,012)	4.1
660TC0	5.50 (139.7)	149.2 (2,390)	2.5
660TC10	3.50 (88.9)	145.0 (2,323)	3.8
660TC20	1.00 (25.4)	138.8 (2,224)	4.5
660TC30	2.50 (63.5)	133.4 (2,137)	4.5
660TC40	3.50 (88.9)	126.4 (2,025)	5.0
660TC50	1.50 (38.1)	124.2(1990)	4.5
705TC0	5.50 (139.7)	144.3 (2,312)	5.5
705TC10	6.50 (165.1)	143.0 (2,291)	6.5
705TC20	7.00 (177.8)	129.2 (2,070)	8.5
705TC30	1.00 (25.4)	132.0 (2,115)	4.8
705TC40	0.50 (12.7)	129.0 (2,067)	4.5
705TC50	2.50 (63.5)	120.2 (1,930)	6.5
660CR10	0.50 (12.7)	141.2 (2,262)	5.3
660CR20	2.00 (50.8)	139.2 (2,230)	4.5
660CR30	1.50 (38.1)	138.6 (2,220)	5.0
660CR40	1.00 (25.4)	136.2 (2,182)	5.5
660CR50	0.00 (0.0)	124.2 (1,990)	7.0
660CR10TC5	0.00 (0.0)	137.0 (2,1950)	5.0
660CR20TC10	0.00 (0.0)	133.0 (2,131)	4.5

Crumb rubberized concrete mixtures exhibited similar erratic slump results to that of the tire chip. The same dosage of HRWRA was used for all crumb rubber mixtures. The 10% replacement produced the lowest slump at 0.5 in (12.7 mm). The remaining mixtures decreased linearly from 2 in (50.8 mm). Two mixtures using a combination of tire chips and crumb rubber as a replacement for coarse and fine aggregate, respectively, produced a slump of 0 in. The slump results for the CR and combination mixtures are shown in Figure 6-2.

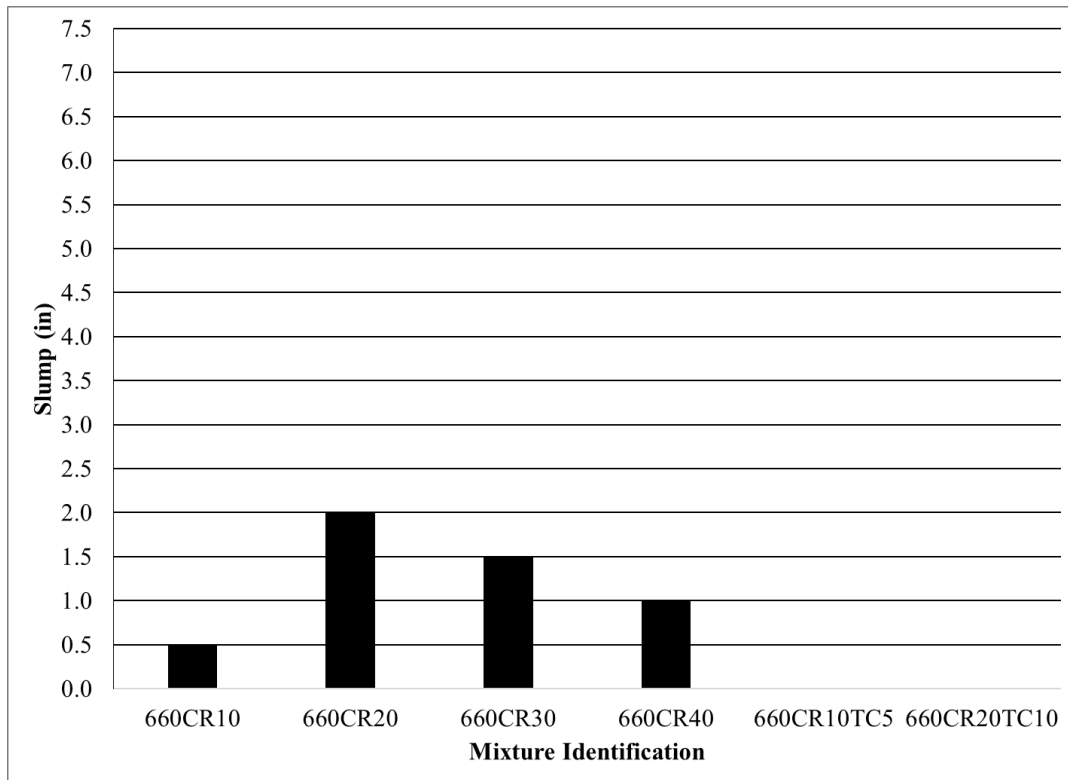


**Figure 6-1: Slump Results for Trial Tire Chip Mixtures**

#### 6.1.2.2 Air Content

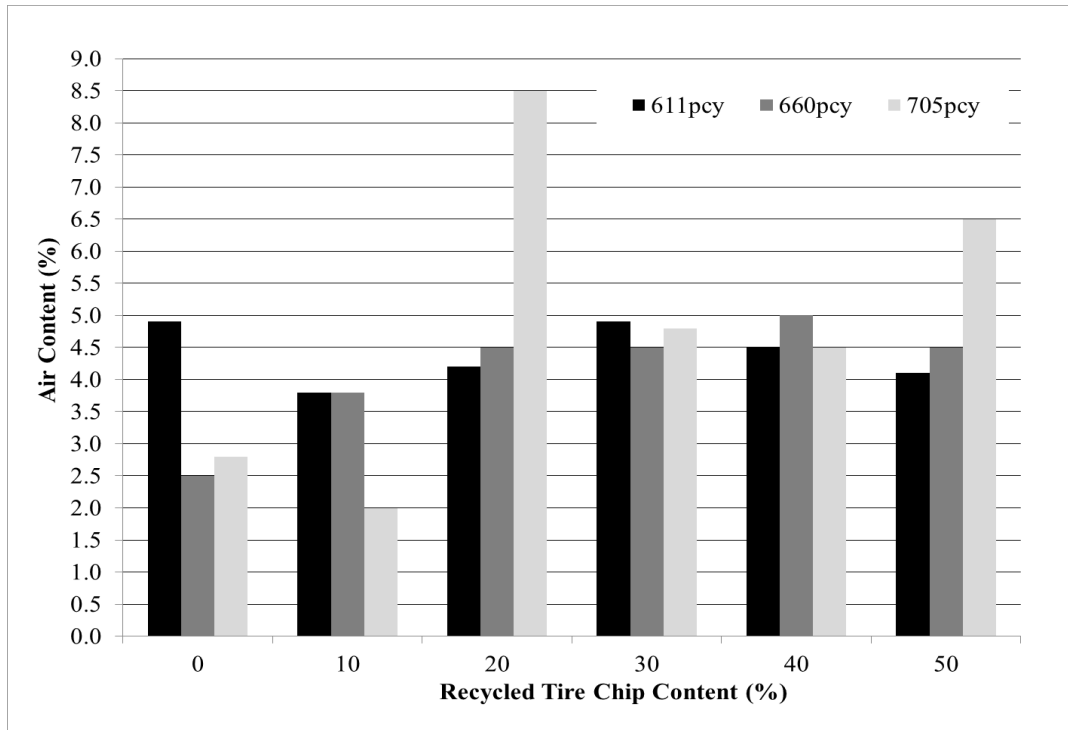
No AEA was utilized for the 611 and 660 lb/yd<sup>3</sup> (362 and 392 kg/m<sup>3</sup>) series mixtures due to appropriate air contents being attained with only the use of a HRWRA. The HRWRA was changed for the 660TC and 705TC mixture series requiring small AEA dosages in order to achieve the desired air content of 2.5-6%, as required by GDOT for Class A concrete mixtures. Previous literature indicated that concrete mixtures with higher rubber contents typically produced higher air contents, and thus small AEA dosages were used to ensure that the air contents would not to exceed the required maximum.

The air contents of the concrete mixtures utilizing tire chips as a replacement for coarse aggregates produced air contents generally ranging between 2 and 5%, though two mixtures had higher air contents, with 705TC20 reaching as high as 8.5%. The high air content measured for the 705TC20 mixture coincides with a high slump measurement for that mixture. This increased workability is likely the reason for the increase in air content for this mixture. See Figure 6-3.



**Figure 6-2: Slump Results for Trial Crumb Rubber and Combination Mixtures**

An AEA was not used until the 705 lb/yd<sup>3</sup> (418 kg/m<sup>3</sup>) series began. The 705TC0 and 705TC10 used a low AEA dosage of 1 fl oz/cwt and had air contents below the GDOT requirement; however, this was accounted for by increasing the dosage slightly to 1.25 fl oz/cwt for the remaining 705 lb/yd<sup>3</sup> mixtures. The air contents for the CR and combination mixtures remained consistent between 4.5% and 5.5% regardless of rubber content. In general, the results of the air content tests showed higher air contents being produced with greater amounts of tire chips and crumb rubber.

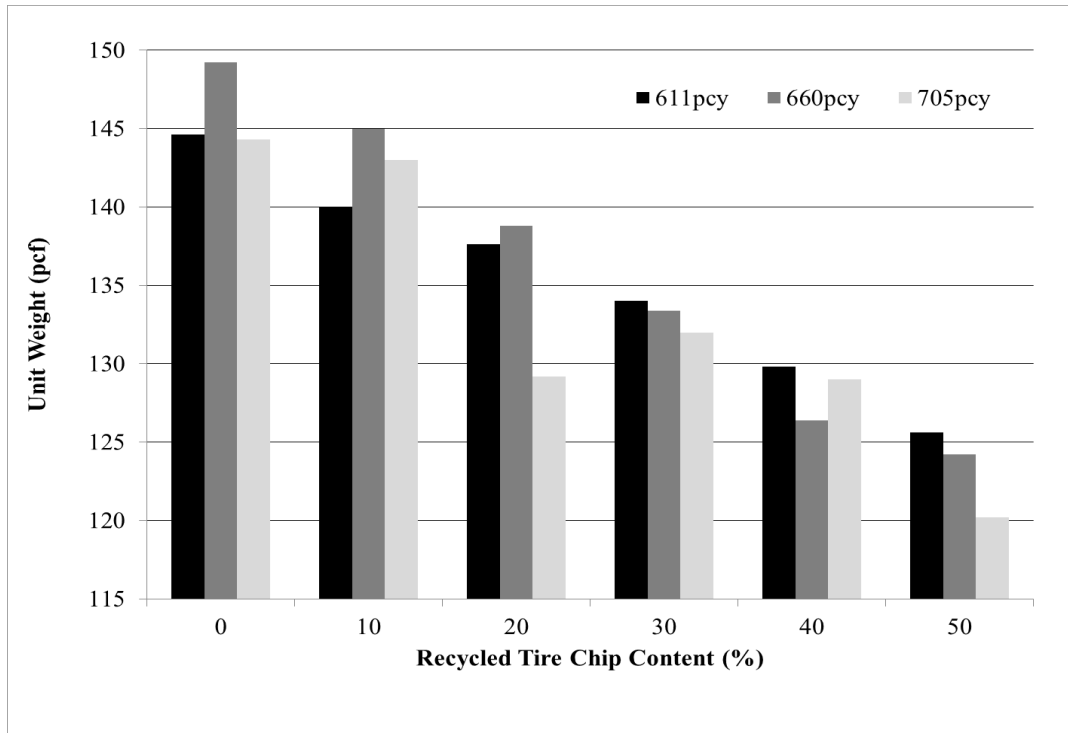


**Figure 6-3: Air Content Results for Trial Tire Chip Mixtures**

### 6.1.2.3 Unit Weight

The unit weight was measured while the concrete was fresh by the methods defined in ASTM C138. The design unit weights for the mixtures replacing coarse aggregates with tire chips ranged between 119.8 lb/ft<sup>3</sup> and 140.9 lb/ft<sup>3</sup> (1,919 kg/m<sup>3</sup> and 2,257 kg/m<sup>3</sup>) while the design unit weights for the crumb rubber mixtures ranged between 131 lb/ft<sup>3</sup> and 137.7 lb/ft<sup>3</sup> (2,098 kg/m<sup>3</sup> and 2,205 kg/m<sup>3</sup>). The design unit weights for the combination mixtures 660CR10TC5 and 660CR20TC10 were 135.7 lb/ft<sup>3</sup> and 131.6 lb/ft<sup>3</sup> (2,174 kg/m<sup>3</sup> and 2,108 kg/m<sup>3</sup>), respectively. The rubberized concrete mixtures' had lower than normal unit weights as a result of the property's dependency on the mixture constituent's specific gravities as well as air content. The study mixtures produced a 3.85 lb/ft<sup>3</sup> (61.7 kg/m<sup>3</sup>) decrease in unit weight for each 10% increase in tire chips. The crumb rubber mixtures decreased by 2.25 lb/ft<sup>3</sup> (36.0 kg/m<sup>3</sup>) for each 10% increase in crumb rubber replacement. The measured unit weights decreased nearly linearly with increased

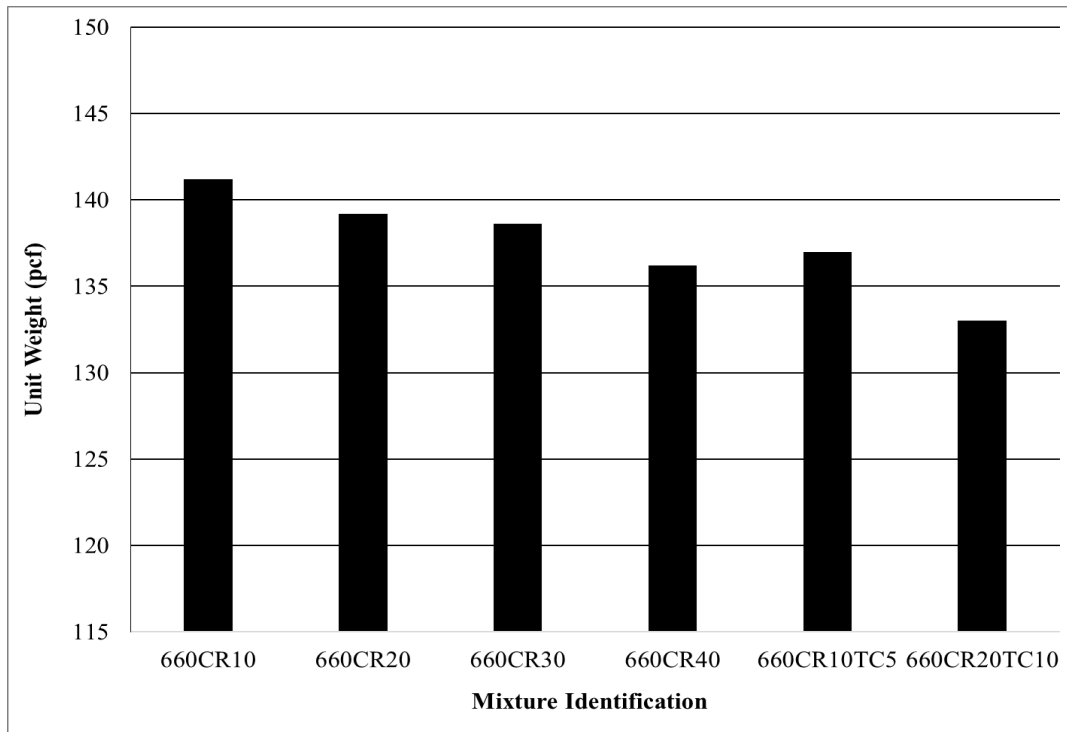
rubber contents. The experimental unit weight results are shown in Figures 6-4 and 6-5 for the tire chips and crumb rubber mixtures, respectively.



**Figure 6-4: Unit Weight Results for Trial Tire Chip Mixtures**

#### 6.1.2.4 Temperature

Concrete temperature is an important characteristic to consider when placing concrete because it is highly dependent on the environment during its plastic state. Previous studies have found that the ideal temperature to batch and place concrete ranges between 50 and 60°F and should not exceed 85°F. This is important because greater temperatures can speed up the cement hydration process as well as lead to the evaporation of water within the concrete mixtures. All of the temperatures recorded during the production of the mixtures for this study were below this maximum temperature.



**Figure 6-5: Unit Weight Results for Trial Crumb Rubber and Combination Mixtures**

### **6.1.3 Hardened Concrete Properties of Trial Mixtures**

#### **6.1.3.1 Compressive Strength**

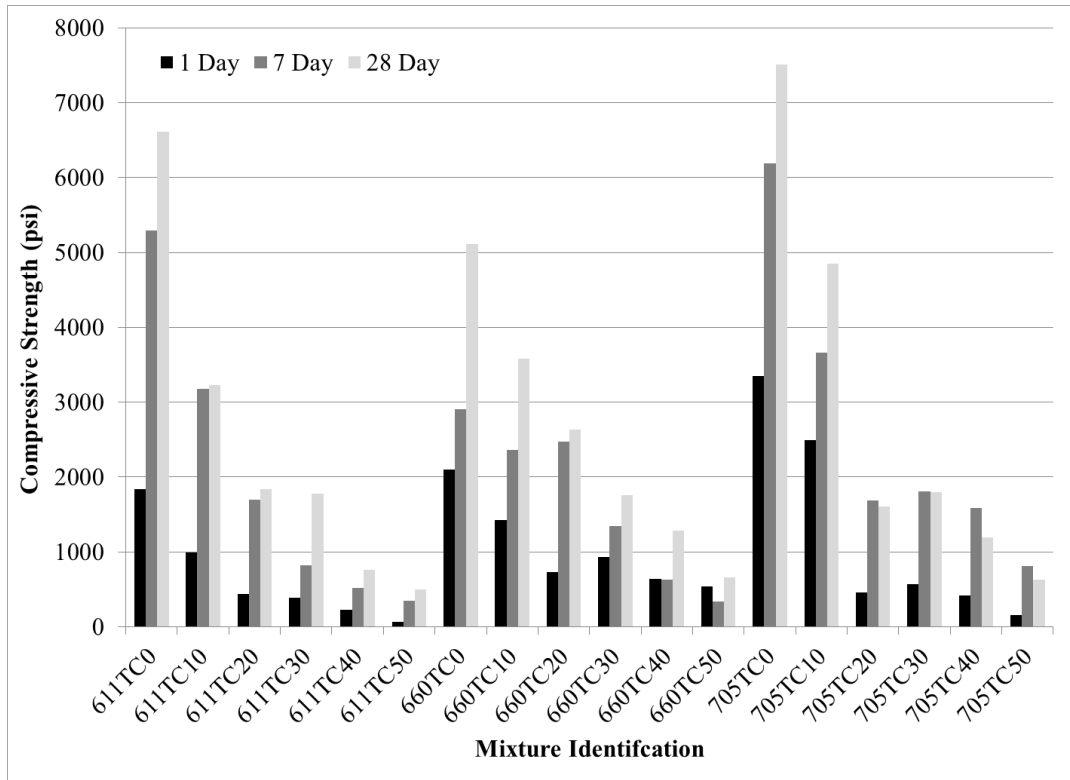
Ultimately, the compressive strength of the rubberized concrete mixtures was the deciding factor as to its acceptability as a GDOT Class A concrete. Each mixture’s compressive strengths were recorded at 1, 7, and 28 days of age in accordance with ASTM C39. Nine cylinders measuring 4 in by 8 in (100 mm by 200 mm) were fabricated for each mixture. Requirements specified by GDOT state that Class A concretes must reach an average 28-day compressive strength of 3,000 psi (20.7MPa). In addition, the compressive strengths were compared to the GDOT Class B concrete mixture requirements to determine whether the mixtures could be used for other applications where compressive strength was not as critical. GDOT Class B concrete fresh property requirements are identical to those of the Class A specification; however, the acceptable compressive strength minimum is only 2,200 psi (15.2 MPa) at 28 days.

The compressive strengths for the rubberized concrete mixtures were compared against the control mixture for each cement content as well as the benchmark value for GDOT Class A and B concrete. The average compressive strengths for tire chip, crumb rubber, and combination mixtures at 1, 7, and 28 days of age are listed in Table 6-2.

On average, concrete mixtures including rubber of any type and combination proved to gain a higher percentage of the 28-day strength within 7 days of age when compared to mixtures without rubber. The average rate of 7 day strength gain is listed in Table 6-2 and compared to the control for each mixture series (i.e., 611, 660, and 705 lb/yd<sup>3</sup> (362, 392, and 418 kg/m<sup>3</sup>)). With the exception of the 611 lb/yd<sup>3</sup> (362 kg/m<sup>3</sup>) mixture series, the average rate of strength gain by 7 days of age was approximately 10-20% higher than the control. The 611TC30 mixture exhibited a much lower rate of strength gain when compared to other tire chip mixtures resulting in a change from this trend.

Figure 6-6 and 6-7 shows the composite results for the compressive strength of tire chip and crumb rubber concrete mixtures, respectively. In addition, Figures 6-8, 6-9, 6-10, and 6-11 show the compressive strength vs. age for the 611, 660, and 705 lb/yd<sup>3</sup> (362, 392, and 418 kg/m<sup>3</sup>) tire chip and 660 lb/yd<sup>3</sup> (392 kg/m<sup>3</sup>) crumb rubber and combination mixtures, respectively. Regardless of cement content, a maximum of 10% coarse aggregate replacement with TC could be used in order to satisfy the required 28-day compressive strength of 3,000 psi. However, replacing up to 40% of the sand volume with crumb rubber met the appropriate specifications. Further, it was determined that adequate strengths could be reached with a 20% replacement of fine aggregate with crumb rubber in conjunction with a 10% replacement of coarse aggregate with tire chip. Overall, the compressive strengths generally decreased with higher rubber contents. The increased cementitious content did improve the compressive strength

of the tire chip mixtures up to 30% replacement; however, had little influence in mixtures with higher rubber contents. While improvement was made with increasing cement content and lower tire chip content, similar to the GDOT Class A, the lesser GDOT Class B requirement was not satisfied for mixtures with greater than 10% tire chips.



**Figure 6-6: Compressive Strength Results for Trial TC Mixtures**

**Table 6-2: Average Compressive Strength of Trial Rubberized Concrete Mixtures**

Mixture Identification	1 Day	7 Day	28 Day	Average Percent of 28 Day Strength by 7 Days of Age
	psi (MPa)	psi (MPa)	psi (MPa)	%
611TC0	1837 (13)	5295 (37)	6613 (46)	80
611TC10	1367 (9)	3179 (22)	3226 (22)	75
611TC20	438 (3)	1696 (12)	1835 (13)	
611TC30	385 (3)	820 (6)	1773 (12)	
611TC40	225 (2)	523 (4)	758 (5)	
611TC50	101 (0.7)	343 (2)	497 (3)	
660TC0	2095 (14)	2908 (20)	5109 (35)	
660TC10	1425 (10)	2361 (16)	3585 (25)	67
660TC20	731 (5)	2471 (17)	2629 (18)	
660TC30	934 (6)	1345 (9)	1755 (12)	
660TC40	643 (4)	634 (4)	1279 (9)	
660TC50	542 (4)	333 (2)	660 (5)	
705TC0	3351 (23)	6184 (43)	7505 (52)	
705TC10	2488 (17)	4271 (29)	4852 (33)	106
705TC20	463 (3)	1682 (12)	1792 (12)	
705TC30	565 (4)	1810 (12)	2050 (14)	
705TC40	414 (3)	1590 (11)	1196 (8)	
705TC50	158 (1)	811 (6)	628 (4)	
660CR10	2239 (15)	5194 (36)	6490 (45)	
660CR20	1821 (13)	4364 (30)	5191 (36)	
660CR30	1189 (8)	3313 (23)	4088 (28)	
660CR40	937 (6)	2653 (18)	3456 (24)	
660TC5CR10	1560 (11)	3968 (27)	5229 (36)	85*
660TC10CR20	688 (5)	2922 (20)	3136 (22)	

\* Compared to the 660TC0 mixture

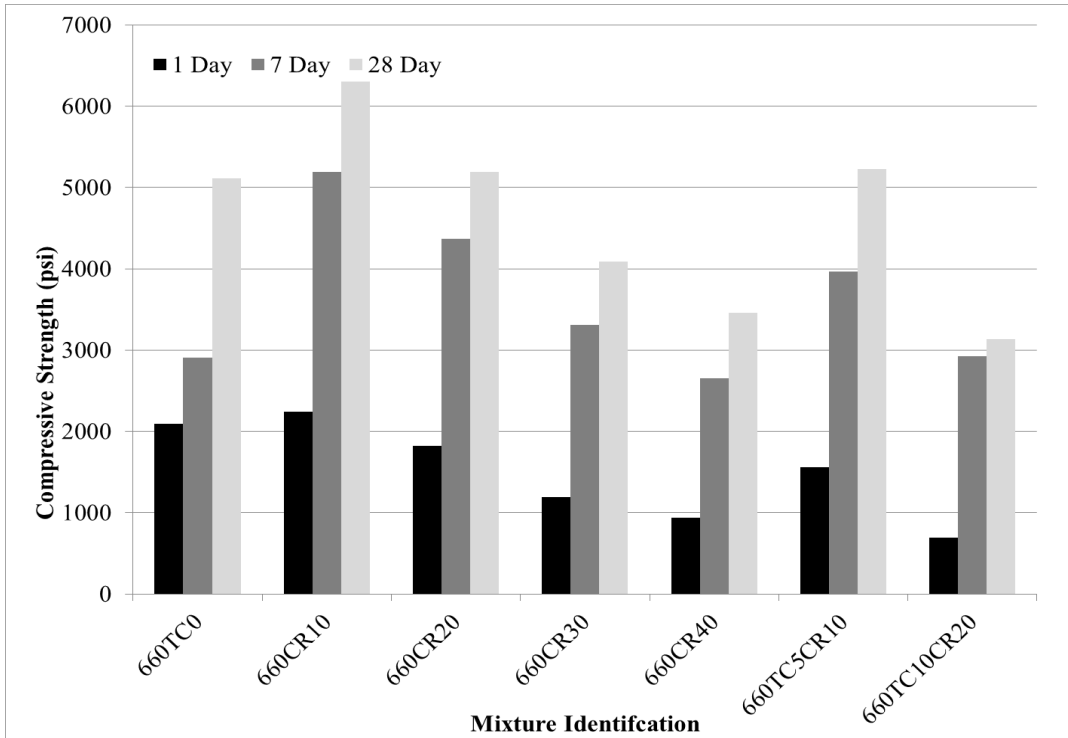


Figure 6-7: Compressive Strength Results for Trial CR and Combination Mixtures

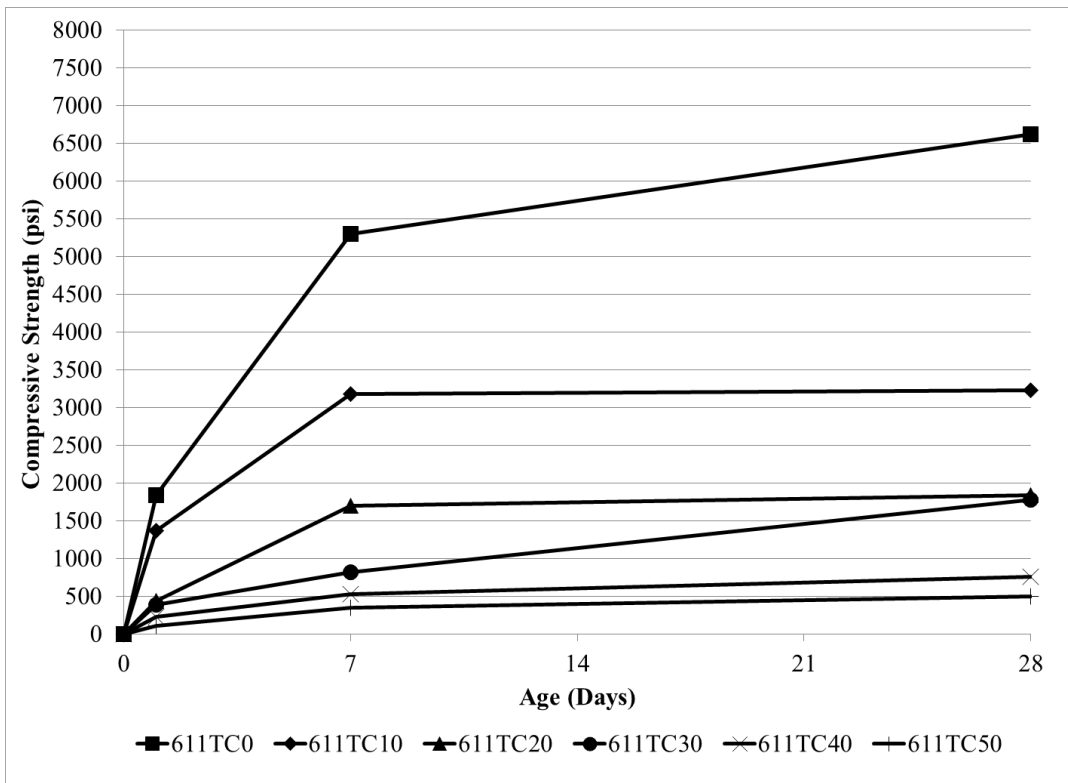


Figure 6-8: Compressive Strength vs. Age for 611 lb/yd<sup>3</sup> (362 kg/m<sup>3</sup>) Trial Series

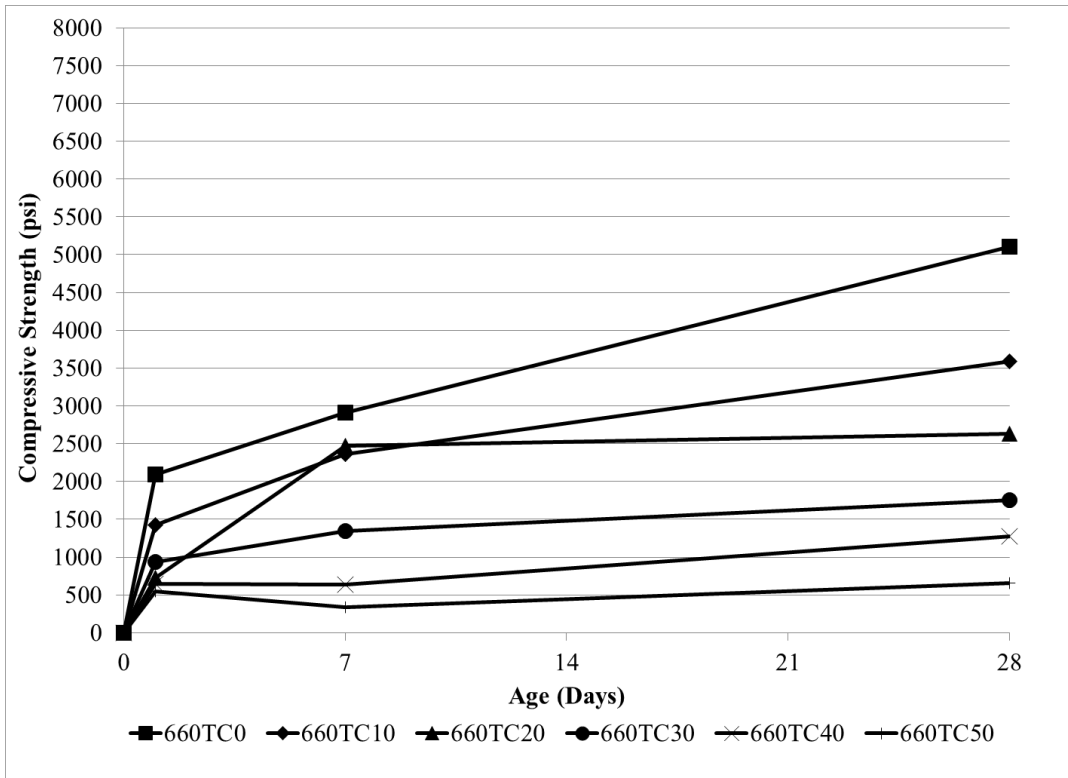


Figure 6-9: Compressive Strength vs. Age for 660 lb/yd<sup>3</sup> (392 kg/m<sup>3</sup>) Trial Series

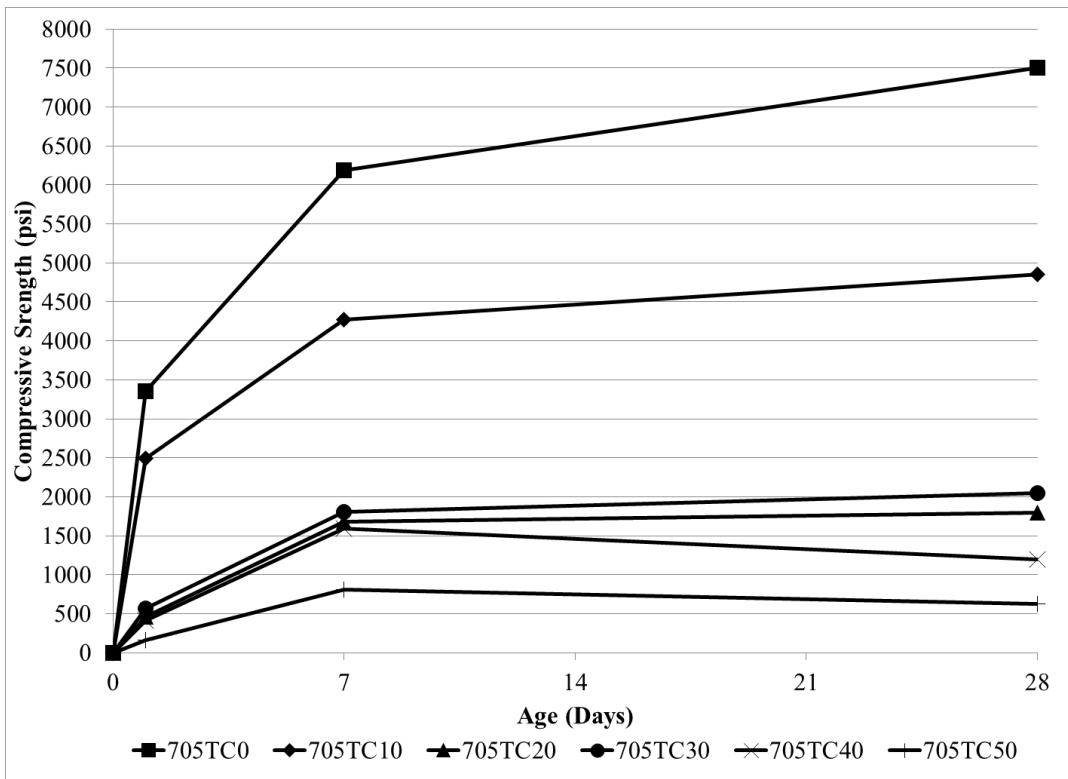
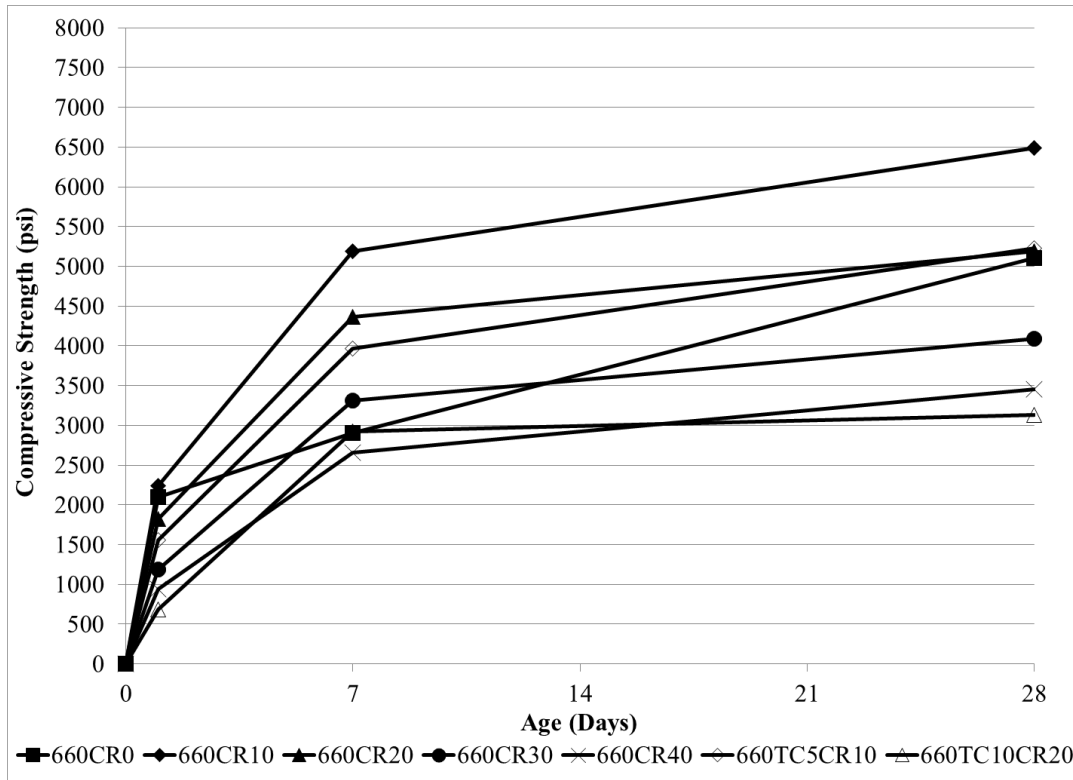
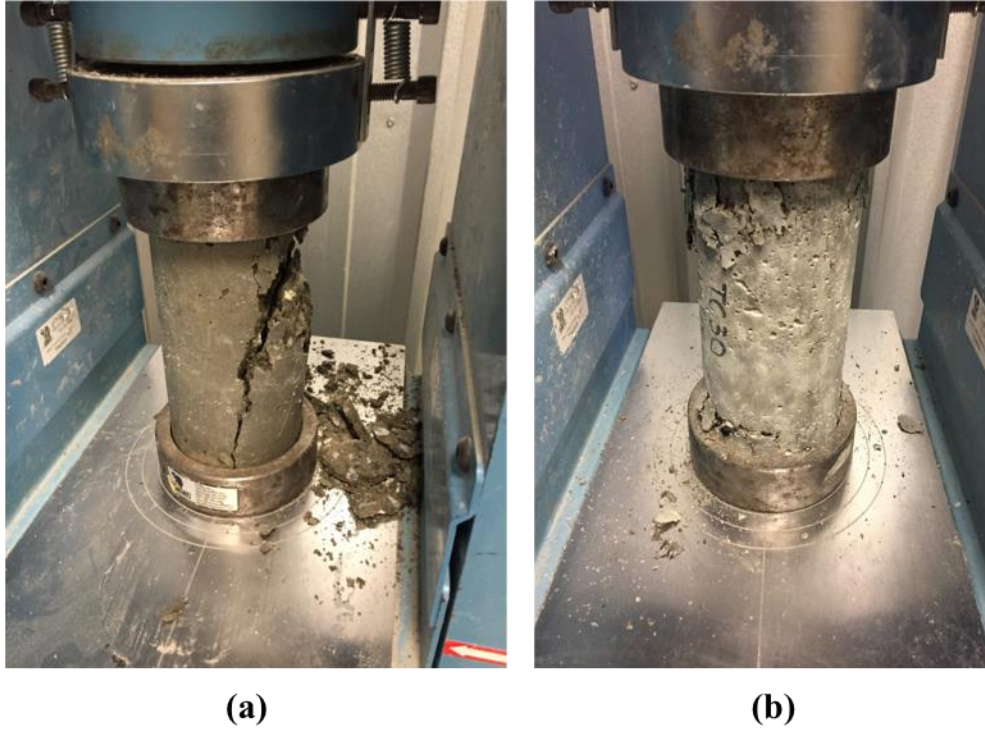


Figure 6-10: Compressive Strength vs. Age for 705 lb/yd<sup>3</sup> (418 kg/m<sup>3</sup>) Trial Series



**Figure 6-11: Compressive Strength vs. Age for 660 lb/yd<sup>3</sup> (392 kg/m<sup>3</sup>) Trial CR and Combination Mixtures**

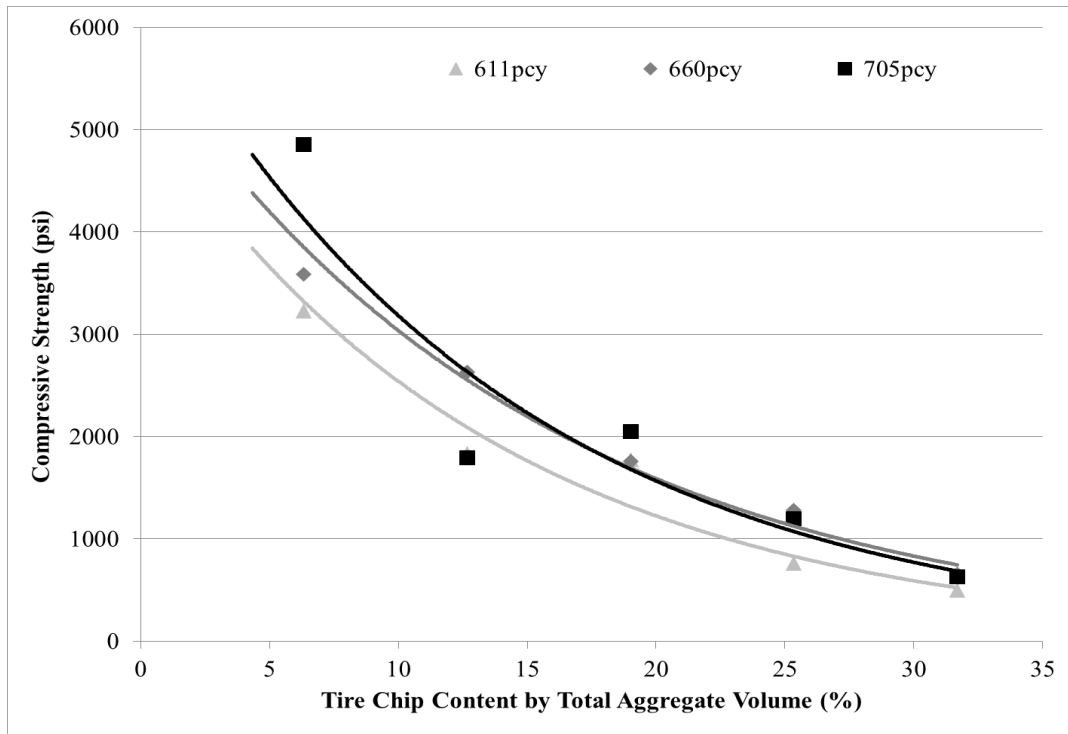
The failure mechanism of the rubber modified concrete was very different than that of the control mixtures. Ordinary concrete mixtures failed abruptly, often splitting down the center of the cylinder; however, the rubberized concrete mixtures crushed during failure. The cylinders containing tire chip in particular typically remained almost entirely intact, with the pieces of rubber bridging the cracks and holding the broken concrete pieces together. Figure 6-12 shows a failed conventional and rubberized concrete cylinders to illustrate this behavior.



**Figure 6-12: Failed (a) Control and (b) 30%TC Concrete Specimens**

### **6.1.3.2 Effect of Cement Content on Rubberized Concrete**

Illustrated in this study, the volume of rubber included as an aggregate replacement will significantly affect the concrete's compressive strength. However, this phenomenon is not a linear relationship. As shown in Figure 6-13, the compressive strength differential at higher rubber volumes (i.e., 25-30% of total aggregate volume) becomes much smaller compared to lower rubber contents (5-10% of total aggregate volume). Additionally, increased cement content will provide higher compressive strengths for the same rubber volume at low replacement levels, but becomes less of a factor at higher rubber contents. This is best illustrated by the trend lines shown in Figure 6-14.

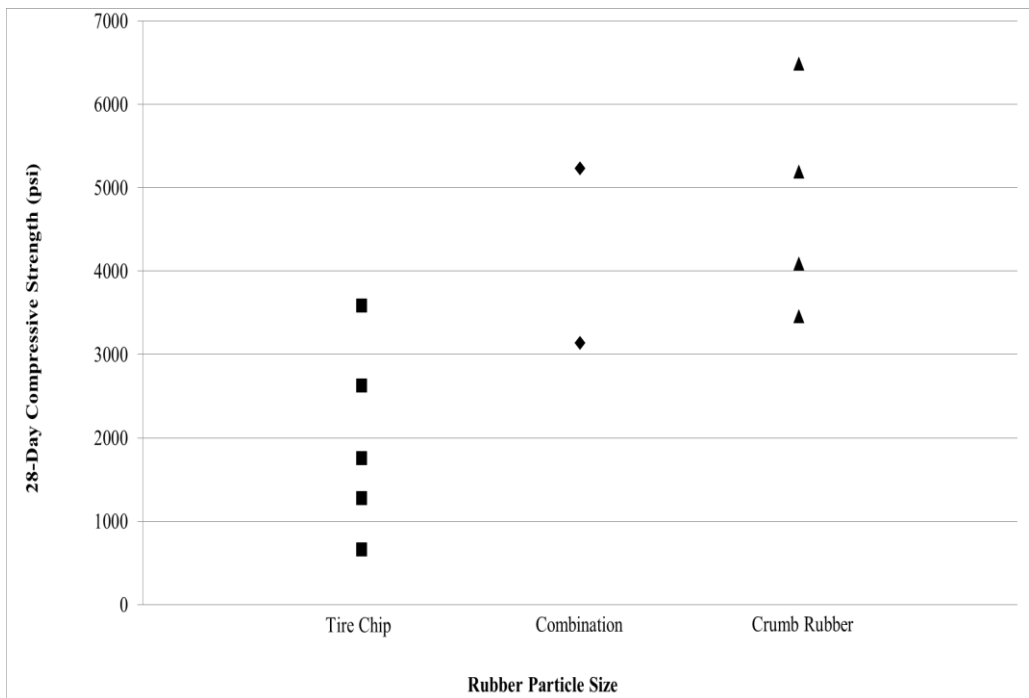


**Figure 6-13: Effect of Cement Content on Rubberized Concrete Compressive Strength**

### 6.1.3.3 Rubber Particle Size on Concrete Strength

While cement content influences the overall compressive strength of rubberized concrete mixtures, the rubber particle size will have a more influential effect the concrete's performance. This study produced concrete mixtures that incorporated a coarse aggregate replacement with tire chip of a similar size, a fine aggregate replacement of a similar size, and a combination of the two recycled products. At a constant cement content, the compressive strength increased when the same replacement percentage of aggregate (coarse vs. fine) was used in the concrete mixture. Figure 6-14 shows the 28-day compressive strength for the 660lb/yd<sup>3</sup> (392 kg/m<sup>3</sup>) tire chip and crumb rubber, mixtures for all recycled aggregate replacement levels. Further, the combination of coarse and fine aggregate replacement aligned with this trend of increasing compressive strength with the incorporation of the finer crumb rubber when tire chips were used in the mixture.

It should be noted, however, that the same percentage of fine aggregate replacement with crumb rubber does not possess the same rubber volume as that of an equal percent replacement of coarse aggregate with tire chip. This is because the fine aggregate volume of the concrete mixtures is typically less than that of the coarse aggregate, thus replacement volumes will yield higher values for the tire chip. When comparing tire chip and crumb rubber mixtures with similar rubber aggregate volumes (i.e., 660TC20 and 660CR40), crumb rubber mixtures had an approximately 24-30% increase in compressive strength over the tire chip mixture. Ultimately, a higher percentage of finer rubber particles can be used in concrete mixtures without significantly sacrificing compressive strength.



**Figure 6-14: Rubber Particle Size on Concrete Compressive Strength**

## 6.2 Research Mixtures

### 6.2.1 Batching of Research Mixtures

The batching of research mixtures including tire chips at 10% and 20% replacement levels of coarse aggregate were subjected to further evaluation in the second phase of the study. The

phase maintained a constant w/cm (0.42) and cement content (611 lb/yd<sup>3</sup> (362 kg/m<sup>3</sup>)) and evaluated three rubber surface treatments in an effort to improve the adhesion between the rubber particles and the cement paste. Specifically, mechanical roughening of the rubber surface, soaking in a sodium hydroxide solution, and application of a silane coating were utilized to increase bond. Similar to the first phase of the study, mixtures will be referred to as its shorthand mixture identification name throughout the remainder of the section with the addition of the surface treatment variables: M – mechanical roughening, NaOH – sodium hydroxide solution, and S – silane coating. For instance, 611TC20/S will be used to refer to the mixture with 611 lb/yd<sup>3</sup> (362 kg/m<sup>3</sup>) of cement and 20% tire chip replacement with a silane coating.

Each of the seven design mixtures were batched and tested for fresh and hardened concrete properties. Additionally, two mixtures, the control and 611TC10/NaOH, were batched in replicate to demonstrate mixture consistency and repeatability. A total of nine mixtures were produced as a part of this phase. At the time of batching each mixture was evaluated for slump, air content, unit weight, and temperature. Specimens were fabricated for testing the mechanical and durability properties of the concrete mixtures at 1, 7, 28, and 56 days of age. Per ASTM C39, all specimens were broken within the permissible tolerances prescribed in Table 6-3.

**Table 6-3: Tolerance Times for Hardened Concrete Tests [ASTM C39]**

Test Age	Permissible Tolerance
24 h	±0.5hr
7 days	6hr
28 days	20hr

### 6.2.2 Fresh Concrete Properties of Research Mixtures

Tests for slump, air content, unit weight, and temperature were performed on each research mixture at the time of batching. Table 6-4 provides the fresh concrete properties results of the research mixtures with the appropriate discussion for each in the following sections.

**Table 6-4: Fresh Concrete Properties in Research Mixtures**

Mix Name	Slump, in (mm)	Unit Weight, lb/ft <sup>3</sup> (kg/m <sup>3</sup> )	Air Content, %	Temperature, °F (°C)
611TC0 - Control	3.00 (76.2)	142.8 (2,288)	6.0	59 (15)
611TC0 - Replicate	3.75 (95.3)	146.0 (2,339)	4.2	77 (25)
611TC10/M	5.00 (127.0)	138.0 (2,211)	6.0	62 (17)
611TC20/M	0.25 (6.4)	136.0 (2,179)	5.3	63 (17)
611TC10/NaOH	3.00 (76.2)	141.0 (2,259)	5.5	68 (20)
611TC10/NaOH Replicate	5.00 (127.0)	135.4 (2,169)	3.0	-
611TC20/NaOH	7.00 (177.8)	137.6 (2,204)	4.9	80 (27)
611TC10/S	2.00 (50.8)	142.8 (2,288)	3.3	70 (21)
611TC20/S	0.25 (6.4)	134.4 (2,153)	4.0	89 (32)

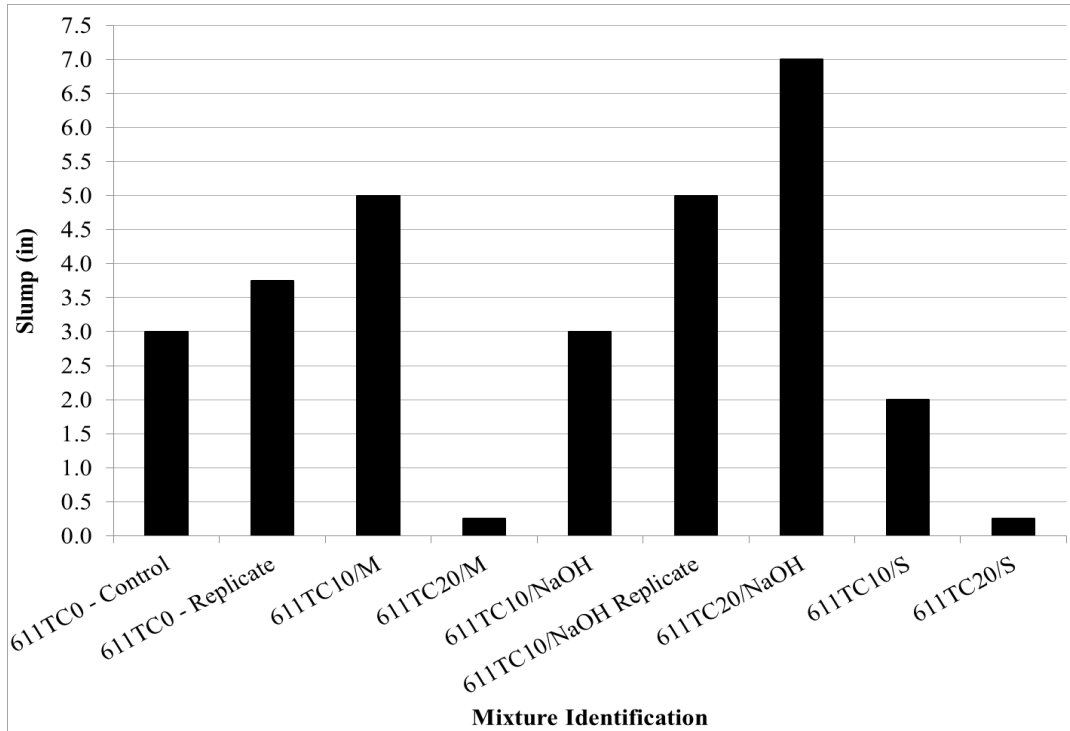
**6.2.2.1 Slump**

The slump results were consistent in terms of the cohesiveness and flow consistency of the mixtures. See Figure 6-15. While the slump varied from as low as 0.25 in (6.35mm) for the 611TC20/M mixture to as high as 7.00 in (177.8 mm) for the 611TC20/NaOH mixture, all mixtures produced quality consistency required for placing concrete and the fabrication of test specimens. A constant HRWRA and VMA were used for all mixtures, thus the fluctuation in slump is likely the result of moisture condition of the coarse and fine aggregates at the time of batching. Although the mixtures are adjusted for aggregate moisture, free water on the surface of the aggregate could change the fluidity of the mixture during the batching operation.

**6.2.2.2 Air Content**

ASTM C173 states that in concrete mixtures containing lightweight aggregates shall use the volumetric method for air content testing. However, it is unknown as to whether recycled waste tire particles are considered a lightweight particle. Most literature consider lightweight aggregate as highly porous with a significant void content. Because the absorption capacity on the tire chips was very small (0.3%), it is concluded that the tire chip does not qualify as a lightweight aggregate

as it relates to the terminology of ASTM C173. Currently, there is limited research related to the type of air content test performed on rubberized concrete mixtures. Kardos and Durham performed both the Roll-a-Meter and Pressure Meter air content tests and determined a slight reduction in air content values; however, the difference was not significant [2015]. The Pressure Meter method was utilized for this study.



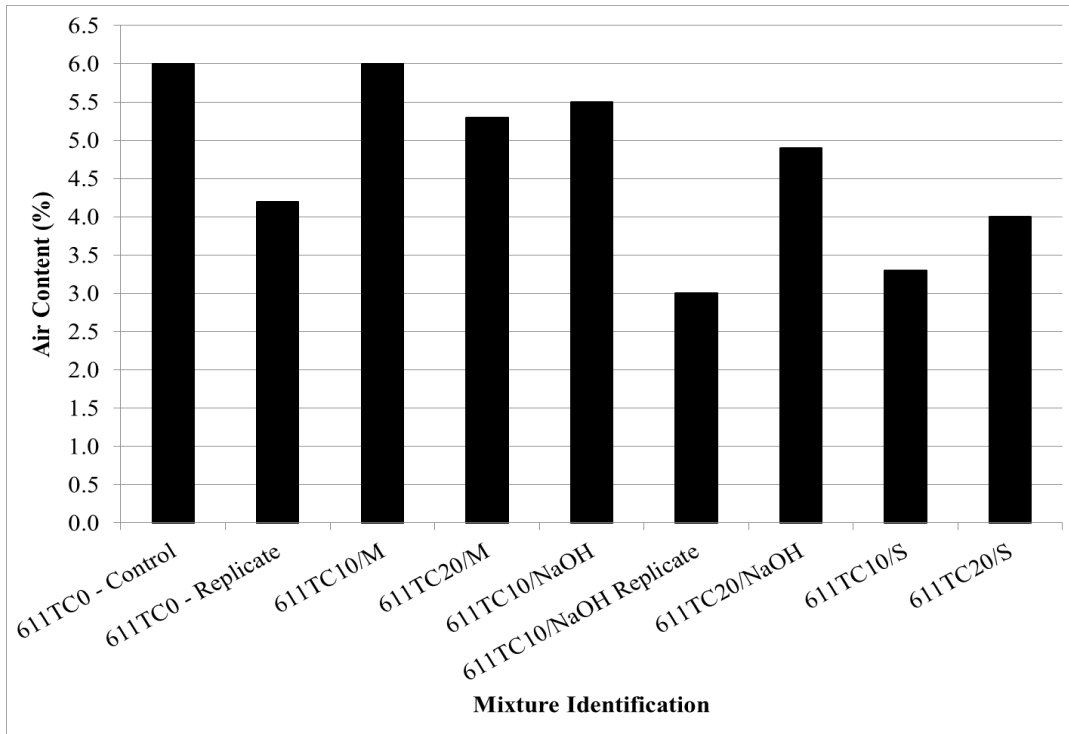
**Figure 6-15: Slump Results for Research Mixtures**

The air content results are presented in Figure 6-16. An AEA was utilized in order to achieve the desired air content of 2.5-6%, as required by GDOT for Class A concrete mixtures. Adjustment of AEA dosage within the trial mixture analysis led to the successful implementation of the correct dosage rate providing satisfactory air contents for all research mixtures. Air contents remained fairly consistent between 3.0-6.0% with no noticeable change as a result of tire chip inclusion.

### 6.2.2.3 Unit Weight

The unit weight of the research mixtures was determined using ASTM C138. The unit

weight was calculated as the weight of fresh concrete per unit volume. The design unit weight for the mixtures ranged from 145.0 to 137.3 lb/ft<sup>3</sup> (2,323 to 2,200 kg/m<sup>3</sup>) depending on the replacement quantity of coarse aggregate with recycled tire chips.



**Figure 6-16: Air Content Results for Research Mixtures**

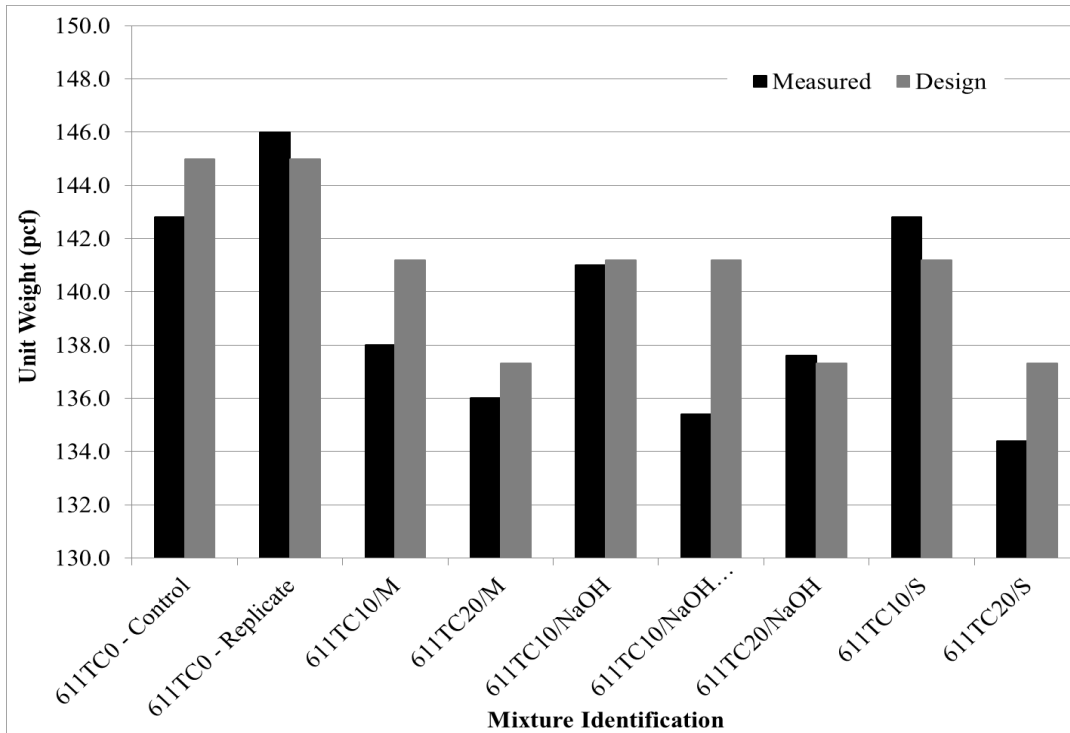
Similar to the trial mixture phase, the measured unit weight decreased with increasing percentage of tire chips. As shown in Figure 6-17, the measured unit weight values did fluctuate from the design due to changes in the air content where by lower than design air contents produced higher unit weights. However, measured unit weight values were all considered within the acceptable range for rubberized concrete ranging from 142.8 to 134.4 lb/ft<sup>3</sup> (2,275 to 2,153 kg/m<sup>3</sup>).

The measured unit weight values were unaffected by the rubber surface treatment with all

#### **6.2.2.4 Temperature**

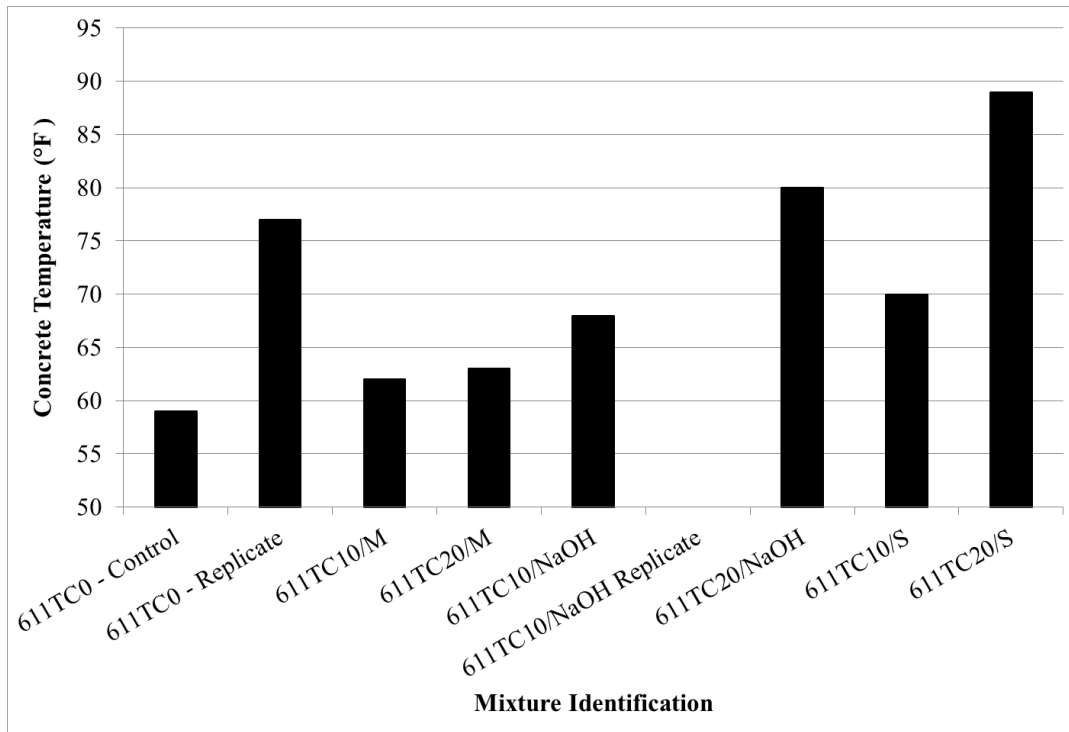
Concrete temperature is an important characteristic to consider when placing concrete because it is highly dependent on the environment during its plastic state. Previous studies have found that the ideal temperature to batch and place concrete ranges between 50 and 60°F and should not

exceed 85°F. This is important because greater temperatures can speed up the cement hydration process as well as lead to the evaporation of water within the concrete mixtures.



**Figure 6-17: Unit Weight Results for Research Mixtures**

With the exception of the 611TC20/S mixture, all recorded concrete temperatures were below this maximum. It is believed the high ambient temperature on the day of batching the 611TC20/S mixture was the cause of higher than normal temperature. In addition, a temperature was inadvertently not recorded for the 611TC10/NaOH replicate mixture. The research mixtures' measured temperatures are presented in Figure 6-18.



**Figure 6-18: Temperature Results for Research Mixtures**

### 6.2.3 Hardened Concrete Properties of Trial Mixtures

Hardened concrete properties were performed on the control and rubber-modified concrete mixtures in accordance to the appropriate ASTM standard. Each mixture produced a total of 34 – 4 in x 8 in x (100 mm x 200 mm) cylinder specimens, 4 – 3 in x 4 in x 16 in prismatic beams, 2 – 6 in x 6 in x 18 in prismatic beams, and 3 – 6 in (diameter) x 2 in (height) pucks. The hardened concrete properties were measured in the following manner:

- Compressive strength – average of 3 cylinders at 1, 7, 28, and 56 days of age
- Indirect splitting tensile strength – average of 3 cylinders at 28 and 56 days of age
- Modulus of rupture strength – average of 2 beams at 28 and 56 days of age
- Dynamic modulus of elasticity – average of 3 cylinders at 28 and 56 days of age
- Static modulus of elasticity – average of 3 cylinders at 28 and 56 days of age
- Rapid chloride ion penetrability – average of 2 cylinders at 28 and 56 days of age

- Impact drop hammer testing – average of 3 pucks at 28 days of age
- Load-deflection testing – 2 beams at 28 days of age.

### **6.2.3.1 Compressive Strength**

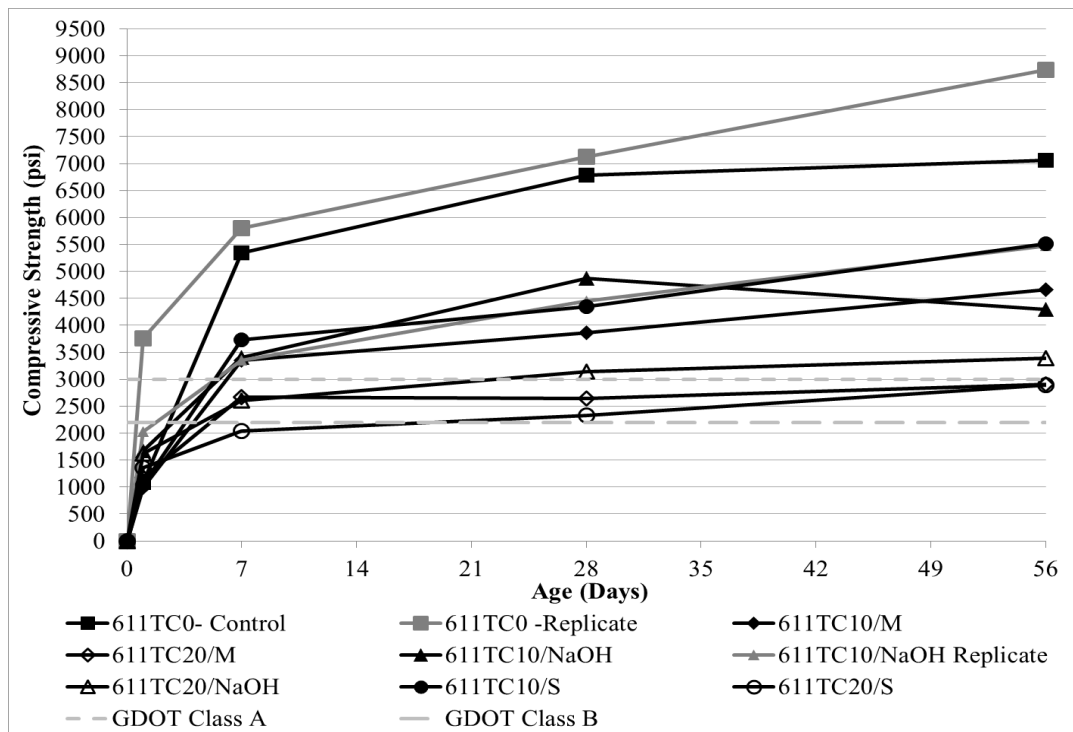
Per Section 500 of the GDOT Supplemental Specification, the concrete classified as Class A and Class B shall have a minimum specified compressive strength,  $f'_c$ , of 3,000 psi (21 MPa) and 2,200 psi (15 MPa), respectively. The minimum compressive strength desired for this study was selected to be 3,000 psi (21 MPa) in order to satisfy concrete typically used in concrete barrier walls.

The compressive strength is an important component in the concrete design and generally the most specified property. The compressive strength was tested in accordance to ASTM C39. Three cylinders were tested for each mixture on the respective day of age. The cylinders were of the dimensions 4 in by 8 in (100 mm by 200 mm). Strength development trends were compared against the control mixtures and among the three rubber surface treatments. The trend was established by calculating the percent change between mixtures.

Table 6-5 lists the average compressive strength,  $f'_c$ , for the nine mixtures examined this phase. These values are plotted versus concrete age in Figure 6-19. All of the mixtures designed and produced during the second phase of the study met the minimum specified compressive strength of 3,000 psi (21 MPa) at 28 days of age with the exception of the 611TC20/M (20% tire chip with mechanical roughening of the surface) and 611TC20/S (20% tire chip with silane coupling agent). However, all mixtures did satisfy the GDOT Class B specified minimum strength of 2,200 psi (15 MPa) at 28 days of age.

**Table 6-5: Average Compressive Strength of Research Mixtures**

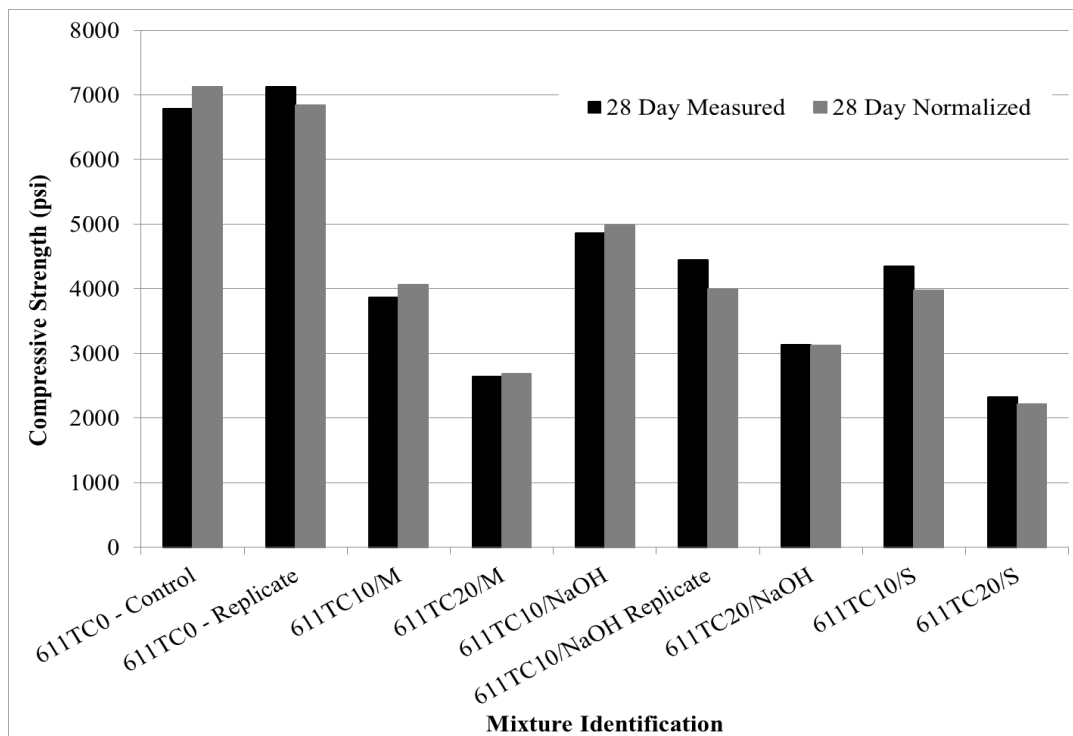
Mixture Identification	1 Day, psi (MPa)	7 Day, psi (MPa)	28 Day, psi (MPa)	56 Day, psi (MPa)
611TC0 - Control	1082 (7)	5348 (37)	6783 (47)	7063 (49)
611TC0 - Replicate	3753 (26)	5805 (40)	7128 (49)	8737 (60)
611TC10/M	997 (7)	3349 (23)	3867 (27)	4659 (32)
611TC20/M	1171(8)	2663 (18)	2642 (18)	2909 (20)
611TC10/NaOH	1677 (12)	3408 (23)	4864 (34)	4294 (30)
611TC10/NaOH Replicate	2030 (14)	3346 (23)	4448 (31)	5468 (38)
611TC20/NaOH	1623 (11)	2607 (18)	3136 (22)	3390 (23)
611TC10/S	1041 (7)	3731 (26)	4350 (30)	5512 (38)
611TC20/S	1359 (9)	2041 (14)	2328 (16)	2896 (20)



**Figure 6-19: Compressive Strength Results for Research Mixtures**

As shown in Figure 6-16, the air content for the mixtures varied from the design of 5.0%. Compressive strength is inversely affected by air content. As the air content of a concrete mixture increases, compressive strength decreases. Specifically, a standard relationship considered within the concrete industry is a 5% decrease in compressive strength for each 1% increase in air content

(Mindess, Young, and Darwin, 2003). To allow for a better comparison of mixtures without the effect of air content, the 28-day compressive strengths were normalized using this relationship. The results of this compressive strength adjustment are illustrated in Figure 6-20. Normalizing the compressive strength results at 28 days had little effect on the overall trend of decreasing strength with increasing rubber content. Additionally, all mixtures satisfied the GDOT Class A specification with the exception of 611TC20/M and 611TC20/S and all mixtures satisfied GDOT Class B requirements.



**Figure 6-20: Compressive Strength Results Normalized for 5% Air Content**

The rubberized concrete mixtures illustrated a 49% decrease in compressive strength when compared to the control without rubber aggregates. The second phase of the research investigation examined surface treatments on the rubber in an effort to improve adhesion between the tire chips and cement past and reduce the strength loss as a result of rubber inclusion. Specifically, the compressive strength for the rubberized mixtures was determined when NaOH and silane coupling agent treatments were performed and compared to the mechanical roughening pretreatment. The

NaOH surface treatment proved to be the most beneficial and consistent in improving the strength of rubberized concrete mixtures. Table 6-6 provides the percent increase in strength for the NaOH and silane coupling agent surface treatments when compared to the mechanical roughening treatment.

**Table 6-6: Percent Increase in Compressive Strength When Compared to Mechanical Roughening Surface Treatment**

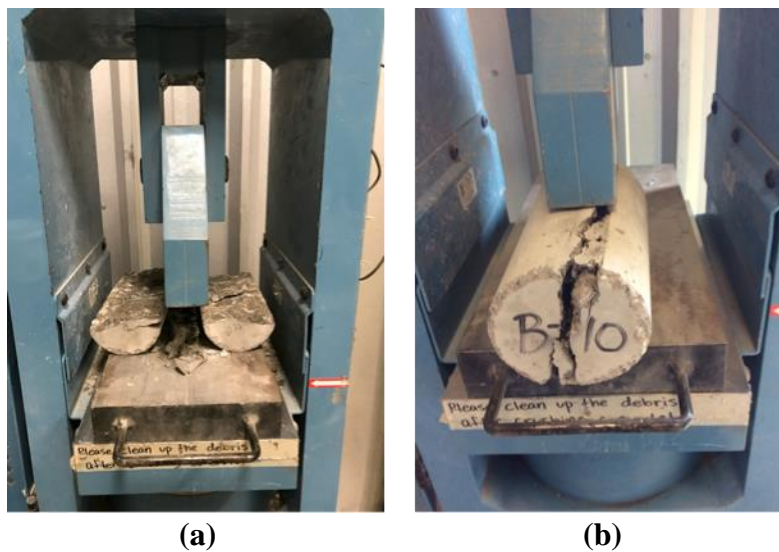
Replacement Level	NaOH	Silane Coupling Agent
10% Tire Chips	17%	11%
20% Tire Chips	16%	-13%

The results indicate an average 16.5% increase in compressive strength across the 10% and 20% tire chip replacement levels. While the silane coupling agent treatment produced a 15% percent increase in strength for the 10% tire chip replacement level, the 20% tire chip silane couple treated mixture experienced a decrease in strength when compared to the mechanical roughening mixture. In addition, it should be recognized that the NaOH surface treatment mixtures were the only concrete mixtures to satisfy the GDOT Class A minimum strength requirement of 3,000 psi at both 10% and 20% replacement levels.

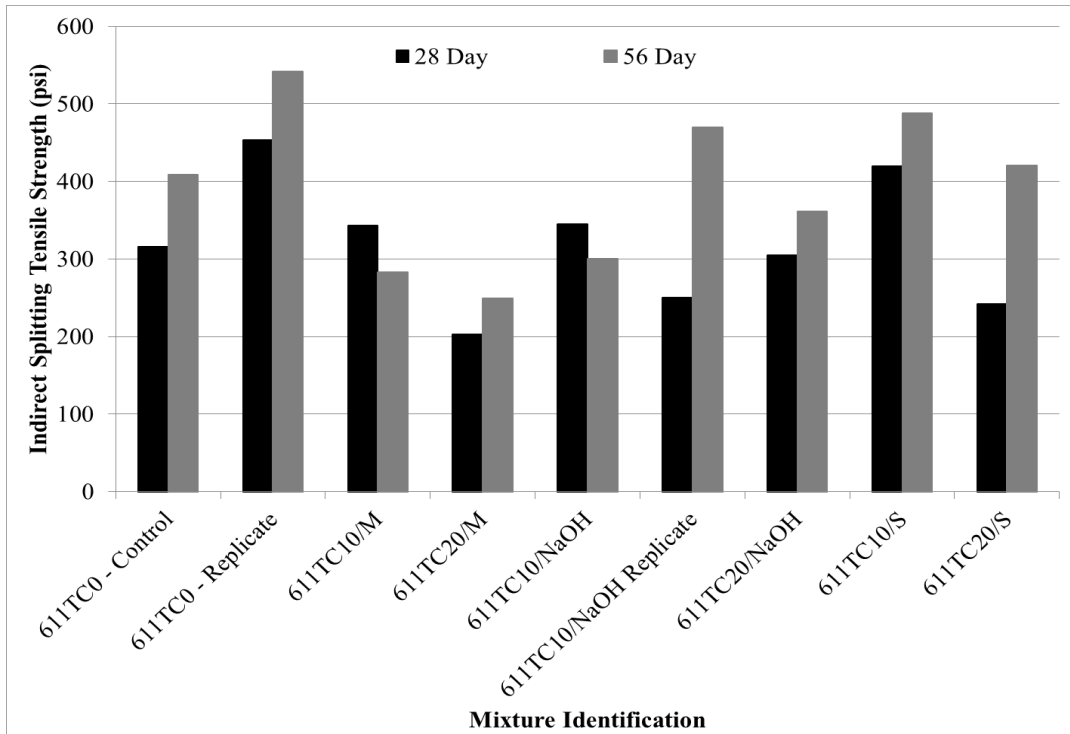
### 6.2.3.2 Indirect Splitting Tensile Strength

The control and rubber-modified concrete mixtures were subjected to indirect splitting tensile strength testing per ASTM C496. Figure 6-21 shows the indirect splitting tensile test configuration with typical failures of the (a) control mixture and (b) tire chip mixtures. The results of the indirect splitting tensile strength test illustrate a similar trend to that of the compressive strength with decreased tensile strength with increasing rubber contents. See Figure 6-22. When comparing the effect of surface treatments on the splitting tensile performance, the NaOH surface treatment specimens performed similarly or slightly better than the mechanical roughing treatment.

However, the silane coupling agent appears to provide better performance in tension when compared to the other two surface treatments producing a tensile strength greater than that of the control specimen without rubber aggregate. Similar to the mode of failure observed in the trial mixture phase of the study, the split cylinder specimens experienced a crushing without complete separation along the cylinder length. The control mixtures without rubber particles did not exhibit this behavior.



**Figure 6-21: Indirect Splitting Tensile Test Configuration and Test Samples (a) Control and (b) 10% Tire Chip**



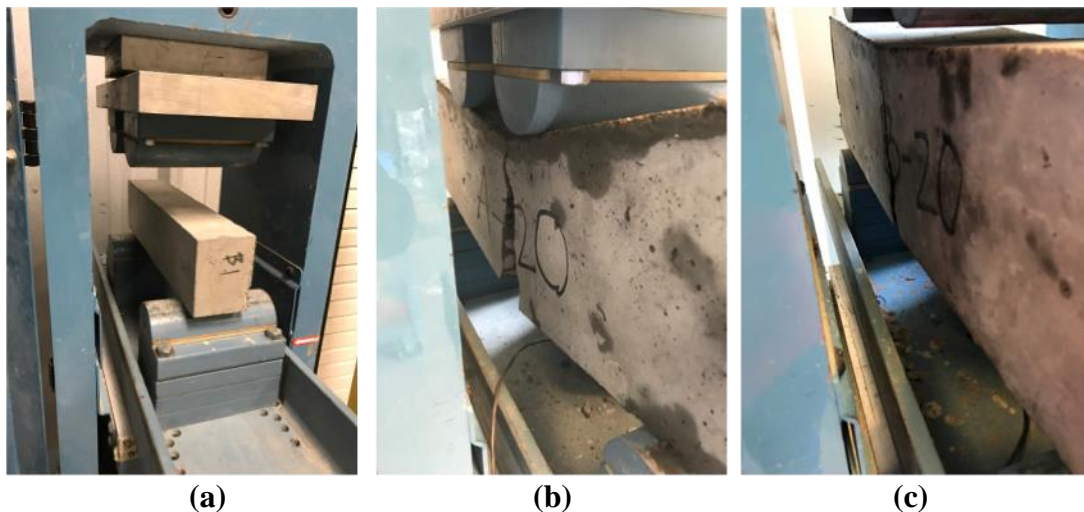
**Figure 6-22: Indirect Splitting Tensile Test Results**

### 6.2.3.3 Modulus of Rupture Strength

Flexural strength was evaluated for the research mixtures in accordance to ASTM C78. See Figure 6-23. There is not a minimum MOR specified by the GDOT Class A or Class B standards. The results obtained for the nine mixtures are shown in Figure 6-24. The nine mixtures produced MOR values ranging from 409 psi to 738 psi (3 MPa to 5 MPa) at 28 days of age and 395psi – 687psi (3MPa to 5MPa) at 56 days of age.

Similar to other literature, the modulus of rupture values collectively were higher than the measure of tensile capacity via the indirect splitting tension test. On average across all specimens tested, the modulus of rupture test results were approximately 43% higher than the indirect splitting tensile strength. When compared to the modulus of rupture empirical prediction equation  $7.5\sqrt{f'_c}$ , the measured strength produces higher values. Even though rubber aggregates were used in the concrete mixtures evaluated in this study, the prediction equation remains a conservative

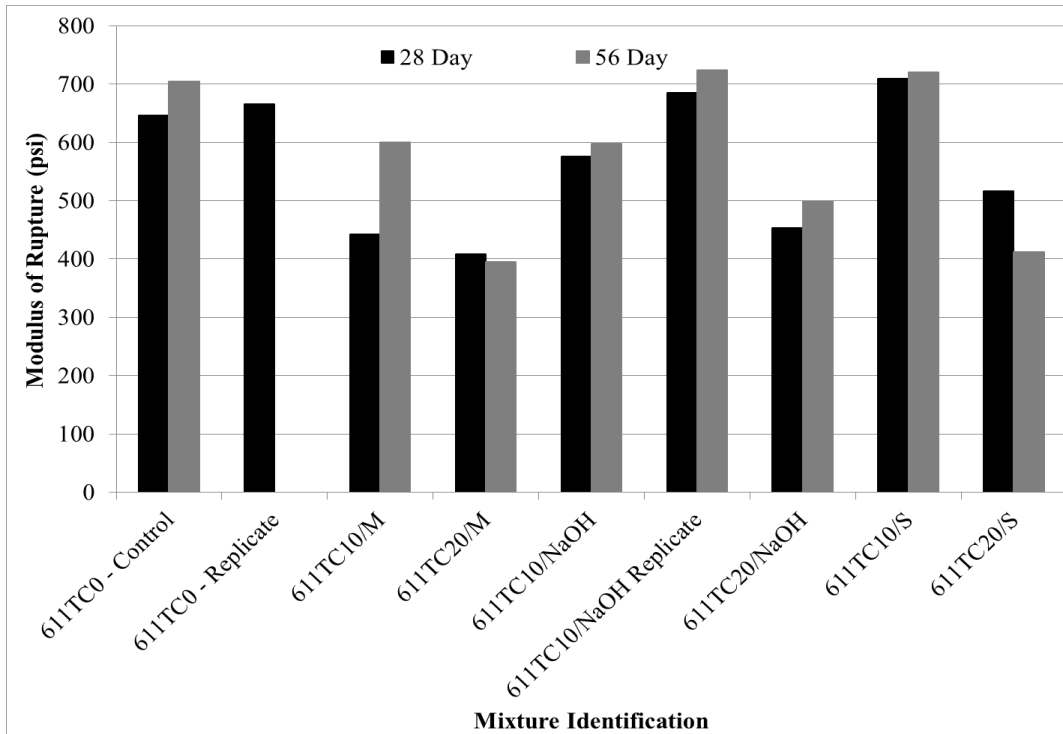
estimation of the modulus of rupture. This is a similar trend for conventional concrete mixtures. Analogous to the indirect splitting tensile test, the trend of decreasing modulus of rupture strength with increasing tire chips was observed for the rubberized concrete mixtures. However, contrary to the indirect tensile strength results, the rubber-modified concrete mixtures incorporating a NaOH treated rubber performed better than mixtures incorporating a silane coupling agent treatment.



**Figure 6-23: Modulus of Rupture Test Configuration and Test Samples (a) Configuration, (b) Control Mixture, and (c) 20% Tire Chip Mixture**

Most notable with the modulus of rupture testing was the behavior of the prismatic beams at and immediately following failure. When the ultimate load was reached for the control mixtures, the beam would crack in the maximum tensile region of the beam resulting in complete failure with no ability for additional load. However, the concrete prismatic beams incorporating the tire chip aggregate demonstrated a behavior such that the beams noticeably deformed and an additional load was carried by the beam immediately following the formation of a tensile crack. This alternate behavior is the result of the tire chip aggregate bridging the crack upon formation. Ultimately, failure is the result of the tire chip pulling out of the cement paste or rupturing of the rubber particle. While the modulus of rupture values for the rubber-modified mixtures were at or

below that for the control specimens, the ability of the rubber particles to act as internal reinforcement (i.e. rubber fibers) may prove beneficial for certain concrete applications where fracturing of the concrete is likely.



**Figure 6-24: Modulus of Rupture Flexural Test Results**

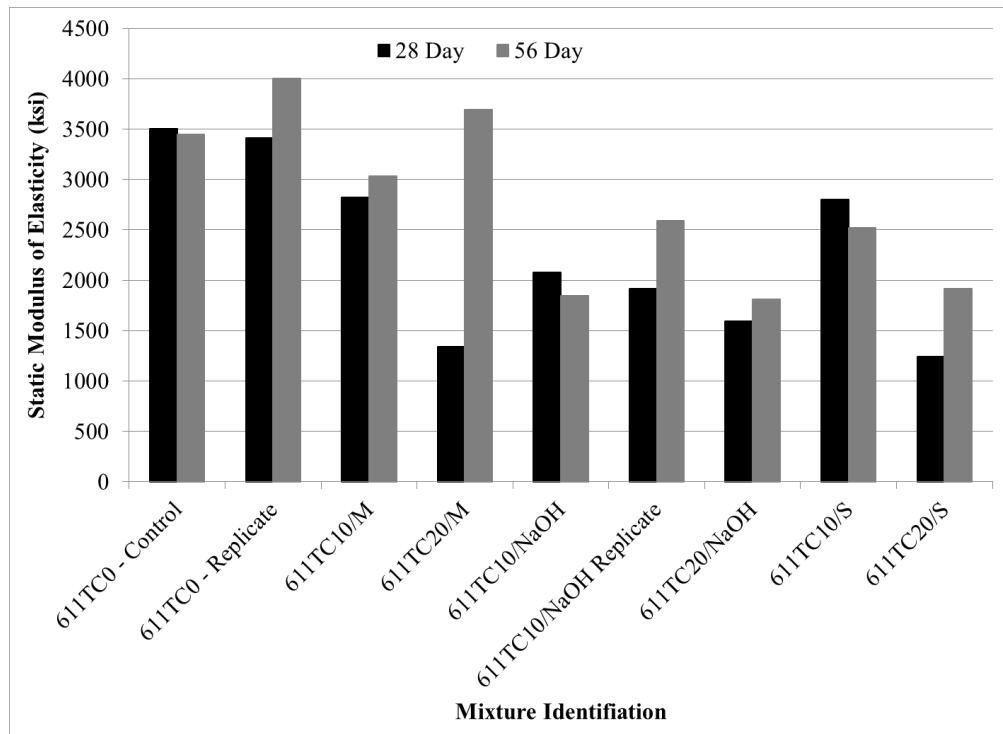
#### 6.2.3.4 Static Modulus of Elasticity

The static modulus of elasticity test was used to examine the concrete response to load. Specifically, this test was used to measure the concrete stiffness. It was expected that the static modulus of elasticity would decrease with an increased tire chip content. This is the result of an elastic material (tire chip) replacing a more rigid material (coarse aggregate). The test configuration utilized for this phase of testing is shown in Figure 6-25. As expected, the static modulus of elasticity decreased with increased tire chip content. The static modulus of elasticity results are presented in Figure 6-26. With the exception of mixture 611TC20/M, the 28 day and 56-day modulus of elasticity values are similar. Thus, little increase in modulus of elasticity is

experienced beyond 28 days of age. Similar to other mechanical properties a decrease in the static modulus of elasticity was observed with increasing tire chip contents. The modulus of elasticity values measured are within the normal range of concrete mixtures (i.e. 3,000 – 5,000 ksi (21 – 34 GPa)).



**Figure 6-25: Static Modulus of Elasticity Test Configuration (a) Motion Capture Camera (b) Detection Sensors**



**Figure 6-26: Static Modulus of Elasticity Test Results**

### 6.2.3.5 Dynamic Modulus of Elasticity

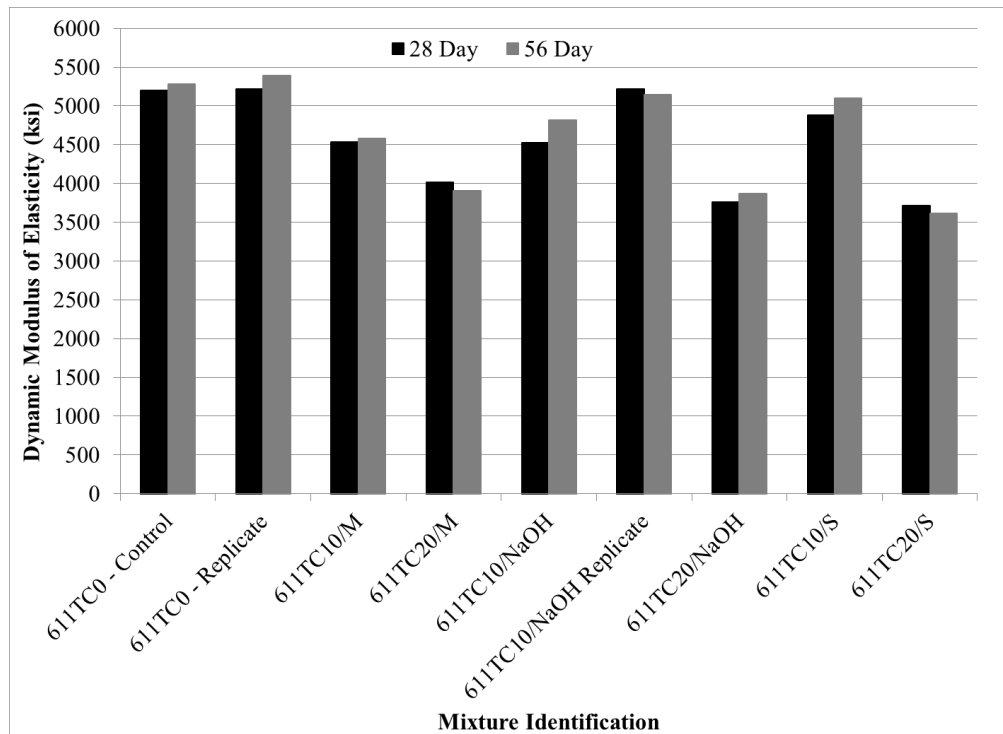
The dynamic Young's modulus of elasticity is the ratio of stress to strain under vibratory conditions. The dynamic modulus of elasticity in this study was tested in accordance to ASTM C215 – *Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens*. The impact resonance method of the standard was utilized during the testing of 4in x 8in (100mm x 200mm) cylinders in the transvers mode. The test set up shown in Figure 6-27 shows the cylinder properly supported with the impactor and accelerometer. From this configuration, the transvers resonance frequency was determined for each mixture. The average of two specimens was recorded. The dynamic modulus of elasticity is calculated by multiplying the square of the transvers frequency (Hz), the mass of the specimen, and a coefficient (C) equal to  $1.6067(L^3T/bt^3)$  where L is the specimen length, d is the cylinder diameter, and T is a correction factor specified by ASTM C215.



**Figure 6-27: Dynamic Modulus of Elasticity Test Configuration**

The results of the dynamic modulus of elasticity test for the research mixtures is presented in Figure 6-28. Observations with the data include little change in the dynamic modulus of

elasticity between 28 and 56 days of age. In addition, when comparing the control mixtures without tire chips and the rubberized concrete mixtures, the test results indicate that the dynamic modulus of elasticity is not as sensitive to the tire chips as other mechanical properties such as compressive strength. While nearly all of the rubberized mixtures produced dynamic modulus of elasticity values were less than the control, the percent difference (16% reduction) was not as great when compared to that of the compressive strength (49% reduction). Thus, the tire chips have less influence on the dynamic modulus of elasticity than other test methods. While all dynamic modulus of elasticity measured results are within the typical range of values for concrete specimens, the dynamic modulus of elasticity results were on average 45% higher than the static modulus of elasticity values. This significant difference in moduli is similar to that experienced by other researchers since the dynamic modulus is more representative of the initial tangent modulus than the secant modulus determined in the static method.

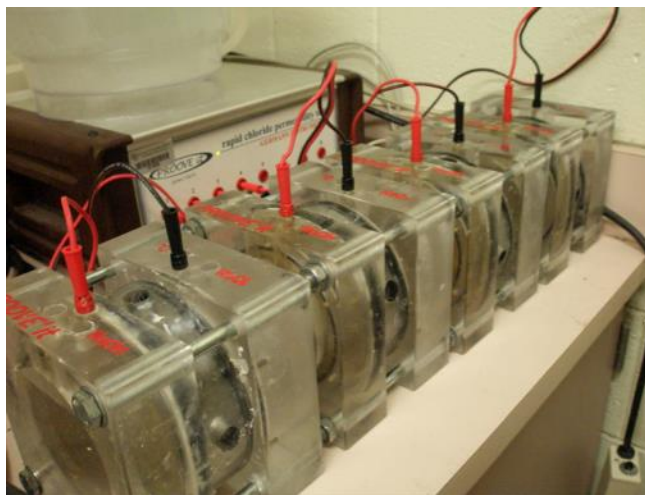


**Figure 6-28: Dynamic Modulus of Elasticity Test Results**

### 6.2.3.6 Rapid Chloride Ion Penetrability Test

The durability of concrete mixtures can often be predicted based upon its permeability. As the permeability of the concrete mixtures increases, aggressive chemicals such as sulfates and chlorides can more easily penetrate the concrete resulting in sulfate attack and reinforcement corrosion. ASTM C1202, rapid chloride ion penetrability test (RCIP), was performed at 28 and 56-days of age for each research mixture. This test procedure involves the monitoring of electrical current passing through a 2 in (51 mm) thick by 4 in (102 mm) nominal diameter cylinder section of concrete for a 6-hour duration.

Samples were first prepared by wet-saw cutting the top finished surface of a 4 in x 8 in (100 mm x 200 mm) concrete cylinder specimen. The samples were placed under a dry vacuum (approximately 25 inches (63.5 cm) of mercury) in a desiccator for 1 hour. Water was then introduced to the desiccator and the samples completely submerged. A wet vacuum was held for 3 hours prior to release. Next the samples were continued to soak in the desiccator for 24 hours. The specimens were then removed from the water and dried. The cylinder was then placed into the test cell as shown in Figure 6-29.



**Figure 6-29: Rapid Chloride Ion Penetrability Test Configuration**

A potential difference of 60-volts (direct-current) is maintained across the ends of the specimen. One side of the specimen cell includes sodium chloride solution (NaCl) while the other specimen includes sodium hydroxide solution (NaOH). ASTM C1202 provides a correlation between the total charge passed (coulombs) through the concrete sample and its ability to resist chloride ion penetration. Table 6-7 provides the permeability designations based upon the coulombs passed during the test.

Even though the GDOT Class A and Class B requirements do not specify a permeability classification, lower ion penetrability will ultimately result in more durable and longer lasting concrete when exposed to aggressive environments. The results of the permeability testing for the research mixtures is presented in Table 6-8 and graphically illustrated in Figure 6-30. The control and rubberized concrete mixtures all produced charges between 2,000 and 4,000 coulombs resulting in the classification of “moderate” permeability.

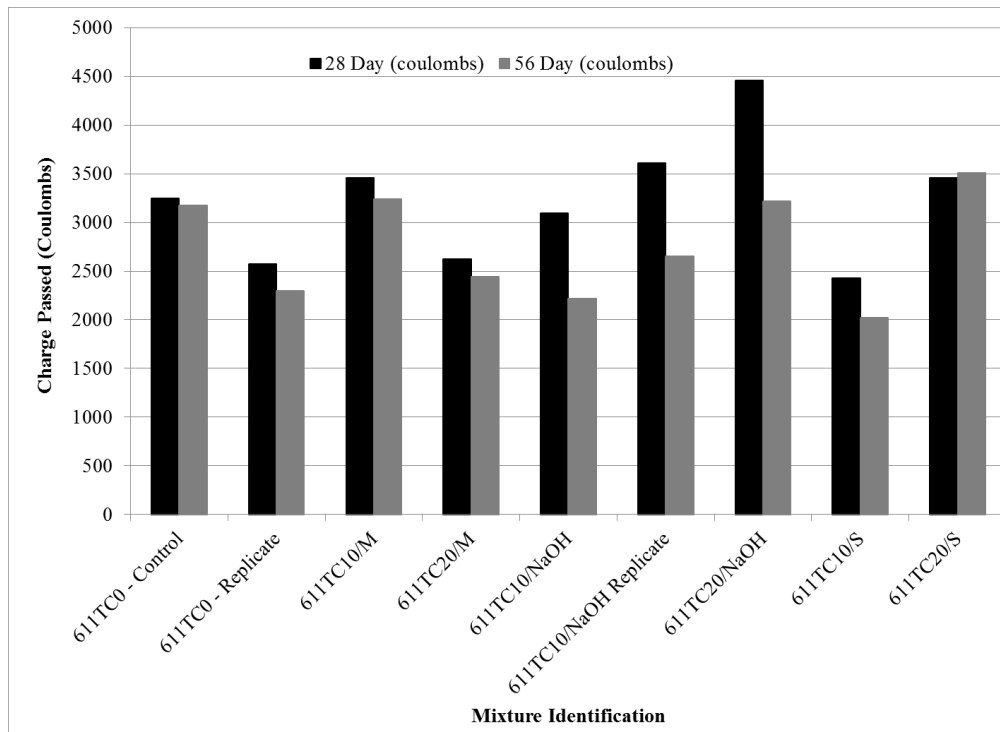
**Table 6-7: Permeability Classification per ASTM C1202**

Charge Passed (Coulombs)	Permeability Classification
> 4000	High
2,000 – 4000	Moderate
1,000 - 2,000	Low
100 - 1,000	Very Low
<100	Negligible

**Table 6-8: Rapid Chloride Ion Penetrability Results**

Mixture Identification	28 Day (coulombs)	Chloride Ion Penetrability	56 Day (coulombs)	Chloride Ion Penetrability
611TC0 - Control	3245	Moderate	3173	Moderate
611TC0 - Replicate	2576	Moderate	2300	Moderate
611TC10/M	3457	Moderate	3239	Moderate
611TC20/M	2622	Moderate	2443	Moderate
611TC10/NaOH	3092	Moderate	2217	Moderate

611TC10/NaOH Replicate	3607	Moderate	2650	Moderate
611TC20/NaOH	4457	High	3215	Moderate
611TC10/S	2425	Moderate	2022	Moderate
611TC20/S	3455	Moderate	3508	Moderate

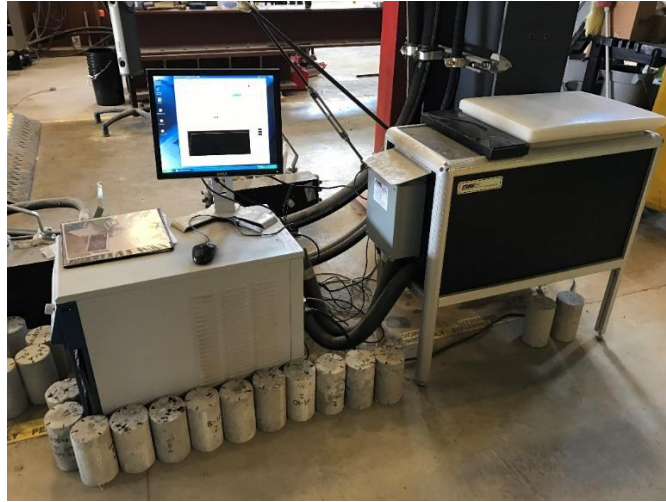


**Figure 6-30: Rapid Chloride Ion Penetrability Test Results**

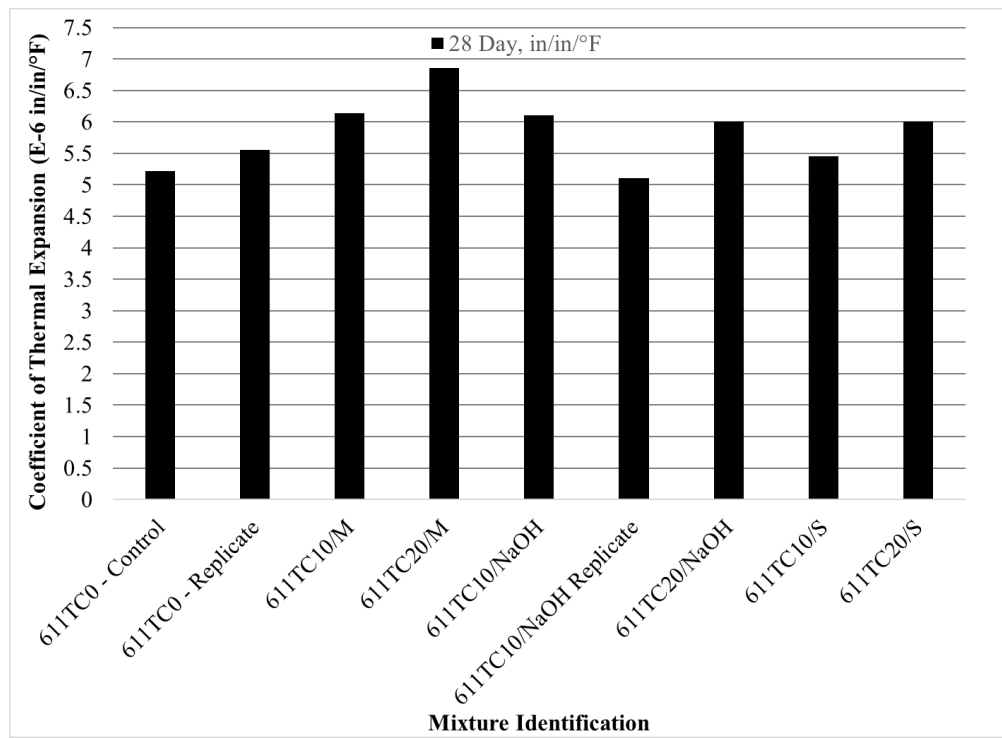
### 6.2.3.7 Coefficient of Thermal Expansion Test

A material's coefficient of thermal expansion describes the elongation that a material will undergo when exposed to temperature differentials. This characteristic is particularly important when discussing concrete pavements because of the potential for stresses to be exerted on the concrete pavement as it expands and contracts. The coefficient of thermal expansion test was conducted on each concrete mixture at 28 days after mixing. The test uses an LVDT to measure the length of concrete specimens as they cycle three times in a water bath between 10°C and 50°C (50°F and 122°F). The results from these tests are displayed in Figure 6-32. The coefficient of thermal expansion increases for concretes incorporating recycled tire chips. Rubberized concrete

mixtures experienced a coefficient of thermal expansion value between  $6.0 - 7.0 \times 10^{-6}$  in/in/ °F which is higher than the control mixture (conventional concrete) at  $5.25 \times 10^{-6}$  in/in/ °F. While these measured coefficient of thermal expansion values may exceed acceptable values when the concrete is used for pavement applications, the use of this concrete for barrier wall applications should be acceptable.



**Figure 6-31: Coefficient of Thermal Expansion Test Equipment**



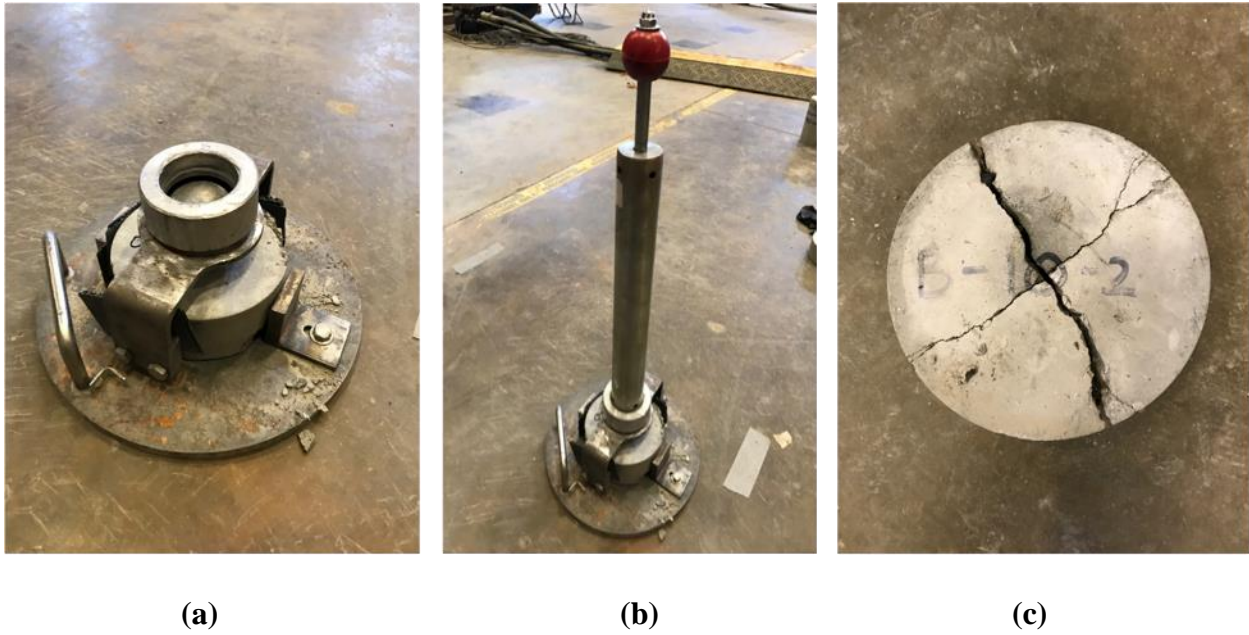
**Figure 6-32: Coefficient of Thermal Expansion Test Results**

### **6.2.3.8 Drop Weight Impact Test**

The primary objective of this research study was to evaluate the use of tire chips as a coarse aggregate replacement in an effort to improve the impact resistance and toughness of concrete. Specifically, because GDOT Class A requirements governs concrete mixtures used in the construction of barrier walls, the fresh and hardened concrete properties herein have been compared to the design standard. While the desire was to produce concrete mixtures that remained in compliance with the standard, the hope was to produce rubber-modified mixtures with the potential to absorb impact and remain intact after impact.

Currently, no standard test method is available to measure such property, thus the research team developed a procedure for evaluating concrete's cracking performance when subjected to repeated impact. Specimens measuring 2 in (51 mm) height by 6 in (152 mm) diameter were placed in a metal ring as to secure the sample from movement during testing. A metal sphere was placed on the top of the metal ring such that impact loading would be transmitted to the specimen via a direct point load. A standard proctor compaction hammer weight 5.5 lb was used to produce the repeated impact loadings. The hammer consisted of a 2 in (51 mm) diameter face and a drop height of 12 in (305 mm). The testing apparatus is shown in Figure 6-33.

Throughout the test, the technician observes the condition of the specimen following each drop. The number of drops to first crack (the initiation of a crack), control failure (equivalent failure as though no rubber was included), and complete failure (complete separation of the concrete specimen) were recorded for each specimen. The progression of cracks recorded for this test are shown in Figure 6-34. The drop hammer impact test results are listed in Table 6-9 and illustrated in Figure 6-35.



**Figure 6-33: Impact Drop Hammer Test Configuration and Test Sample: (a) Sample in Test Ring, (b) Compaction Hammer, and (c) Sample After Complete Failure**



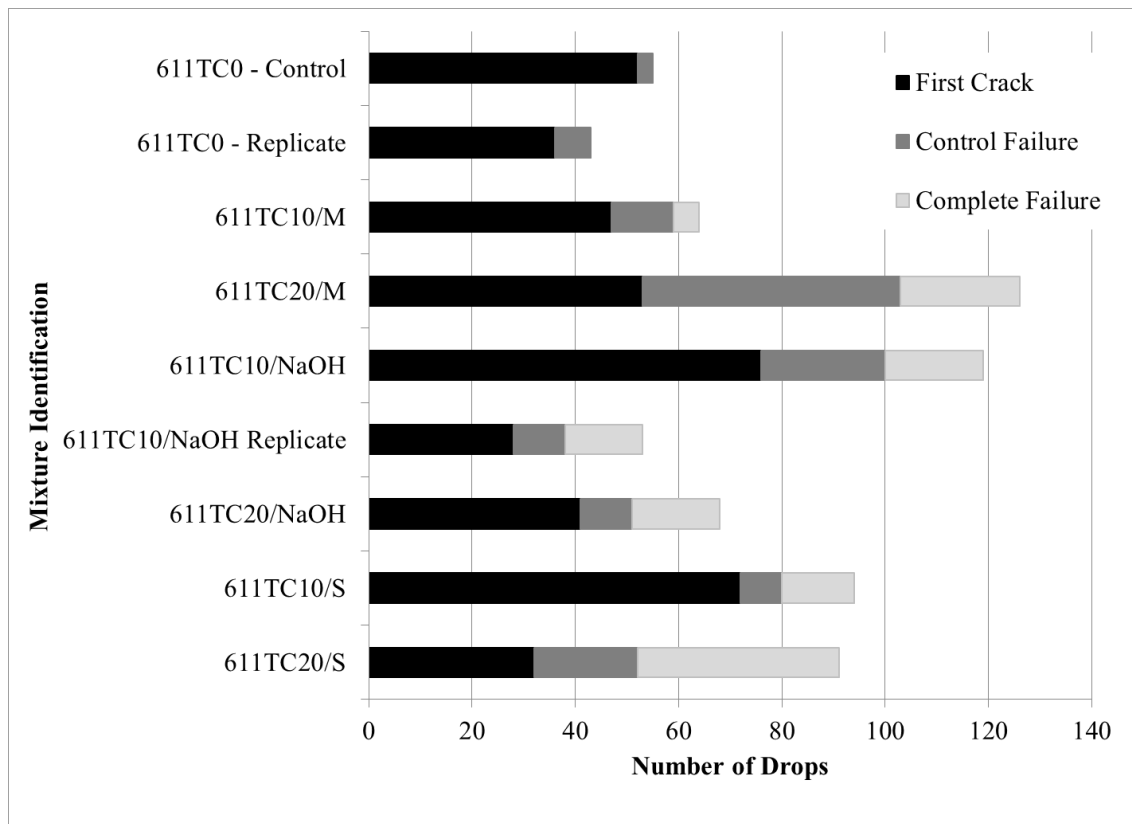
**Figure 6-34: Progression of Cracks Measured in Drop Weight Hammer Test: (a) Initial Crack, (b) Control Failure, and (c) Complete Failure**

As expected, the tire chip concrete mixtures increased the number of repeated impacts when compared to the control mixture. The most notable improvement is the number of drops the rubberized concrete mixtures absorbed prior to complete failure. The control was only capable of withstanding 3 additional drops following the formation of an initial crack. However, the rubberized concrete mixtures averaged an additional 19 drops following the formation of the crack

before the control failure condition was reached and an additional 38 drops after the initial crack prior to complete failure.

**Table 6-9: Drop Hammer Impact Test Results**

Mixture Identification	First Crack	Control Failure	Complete Failure
611TC0 - Control	52	55	55
611TC0 - Replicate	36	43	43
611TC10/M	47	59	64
611TC20/M	53	103	126
611TC10/NaOH	76	100	119
611TC10/NaOH Replicate	28	38	53
611TC20/NaOH	41	51	68
611TC10/S	72	80	94
611TC20/S	32	52	91



**Figure 6-35: Drop Hammer Impact Test Results**

In nearly all cases, the concrete mixtures incorporating the highest tire chip content (20%) were capable of withstanding the largest number of drop hammer impacts. There was variation in the results between the surface treatments making it difficult to conclude one surface treatment performing better than another. The major conclusion from this test was the improved behavior of the concrete when subjected to repeated impact making rubberized concrete mixtures ideal for applications that may experience regular and instantaneous impact loadings.

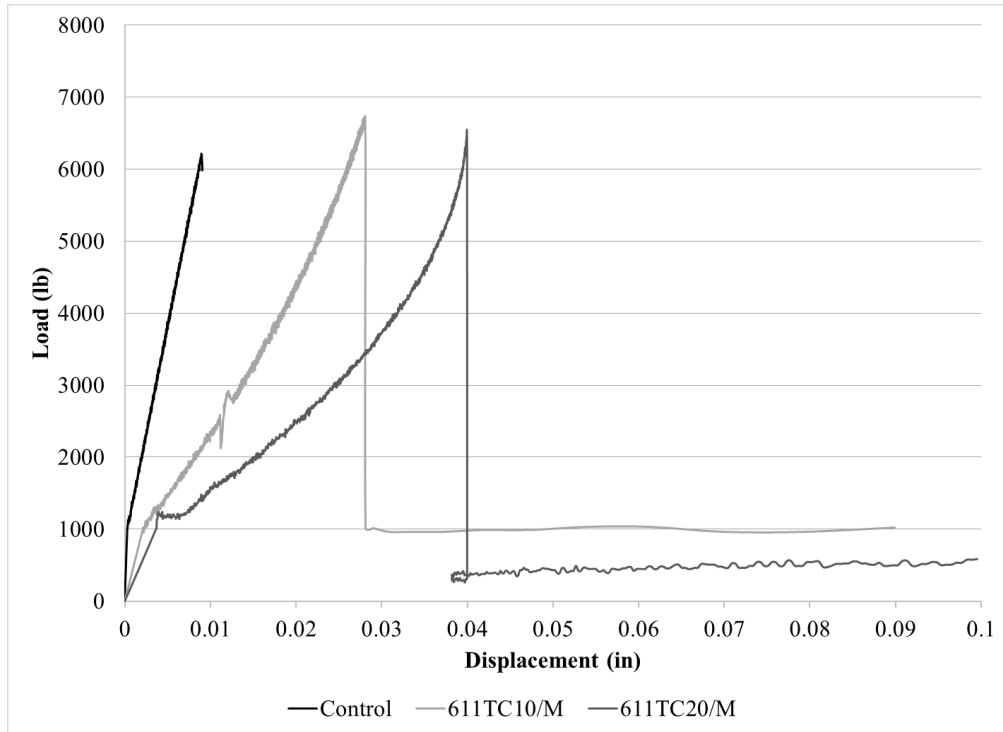
#### **6.2.3.9 Load-Deflection**

The primary objective of this research was to optimize concrete mixtures to improve the impact resistance of the material while maintaining characteristics required by GDOT concrete specifications. A primary measure of this quality is the ability of the concrete to deflect when subjected to loading. The area beneath a load-displacement curve indicates the energy that the concrete can absorb prior to failure.

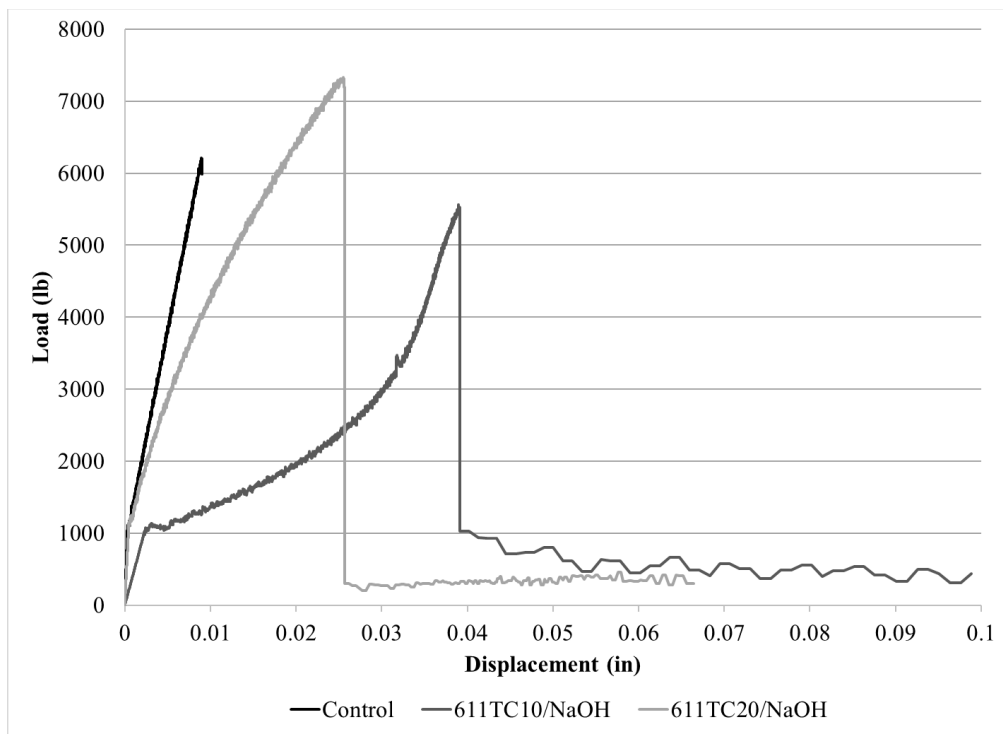
There currently exists no standard test procedure to measure the load-deflection of concrete beams. The research team developed two methods of producing the results for this property. The first method included the use of a TE connectivity (TE) string potentiometer, commonly referred to as a string pot, that was connected to the middle of each concrete beam to measure the deflection of each specimen. Beams sized 6 in x 6 in x 22 in (15.24 cm x 15.24 cm x 55.88 cm) were subjected to a standard MOR test while the deflection data was being simultaneously captured. The string pot records electrical signals that are proportional to the length of the cable that extends from the mechanism. The deflection data was then converted to a displacement in inches and matched to the corresponding load data from the MOR test.

The second method of performing this test used a high-speed motion capture camera and sensors attached to concrete beams to collect the deflection data points. The motion capture sensors

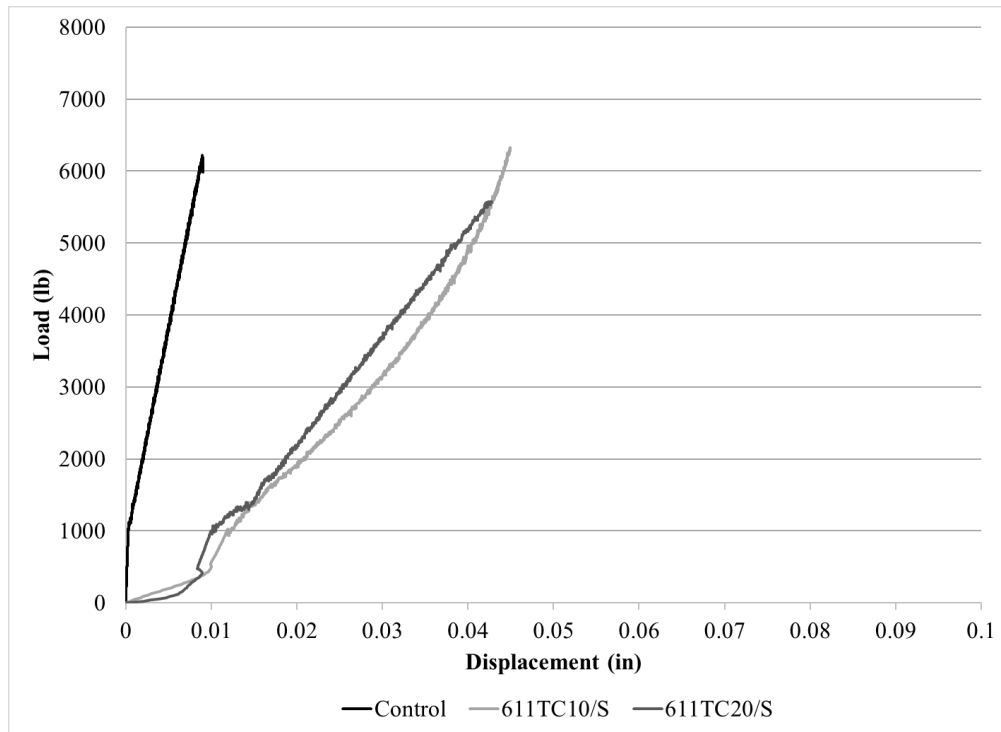
were attached to the sides of the 6 in x 6 in x 22 in (15.24 cm x 15.24 cm x 55.88 cm) concrete beams faced toward the motion capture camera. Similar to the previous method, concrete beam was subjected to an MOR test. While the MOR test is running, the motion capture camera recorded the location of the sensor at the side of the beam. Once complete, the load data was matched to the corresponding displacement data. The toughness of each concrete beam was calculated from the load-deflection plot generated from conducting these tests and presented in Table 6-10. The load deflection curves for the mechanical abrasion, sodium hydroxide, and silane coupling agent pretreatments are shown in Figures 6-36, 6-37, and 6-38. From the load-deflection curves, it is observed that the rubber modified concrete beams deflected much more than the control mixtures while still approaching or obtaining similar MOR values when compared to the control mixtures. This provided more substantial calculated toughness values for the rubber modified concrete beams than the control mixtures due to the residual load capacity experienced by the rubberized concrete mixtures. In addition, the toughness calculations demonstrate that higher percentages of rubber contents produce greater toughness values. The average toughness for each mixture is provided in Table 6-10.



**Figure 6-36: Load Displacement of Mechanical Abrasion Pretreatment Concrete Mixtures**



**Figure 6-37: Load Displacement of NaOH Pretreatment Concrete Mixtures**



**Figure 6-38: Load Displacement of Silane Pretreatment Concrete Mixtures**

**Table 6-10: Area Under the Load-Deflection Curve**

Mixture Identification	Toughness, lb-in
611TC0 - Control	45.131
611TC0 - Replicate	70.319
611TC10/M	120.714
611TC20/M	168.949
611TC10/NaOH	177.218
611TC10/NaOH Replicate	64.525
611TC20/NaOH	121.312
611TC10/S	121.934
611TC20/S	193.405

## CHAPTER 7

### ECONOMIC CONSIDERATIONS

Construction materials are often evaluated not only on their mechanical performance but on economic value. While the rubber tire chips and crumb rubber in this study were recycled products, there is a cost associated with the recycling and processing of the rubber from a waste tire to rubber particles. Material unit costs were gathered in an effort to compare the cost of the control mixture (611TC0) to the rubberized concrete mixtures incorporating 10% (611TC10) and 20% (611TC20) tire chips. In addition, the cost of the 20% crumb rubber mixture was determined. The local producer and distributor of the product, Liberty Tire Recycling, provided the unit costs for the tire chip and crumb rubber. The cost for both products was \$350 per ton (0.91 metric ton). Table 7-1 provides the materials unit costs and total cost of the control, 10% and 20% tire chip and 20% crumb rubber mixtures. It should be noted that the costs included in the table are only material costs and does not include costs associated with concrete delivery and indirect costs required by a ready-mixed concrete producer.

A noticeable difference is observed in the cost between the control and rubberized concrete mixtures. A cost increase of approximately 15% for each 10% increase in tire chip content was determined for the rubberized concrete mixtures. This equates to a cost increase of \$1.17 per percent addition of tire chip. The crumb rubber had a slightly less increase in cost resulting in a cost increase of 11% for each 10% increase in crumb rubber or \$1.12 per percent addition of the product. Although the addition of the tire particles results in an increased cost of the concrete mixture, the benefit of adding rubber to the concrete mixtures for applications subjected to impact

may outweigh this additional costs. In order to compare the improved impact resistance with the increased costs, Figure 7-1 was produced relating the number of drop impacts to mixture cost. For the purposes of this analysis, all of the 611TC10 mixtures regardless of surface treatment were averaged. Similarly, all of the 611TC20 mixtures were averaged. The cost comparisons for the rubber surface pretreatments are shown in Figure 7-2. While the unit cost for the silane coating far exceeds that of the NaOH, very little of the chemical is used per mixture, thereby evening out the costs of the treatments. One disadvantage of using the silane, however, is that large quantities must be purchased whereas smaller amounts of the NaOH pellets may be acquired. Both of the treatments were similar in economic impact, costing around \$15 per mixture.

**Table 7-1: Economic Comparison of Control and Rubberized Concrete Mixtures**

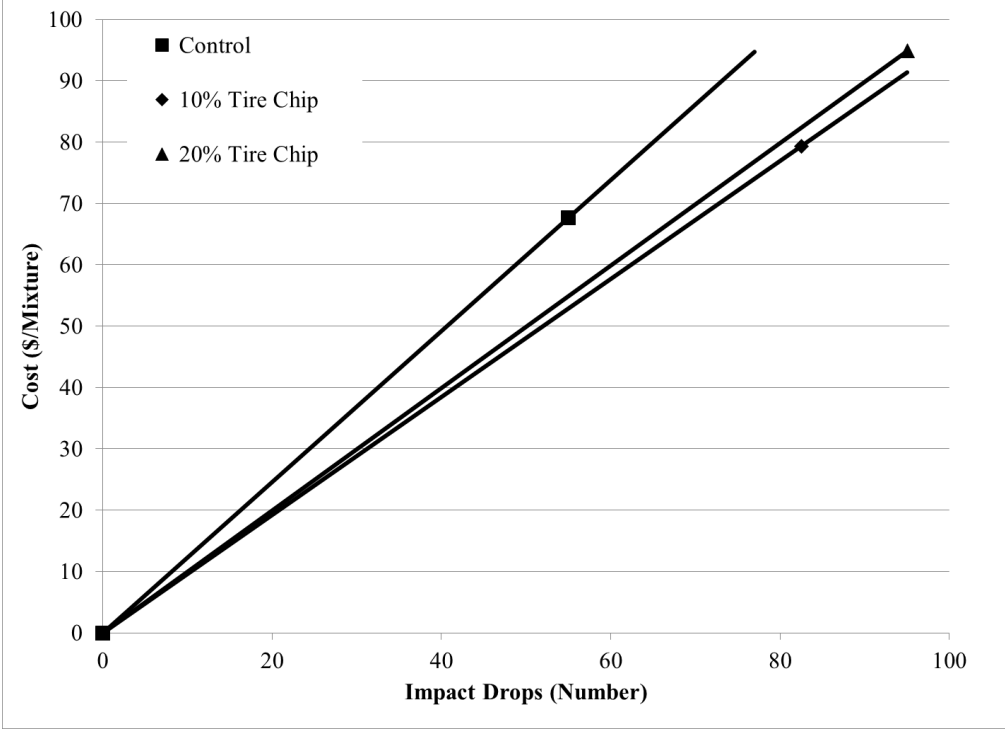
Material	Unit Costs	Mixture Identification			
		611TC0	611TC10	611TC20	660CR20
Cement	\$140/ton	\$36.66	\$36.66	\$36.66	\$39.60
Water	\$5/1000 gal	\$0.08	\$0.08	\$0.08	\$0.08
Coarse Aggregate	\$24/ton	\$16.20	\$14.58	\$12.96	\$16.20
Tire Chip	\$350/ton	-	\$13.31	\$30.43	-
Fine Aggregate	\$18/ton	\$8.57	\$8.57	\$8.57	\$7.49
Crumb Rubber	\$350/ton	-	-	-	\$17.58
AEA	\$3.50/gal	\$0.48	\$0.48	\$0.48	\$0.48
HRWRA	\$8/gal	\$2.64	\$2.64	\$2.64	\$2.64
VMA	\$15/gal	\$3.04	\$3.04	\$3.04	\$3.04
Total Cost =		\$67.67	\$79.36	\$94.86	\$87.11

**Table 7-2: Economic Comparison of Tire Chip Surface Pretreatments**

Treatment	Unit Costs	611TC10/M	611TC10/NaOH	611TC10/S
NaOH	\$3/lb	-	\$15.00	-
Silane	\$180/gal	-	-	\$14.26
Total Cost =		\$79.36	\$94.36	\$93.62

Because the slope of the lines for the 10% and 20% tire chip are smaller than that of the control, the rubberized concrete mixtures considered to be more economical with regards to impact

resistance. Ultimately, the 10% and 20% rubberized mixtures produced similar slopes with the 10% tire chip mixture being slightly lower. In summary, the economic analysis demonstrates that while the rubberized concrete mixtures have an added cost when compared to a conventional concrete mixture, the additional expense may be warranted for concrete structures subjected to impact where added resistance and toughness prove beneficial.



**Figure 7-1: Cost vs. Impact Performance Relationship**

## CHAPTER 8

### FUTURE WORK

The work completed in this study determined the optimal levels of recycled tire chips to improve impact resistance and energy absorption while still satisfying the GDOT Class A concrete specification for potential use in concrete barrier walls and other applications. In addition, mechanical roughening, sodium hydroxide soaking, and a silane coupling agent were evaluated to improve adhesion between cementitious materials and the rubber particle surface.

The results of this study demonstrated the successful inclusion of rubber tire chips in concrete mixtures up to 20% replacement of coarse aggregate. Additionally, the rubberized mixtures may prove to be advantageous in application subject to repeated impact as a result of its toughness. In order to optimize concrete barrier wall designs incorporating tire chips, a performance-based evaluation must be accompanied. However, testing truck impacts is often unrealistic to evaluate the effect of rubberized concrete designs on the barrier performance. To study the impact performance, it is essential to develop a computer simulation model. In addition, the simulation model must be validated by reasonably predicting the results of a small-scale impact test or a component test. Once the analytical approach and material models are validated, a full-scale crash simulation conducted in the absence of a full-scale test may be considered reliable for design optimization.

Future work should involve developing a nonlinear finite element analysis model for crash simulation of vehicle impacts and to assess the likely impact and full potential of the concrete barrier design utilizing the experimental results from this study coupled with a new examination

of fiber reinforced concrete. In addition, the analytical model must be validated through the construction of scaled concrete barrier walls incorporating the recycled tire chips and/or fibers utilizing drop-weight impact tests.

The development of a computer simulation model will provide a more detailed understanding of the three-dimensional impact response and energy absorption capacity of the current, rubber-modified and fiber reinforced concrete barrier designs, assist in enhancing the cementitious composite designs used in GDOT concrete barriers and better inform for future full-scale safety testing at a certified vehicle-barrier testing facility, if deemed necessary.

## CHAPTER 9

### CONCLUSIONS AND RECOMMENDATIONS

This study researched the effect of using recycled rubber aggregates on the fresh properties and compressive strength of concrete mixtures. A total of twenty-four mixtures were evaluated in the preliminary phase and nine mixtures in the more comprehensive research phase. Initially, three series of mixtures with varying cement contents of 611, 660, and 705 lb/yd<sup>3</sup> (362, 392, and 418 kg/m<sup>3</sup>) were evaluated with tire chip replacement levels for coarse aggregate in increments of 10% by volume, up to a maximum of 50%. In addition, one series of mixtures with a cement content of 660 lb/yd<sup>3</sup> replaced fine aggregate with crumb rubber in 10% increments up to a 40% replacement. Lastly, two mixtures within the preliminary phase were evaluated which replaced percentages of both coarse and fine aggregates for their rubber counterparts. Three rubber surface treatments were investigated in the research phase to improve the adhesion between the rubber particles and cement paste. Ultimately, the objective was to recover a portion of the strength lost as a result of the elastic rubber materials replacing the more rigid virgin aggregate. The treatments evaluated in the study included: roughening through mechanical abrasion, soaking in a sodium hydroxide solution, and application of a silane coupling agent. A comprehensive suite of tests was conducted on the research mixtures that evaluated the rubberized concrete mixtures for fresh concrete properties, compressive strength, indirect splitting tensile strength, flexural modulus of rupture, static modulus of elasticity, dynamic modulus of elasticity, rapid chloride ion penetrability, drop hammer impact resistance, and load-deflection area. The major findings and conclusions as a result of this work are summarized in the following.

## **9.1 Fresh Concrete Properties Summary**

Overall, it was determined that rubber aggregates have a significant effect on fresh concrete properties. Generally, when HRWRA dosages remained constant, slump values tended to decrease with increased rubber contents. Even though the slump values were low for some rubberized concrete mixtures, the mixtures remained cohesive and easy to place. Concrete air contents were shown to increase slightly with increased rubber replacement levels; however, the appropriate air contents were maintained with low AEA addition rates. As was expected, the unit weight decreased nearly linearly with increased rubber contents. Ultimately, the fresh concrete properties were able to be maintained to within the GDOT Class A and Class B specification.

## **9.2 Hardened Concrete Properties Summary**

The compressive strengths of the concrete mixtures decreased with increased rubber aggregate contents. Cement contents were observed to have greater influence on rubberized concrete compressive strength at lower rubber contents than higher levels. In addition, the replacement of fine aggregate with crumb rubber produced higher compressive strengths when compared to an equal percent replacement of coarse aggregate with tire chip. Ultimately, concrete mixtures containing 10% tire chip were able to attain adequate compressive strengths for GDOT Class A concrete at all cement levels tested without a rubber surface treatment and 20% when a sodium hydroxide treatment was performed. Concrete mixtures utilizing crumb as a fine aggregate replacement were able to gain adequate strengths up to a 40% replacement level. Additionally, adequate strengths were attained with up to a 20% crumb rubber and 10% tire chip replacement.

The results of the indirect splitting tensile strength test showed a decrease in tensile strength with increasing rubber contents. The NaOH surface treatment performed similarly or slightly better than the mechanical roughing treatment; however, the silane coupling agent appeared to provide

better performance in tension when compared to the other two surface treatments. Similar to the indirect splitting tensile strength results, a decrease in modulus of rupture was experienced with increasing rubber contents. Most notable observation with the modulus of rupture testing was the behavior of the prismatic beams at and immediately following failure where additional load below the peak was carried by the specimen for an appreciable amount of time after cracking. The static and dynamic modulus of elasticity tests produced results within the typical range of concrete. Similar to trends found in the literature, the dynamic modulus of elasticity values were considerably higher than that of the static method. Rubber inclusion appeared to have less impact on the dynamic modulus of elasticity test when compared to other mechanical properties. Rubberized concrete mixtures were categorized as having moderate permeability per the rapid chloride ion penetrability test. This was comparable to the control mixture.

The most influential outcome was the performance of the rubberized concrete mixtures during the drop hammer impact test. The rubberized mixtures at 10% and 20% replacement levels and all surface treatments out-performed the control mixture by remaining intact after initial crack formation and the ability to absorb additional impact loads without fracturing.

### **9.3 Recommendation**

Based upon the results from this study, the recommended use of rubber aggregates in concrete mixtures include:

- The use of recycled tire chips or crumb rubber may be used in the proportioning of concrete mixtures so long as the blended aggregate gradation remains in satisfactory compliance with ASTM C33.
- Rubberized concrete mixtures shall be proportioned using the absolute volume method where the replacement of coarse and fine aggregate is made on a volume basis.

- The use of chemical admixtures is necessary to ensure rubberized concrete mixtures entrain the appropriate quantity of air voids while maintaining adequate workability and consistency. A VMA was necessary to suspend the rubber particles and prevent them from floating to the top of the concrete surface.
- The inclusion of 10% replacement of coarse aggregate with tire chip without a rubber pretreatment and up to 20% replacement with a sodium hydroxide treatment may be used and satisfy the GDOT Class A and Class B compressive strength requirements.
- The impact resistance of the concrete was significantly improved through the incorporation of tire chips.

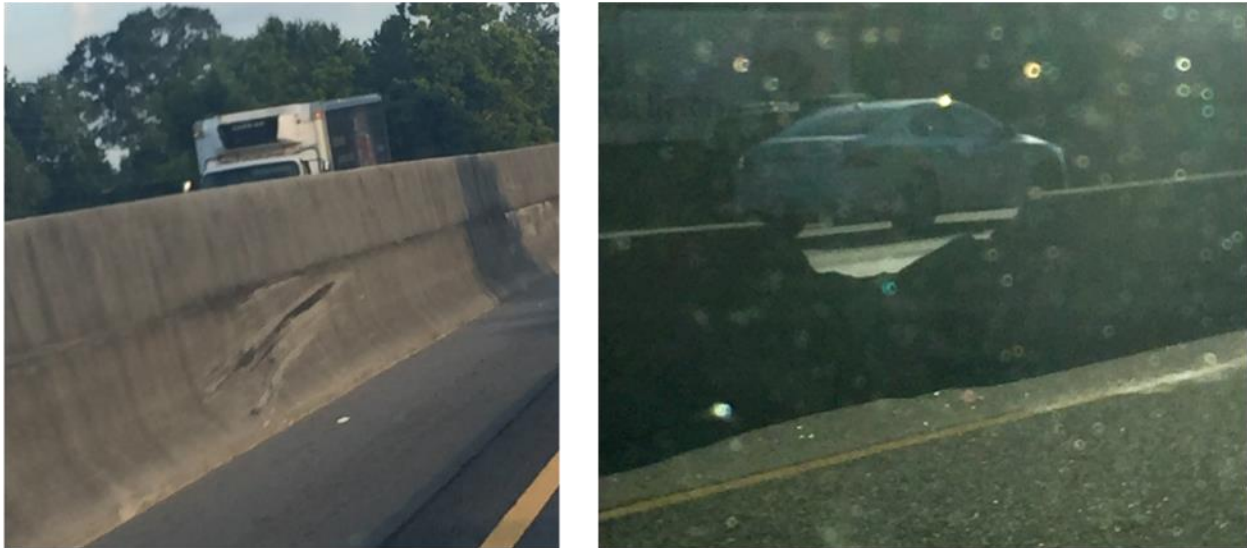
### **9.3.1 Applications for Rubberized Concrete**

Although compressive strength may be sacrificed to a reduced level, the impact resistance of rubberized concrete may prove beneficial in certain applications. The results of this study demonstrated satisfactory mechanical performance (compressive strength, tensile capacity, modulus of elasticity, and permeability) for mixtures incorporating a maximum of 20% tire chips. The improved resistance of the rubber-modified concrete to impact will benefit concrete structures subject to repeated and instantaneous loadings. This section discusses a few applications for which rubberized concrete in structural applications should be explored.

#### **9.3.1.1 Concrete Barrier Walls**

Concrete barrier walls are a necessary part of GDOT's interstate system and are frequently impacted by vehicles. Figure 9-1 shows impacted and damaged barrier walls along I-20 near Conyers, GA. The results of this study signify the utilization of recycled tire chips for concrete mixtures designated for barrier walls may result in better performance, yielding greater plastic deformation on impact and smaller deceleration forces during vehicle-wall collisions, and

ultimately creating a safer barrier for the motoring public and saving lives from vehicle impact. Section 8.0, Future Work, discusses the need to extend this investigation into the development of a nonlinear finite element analysis model for crash simulation on concrete barrier walls incorporating tire chips as well as testing on scaled concrete barriers to confirm the analytical model. Further, the addition of fibers should be evaluated for improved performance.



**Figure 9-1: Impacted and Damaged Concrete Barrier Walls on I-20**

### **9.3.1.2 Concrete Barrier Glare Protection Section**

Conventional concrete is often used in the construction of the concrete glare protection section that extends from the top of the standard concrete barrier walls. These sections cast on top of the barrier wall may not require the same stringent requirements as that of the barrier wall itself. However, the glare protection section will often be damaged during vehicular impact resulting in section loss. Incorporating a concrete such as the rubberized concrete mixtures produced in this study that exhibited improved impact resistance and remained intact through repeated loadings may prove beneficial for this type of section. Figure 9-2 shows damaged glare protection concrete sections along EB I-20. Figure 9-3 shows a recently repaired section.



**Figure 9-2: Damaged Glare Protection Concrete Sections on EB I-20**



**Figure 9-3: Repaired Glare Protection Concrete Sections on EB I-20**

### 9.3.1.3 Concrete Curb and Raised Medians

Other applications for which the rubberized concrete mixtures could be used include concrete curbs and raised concrete medians. These structures are often subjected to repeated loading when drivers veer out of the roadway lane impacting the curb. Over time, these structures experience severe cracking resulting in complete section loss. See Figure 9-4. In addition, raised concrete medians, Figure 9-5, have become a popular addition to highways located within urban areas. These may see repeated impact loading as a result of turning semi-trucks with wide turning radii. The improved toughness and ability to remain intact through significant impact loadings make rubberized concrete an ideal material for construction of curb and raised concrete medians.



**Figure 9-4: Concrete Curb Section Loss**



**Figure 9-5: Raised Concrete Medians**

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## 1 Identification

### Product identifier

Trade name: DAREX II AEA

SDS ID Number: 60059

Relevant identified uses of the substance or mixture, and uses advised against  
Specialty construction product. Not intended for other uses

### Details of the supplier of the safety data sheet

#### Manufacturer/Supplier:

GCP Applied Technologies  
62 Whittemore Avenue  
Cambridge, MA 02140 USA

GCP Canada, Inc.  
294 Clements Road W.  
Ajax, Ontario L1S 3C6 Canada

#### Information department:

In Canada: +1-905-683-8561

Environmental Health & Safety

USA: +1-617-876-1400 (24 hours)

+1-800-354-5414 (8AM - 5PM) Not functional within Massachusetts

CAN: 1-905-683-8561 (24 hours)

Transport Emergency: Chemtrec +1-800-424-9300 (24 hours)

## 2 Hazard(s) identification

### Classification of the substance or mixture

Causes serious eye irritation.

### Label elements:

#### Hazard pictograms



GHS07

Warning

#### Hazard statements

Causes serious eye irritation.

#### Precautionary statements

Wash thoroughly after handling.

Wear eye protection / face protection.

If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

If eye irritation persists: Get medical advice/attention.

(Cont. on page 2)

USGHS

## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

Trade name: *DAREX II AEA*

## NFPA ratings (scale 0 - 4)

(Cont. from page 1)



Health = 1  
Fire = 1  
Reactivity = 0

## HMIS-ratings (scale 0 - 4)



Health = 2  
Flammability = 1  
Reactivity = 0

## Other hazards

## Results of PBT and vPvB assessment

PBT: Not applicable.

vPvB: Not applicable.

## \* 3 Composition/information on ingredients

## Chemical characterization: Mixtures

## Description:

Mixture of the substances listed below with additional nonhazardous ingredients.

Mixture of the substances listed below with additional nonhazardous ingredients.

## Hazardous components:

61790-45-2	Fatty acids, tall-oil, sodium salt	2.0-5.0%
61790-44-1	Fatty acids, tall oil, potassium salts	2.0-5.0%

Additional information: For the wording of the listed hazard phrases refer to section 16.

## \* 4 First-aid measures

## Description of first aid measures

## General information:

Get medical advice/attention if you feel unwell.

## After inhalation:

Supply fresh air. If required, provide artificial respiration. Keep patient warm. Consult doctor if symptoms persist.

## After skin contact:

Immediately wash contaminated skin with soap or mild detergent and water. If this chemical soaks clothing, immediately remove clothing and wash skin.

## After eye contact:

Rinse opened eye for several minutes under running water.

Rinse cautiously with water for several minutes.

Seek immediate medical advice.

## After swallowing:

Wash out mouth with water

Rinse mouth.

(Cont. on page 3)

USGHS

## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

**Trade name: DAREX II AEA**

(Cont. from page 2)

Do not induce vomiting; immediately call for medical help.

Never give anything by mouth to an unconscious person.

**Information for doctor:**

**Most important symptoms and effects, both acute and delayed** No further relevant information available.

**Indication of any immediate medical attention and special treatment needed**

No further relevant information available.

**5 Fire-fighting measures**

**Special hazards arising from the substance or mixture** No further relevant information available.

**Additional information** Collect contaminated fire fighting water separately. It must not enter the sewage system.

**6 Accidental release measures****Personal precautions, protective equipment and emergency procedures**

Wear protective equipment. Keep unprotected persons away.

**Methods and material for containment and cleaning up:**

Contain and/or absorb spill with inert material (i.e. sand, vermiculite) then place in a suitable container.

Sweep up spilled product into receptacles.

Dispose contaminated material as waste according to section 13 of the SDS.

**Reference to other sections**

See Section 7 for information on safe handling.

See Section 8 for information on personal protection equipment.

See Section 13 for disposal information.

**7 Handling and storage****Handling:****Precautions for safe handling**

Open and handle receptacle with care.

Avoid contact with eyes, skin and clothing.

Do not take internally.

Practice good personal hygiene to avoid ingestion.

Use only with adequate ventilation.

Wash clothing before reuse.

FOR PROFESSIONAL USE ONLY. KEEP OUT OF CHILDREN'S REACH.

**Information about protection against explosions and fires:** No special measures required.

**Conditions for safe storage, including any incompatibilities****Storage:**

**Information about storage in one common storage facility:** No special measures required.

**Further information about storage conditions:** Keep receptacle tightly sealed.

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## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

Trade name: *DAREX II AEA*

(Cont. from page 3)

**Specific end use(s)** No further relevant information available.**8 Exposure controls/personal protection****Additional information about design of technical systems:** No further data; see item 7.**Control parameters****Components with limit values that require monitoring at the workplace:**

The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.

**Additional information:** The lists that were valid during the creation were used as basis.

**Exposure controls****Personal protective equipment:****General protective and hygienic measures:**

Avoid contact with the eyes and skin.

The usual precautionary measures for handling chemicals should be followed.

**Breathing equipment:**

Respiratory protection is not normally required. However, a chemical cartridge respirator with organic vapor cartridge and a prefilter for dusts/mists is required at or above the applicable exposure limits (consult exposure guidelines). If no limits exist, use an approved respirator whenever a vapor or mist is generated or if respiratory irritation occurs. Supplied air respirator (SCBA) is required at exposure levels above the capabilities of a chemical cartridge respirator.

**Protection of hands:**

Gloves should be worn to prevent skin contact and should be impermeable and resistant to the product. Rubber or other impervious gloves should be worn to prevent skin contact.

**Material of gloves**

Gloves should be worn to prevent skin contact and should be impermeable and resistant to the product.

**Eye protection:**

Safety glasses with side shield protection.

Safety glasses with side shields should be worn to prevent contact due to splashing. Under high vapor mist concentrations, tightly sealed goggles should be worn.



A face shield should also be worn if there is potential exposure to splash or spray.

**Body protection:**

Protective work clothing

Use personal protective equipment as required.

Take off contaminated clothing.

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(Cont. on page 5)

## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

Trade name: *DAREX II AEA*

(Cont. from page 4)

\* **9 Physical and chemical properties****Information on basic physical and chemical properties****General Information****Appearance:**

<b>Form:</b>	Liquid
<b>Color:</b>	According to product specification
<b>Odor:</b>	Characteristic
<b>Odor threshold:</b>	Not determined.

pH-value (~) at 20 °C (68 °F): 10

**Change in condition**

<b>Melting point/Melting range:</b>	Undetermined.
<b>Boiling point/Boiling range:</b>	Undetermined.
<b>Flash point:</b>	Not applicable.

**Flammability (solid, gaseous):** Not applicable.

<b>Decomposition temperature:</b>	Not determined.
<b>Auto igniting:</b>	Product is not selfigniting.
<b>Danger of explosion:</b>	Product does not present an explosion hazard.

**Explosion limits:**

<b>Lower:</b>	Not determined.
<b>Upper:</b>	Not determined.
<b>VOC Content (max):</b>	Not determined.

<b>Vapor pressure:</b>	Not determined.
<b>Density: (~) at 20 °C (68 °F)</b>	1 g/cm <sup>3</sup> (8.345 lbs/gal)
<b>Relative density</b>	Not determined.
<b>Vapor density</b>	Not determined.
<b>Evaporation rate</b>	Not determined.

**Solubility in / Miscibility with****Water:** Not miscible or difficult to mix.**Partition coefficient (n-octanol/water):** Not determined.**Viscosity:**

<b>Dynamic:</b>	Not determined.
<b>Kinematic:</b>	Not determined.
<b>Molecular weight</b>	Not applicable.

**Other information** No further relevant information available.\* **10 Stability and reactivity****Reactivity** Stable under normal conditions.**Chemical stability****Thermal decomposition:** No decomposition if used according to specifications.**Conditions to avoid** No further relevant information available.**Incompatible materials:** No further relevant information available.**Hazardous decomposition products:** Carbon monoxide and carbon dioxide**Additional information:** See section 7 for information on handling, storage and conditions to be avoided.

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(Cont. on page 6)

## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

Trade name: *DAREX II AEA*

(Cont. from page 5)

**11 Toxicological information****Information on toxicological effects****Acute toxicity:****Primary irritant effect:****on the skin:** No irritating effect expected**on the eye:** Causes serious eye damage.**inhalation:** No irritating effect expected**Ingestion:****Additional toxicological information:****Carcinogenic categories****IARC (International Agency for Research on Cancer) Human Carcinogenicity:**  
**Group 1- Positive, Group 2A- Probable, Group 2B- Possible, Group 3- Not Classifiable**

None of the ingredients is listed.

**NTP (National Toxicology Program)****K-Known to be carcinogenic, R-May reasonably be anticipated to be carcinogenic**

None of the ingredients is listed.

**OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients is listed.

**12 Ecological information****Toxicity****Aquatic toxicity:** No further relevant information available.**Persistence and degradability** No further relevant information available.**Behavior in environmental systems:****Bioaccumulative potential** No further relevant information available.**Mobility in soil** No further relevant information available.**Additional ecological information:****General notes:** Not known to be hazardous to water.**Results of PBT and vPvB assessment****PBT:** Not applicable.**vPvB:** Not applicable.**Other adverse effects** No further relevant information available.**13 Disposal considerations****Waste treatment methods** Comply with Federal, State and local regulations.

(Cont. on page 7)

USGHS

## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

Trade name: *DAREX II AEA*

(Cont. from page 6)

**Recommendation:**

Must not be disposed of together with household garbage. Do not allow product to reach sewage system.

**Uncleaned packagings:****Recommendation:** Disposal must be made according to official regulations.**14 Transport information****UN-Number**

DOT, ADR, ADN, IMDG, IATA Not applicable.

**UN proper shipping name**

DOT, ADR, ADN, IMDG, IATA Not applicable.

**Transport hazard class(es)**DOT, ADR, ADN, IMDG, IATA  
Class Not applicable.**Packing group**

DOT, ADR, IMDG, IATA Not applicable.

**Environmental hazards:**

Marine pollutant: No

**Special precautions for user** Not applicable.**Transport/Additional information:** Not classified as a dangerous good for transport by road, rail or air.**DOT****Remarks:** Not Regulated.**UN "Model Regulation":** Not applicable.**15 Regulatory information****SARA (Superfund Amendments and Reauthorization Act)****Section 302/304 (extremely hazardous substances):**

None of the ingredients is listed.

**Section 313 Reportable Ingredients (Chemicals present below reporting threshold are exempt):**

None of the ingredients is listed.

**SARA Section 312/Tier I & II Hazard Categories:**

Health Delayed (chronic)	No
Flammable	No
Reactive	No
Pressure	No
Health Immediate (acute)	Yes

**North America Chemical Inventory Status****TSCA (Toxic Substances Control Act - United States):**

All ingredients are listed or exempt from listing unless otherwise noted below.

(Cont. on page 8)

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## Safety Data Sheet

Printing date 02/18/2016

Version Number 1.2

Reviewed on 02/18/2016

**Trade name: DAREX II AEA**

(Cont. from page 7)

**CEPA (Canadian DSL):**

All ingredients are listed or exempt from listing unless otherwise noted below.

**Right to Know Ingredient Disclosure**

8002-26-4 Tall Oil

7732-18-5 Water

**California Proposition 65****Chemicals known to cause cancer:**

None of the ingredients is listed.

**Chemicals known to cause reproductive toxicity for females:**

None of the ingredients is listed.

**Chemicals known to cause reproductive toxicity for males:**

None of the ingredients is listed.

**Chemicals known to cause developmental toxicity:**

67-56-1 Methanol

**Carcinogenicity Categories****EPA (Environmental Protection Agency)**

None of the ingredients is listed.

**TLV-ACGIH (THE American Conference of Governmental Industrial Hygienists)  
Human Carcinogen - A1 Confirmed, A2 Suspected, A3 Unknown Relevance, A4 Not Classifiable**

None of the ingredients is listed.

**NIOSH-Cancer (National Institute for Occupational Safety and Health)**

None of the ingredients is listed.

**Volatile Organic Compounds (VOC) reported per the Emission Standards.**

If no g/L value is provided this product is not subject to above standard.

**16 Other information**

The data included herein are presented in accordance with various environment, health and safety regulations. It is the responsibility of a recipient of the data to remain currently informed on chemical hazard information, to design and update its own program and to comply with all national, federal, state and local laws and regulations applicable to safety, occupational health, right-to-know and environmental protection.

**Department issuing SDS:**

GCP Applied Technologies  
62 Whittemore Avenue  
Cambridge, MA 02140 USA  
USA: +1-617-876-1400 (24 hours)  
+1-800-354-5414

**Date of preparation / last revision** 02/18/2016 / 1.1**The first date of preparation** 04/05/2013**Number of revision times and the latest revision date** 1.2 / 02/18/2016

USGHS

## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

### 1 Identification

#### Product identifier

Trade name: ADVA 198

SDS ID Number: 2098

Relevant identified uses of the substance or mixture, and uses advised against  
Specialty construction product. Not intended for other uses

#### Details of the supplier of the safety data sheet

##### Manufacturer/Supplier:

GCP Applied Technologies  
62 Whittemore Avenue  
Cambridge, MA 02140 USA

GCP Canada, Inc.  
294 Clements Road W.  
Ajax, Ontario L1S 3C6 Canada

##### Information department:

Environmental Health & Safety  
USA: +1-617-876-1400 (24 hours)  
+1-800-354-5414 (8AM - 5PM) Not functional within Massachusetts  
CAN: 1-905-683-8561 (24 hours)

Transport Emergency: Chemtrec +1-800-424-9300 (24 hours)

### 2 Hazard(s) identification

#### Classification of the substance or mixture

May cause an allergic skin reaction.

#### Label elements:

##### Hazard pictograms



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Warning

##### Hazard statements

May cause an allergic skin reaction.

##### Precautionary statements

Avoid breathing dust/fume/gas/mist/vapors/spray

Wear protective gloves.

IF ON SKIN: Wash with plenty of water.

If skin irritation or rash occurs: Get medical advice/attention.

Wash contaminated clothing before reuse.

Dispose of contents/container in accordance with local/regional/national/international regulations.

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## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

Trade name: *ADVA 198*

## NFPA ratings (scale 0 - 4)

(Cont. from page 1)



Health = 1  
 Fire = 1  
 Reactivity = 0

## HMIS-ratings (scale 0 - 4)



Health = 1  
 Flammability = 1  
 Reactivity = 0

## Other hazards

## Results of PBT and vPvB assessment

PBT: Not applicable.  
 vPvB: Not applicable.

## \* 3 Composition/information on ingredients

## Chemical characterization: Mixtures

**Description:** Mixture of the substances listed below with additional nonhazardous ingredients.

## Hazardous components:

26172-55-4	5-chloro-2-methyl-2H-isothiazol-3-one	0.0-0.1%
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**Additional information:** For the wording of the listed hazard phrases refer to section 16.

## \* 4 First-aid measures

## Description of first aid measures

**General information:** Get medical advice/attention if you feel unwell.

## After inhalation:

Supply fresh air. If required, provide artificial respiration. Keep patient warm. Consult doctor if symptoms persist.

## After skin contact:

Immediately wash contaminated skin with soap or mild detergent and water. If this chemical soaks clothing, immediately remove clothing and wash skin.

## After eye contact:

Rinse opened eye for several minutes under running water.

Rinse cautiously with water for several minutes.

Seek immediate medical advice.

## After swallowing:

Wash out mouth with water

Do not induce vomiting; immediately call for medical help.

Never give anything by mouth to an unconscious person.

## Information for doctor:

**Most important symptoms and effects, both acute and delayed** May cause sensitization by skin contact.

(Cont. on page 3)

USGHS

## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

**Trade name:** *ADVA 198*

(Cont. from page 2)

**Indication of any immediate medical attention and special treatment needed**

No further relevant information available.

**5 Fire-fighting measures****Special hazards arising from the substance or mixture** No further relevant information available.**Additional information** Collect contaminated fire fighting water separately. It must not enter the sewage system.**6 Accidental release measures****Personal precautions, protective equipment and emergency procedures**

Wear protective equipment. Keep unprotected persons away.

**Methods and material for containment and cleaning up:**

Contain and/or absorb spill with inert material (i.e. sand, vermiculite) then place in a suitable container.

Sweep up spilled product into receptacles.

Dispose contaminated material as waste according to section 13 of the SDS.

**Reference to other sections**

See Section 7 for information on safe handling.

See Section 8 for information on personal protection equipment.

See Section 13 for disposal information.

**7 Handling and storage****Handling:****Precautions for safe handling**

Open and handle receptacle with care.

Prevent formation of aerosols.

Avoid contact with eyes, skin and clothing.

Do not take internally.

Practice good personal hygiene to avoid ingestion.

Use only with adequate ventilation.

Wash clothing before reuse.

FOR PROFESSIONAL USE ONLY. KEEP OUT OF CHILDREN'S REACH.

**Information about protection against explosions and fires:** No special measures required.**Conditions for safe storage, including any incompatibilities****Storage:****Information about storage in one common storage facility:** No special measures required.**Further information about storage conditions:** Keep receptacle tightly sealed.**Specific end use(s)** No further relevant information available.

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(Cont. on page 4)

## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

Trade name: *ADVA 198*

(Cont. from page 3)

**8 Exposure controls/personal protection**

**Additional information about design of technical systems:** No further data; see item 7.

**Control parameters****Components with limit values that require monitoring at the workplace:**

The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.

**Additional information:** The lists that were valid during the creation were used as basis.

**Exposure controls****Personal protective equipment:****General protective and hygienic measures:**

Avoid contact with the eyes and skin.

The usual precautionary measures for handling chemicals should be followed.

**Breathing equipment:**

Respiratory protection is not normally required. However, a chemical cartridge respirator with organic vapor cartridge and a prefilter for dusts/mists is required at or above the applicable exposure limits (consult exposure guidelines). If no limits exist, use an approved respirator whenever a vapor or mist is generated or if respiratory irritation occurs. Supplied air respirator (SCBA) is required at exposure levels above the capabilities of a chemical cartridge respirator.

**Protection of hands:**

Gloves should be worn to prevent skin contact and should be impermeable and resistant to the product. Rubber or other impervious gloves should be worn to prevent skin contact.

**Material of gloves**

Gloves should be worn to prevent skin contact and should be impermeable and resistant to the product.

**Eye protection:**

Safety glasses with side shield protection.

Safety glasses with side shields should be worn to prevent contact due to splashing. Under high vapor mist concentrations, tightly sealed goggles should be worn.



A face shield should also be worn if there is potential exposure to splash or spray.

**Body protection:**

Protective work clothing

Use personal protective equipment as required.

Take off contaminated clothing.

**9 Physical and chemical properties****Information on basic physical and chemical properties****General Information****Appearance:**

**Form:** Liquid

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## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

Trade name: *ADVA 198*

(Cont. from page 4)

<b>Color:</b>	According to product specification
<b>Odor:</b>	Characteristic
<b>Odor threshold:</b>	Not determined.
<b>pH-value (~):</b>	Not determined.
<b>Change in condition</b>	
<b>Melting point/Melting range:</b>	Undetermined.
<b>Boiling point/Boiling range:</b>	100 °C (212 °F)
<b>Flash point:</b>	100 °C (212 °F)
<b>Flammability (solid, gaseous):</b>	Not applicable.
<b>Decomposition temperature:</b>	Not determined.
<b>Auto igniting:</b>	Product is not selfigniting.
<b>Danger of explosion:</b>	Product does not present an explosion hazard.
<b>Explosion limits:</b>	
<b>Lower:</b>	Not determined.
<b>Upper:</b>	Not determined.
<b>VOC Content (max):</b>	Not determined.
<b>Vapor pressure:</b>	Not determined.
<b>Density: (~)</b>	Not determined.
<b>Relative density</b>	Not determined.
<b>Vapor density</b>	Not determined.
<b>Evaporation rate</b>	Not determined.
<b>Solubility in / Miscibility with Water:</b>	Not miscible or difficult to mix.
<b>Partition coefficient (n-octanol/water):</b>	Not determined.
<b>Viscosity:</b>	
<b>Dynamic:</b>	Not determined.
<b>Kinematic:</b>	Not determined.
<b>Molecular weight</b>	Not applicable.
<b>Other information</b>	No further relevant information available.

\* **10 Stability and reactivity**

**Reactivity** Stable under normal conditions.

**Chemical stability**

**Thermal decomposition:** No decomposition if used according to specifications.

**Conditions to avoid** No further relevant information available.

**Incompatible materials:** No further relevant information available.

**Hazardous decomposition products:** Carbon monoxide and carbon dioxide

**Additional information:** See section 7 for information on handling, storage and conditions to be avoided.

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(Cont. on page 6)

## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

Trade name: *ADVA 198*

(Cont. from page 5)

**11 Toxicological information****Information on toxicological effects****Acute toxicity:****Primary irritant effect:****on the skin:** No irritating effect expected**on the eye:** No irritating effect expected**Sensitization:** Sensitization possible through skin contact.**Skin sensitization** May cause an allergic skin reaction.**Additional toxicological information:****Carcinogenic categories****IARC (International Agency for Research on Cancer) Human Carcinogenicity:**  
**Group 1- Positive, Group 2A- Probable, Group 2B- Possible, Group 3- Not Classifiable**

None of the ingredients is listed.

**NTP (National Toxicology Program)****K–Known to be carcinogenic, R–May reasonably be anticipated to be carcinogenic**

None of the ingredients is listed.

**OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients is listed.

**12 Ecological information****Toxicity****Aquatic toxicity:** No further relevant information available.**Persistence and degradability** No further relevant information available.**Behavior in environmental systems:****Bioaccumulative potential** No further relevant information available.**Mobility in soil** No further relevant information available.**Additional ecological information:****General notes:** Not known to be hazardous to water.**Results of PBT and vPvB assessment****PBT:** Not applicable.**vPvB:** Not applicable.**Other adverse effects** No further relevant information available.**13 Disposal considerations****Waste treatment methods** Comply with Federal, State and local regulations.

(Cont. on page 7)

USGHS

## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

Trade name: *ADVA 198*

(Cont. from page 6)

**Recommendation:**

Must not be disposed of together with household garbage. Do not allow product to reach sewage system.

**Uncleaned packagings:****Recommendation:** Disposal must be made according to official regulations.\* **14 Transport information****UN-Number**

DOT, ADR, ADN, IMDG, IATA Not applicable.

**UN proper shipping name**

DOT, ADR, ADN, IMDG, IATA Not applicable.

**Transport hazard class(es)**DOT, ADR, ADN, IMDG, IATA  
Class Not applicable.**Packing group**

DOT, ADR, IMDG, IATA Not applicable.

**Environmental hazards:**

Marine pollutant: No

**Special precautions for user** Not applicable.**Transport/Additional information:** Not classified as a dangerous good for transport by road, rail or air.**DOT****Remarks:** Not Regulated.**UN "Model Regulation":** Not applicable.\* **15 Regulatory information****SARA (Superfund Amendments and Reauthorization Act)****Section 302/304 (extremely hazardous substances):**

None of the ingredients is listed.

**Section 313 Reportable Ingredients (Chemicals present below reporting threshold are exempt):**

None of the ingredients is listed.

**SARA Section 312/Tier I & II Hazard Categories:**

Health Immediate (acute)	Yes
Health Delayed (chronic)	No
Flammable	No
Reactive	No
Pressure	No

**North America Chemical Inventory Status****TSCA (Toxic Substances Control Act - United States):**

All ingredients are listed or exempt from listing unless otherwise noted below.

(Cont. on page 8)

USGHS

## Safety Data Sheet

Printing date 06/15/2016

Version Number 1.0

Reviewed on 06/15/2016

Trade name: *ADVA 198*

(Cont. from page 7)

**CEPA (Canadian DSL):**

All ingredients are listed or exempt from listing unless otherwise noted below.

**Right to Know Ingredient Disclosure:**

	Proprietary Polyacrylate NJTSN 801416052
	Proprietary Copolymer - NJTSN801416055
527-07-1	Sodium gluconate
7732-18-5	Water

**California Proposition 65****Chemicals known to cause cancer:**

Ethylene oxide

propylene oxide

**Chemicals known to cause reproductive toxicity for females:**

75-21-8 | Ethylene oxide

**Chemicals known to cause reproductive toxicity for males:**

75-21-8 | Ethylene oxide

**Chemicals known to cause developmental toxicity:**

75-21-8 | Ethylene oxide

**Carcinogenicity Categories****EPA (Environmental Protection Agency)**

None of the ingredients is listed.

**TLV-ACGIH (THE American Conference of Governmental Industrial Hygienists)****Human Carcinogen - A1 Confirmed, A2 Suspected, A3 Unknown Relevance, A4 Not Classifiable**

None of the ingredients is listed.

**NIOSH-Cancer (National Institute for Occupational Safety and Health)**

None of the ingredients is listed.

**Volatile Organic Compounds (VOC) reported per the Emission Standards.**

If no g/L value is provided this product is not subject to above standard.

**16 Other information**

The data included herein are presented in accordance with various environment, health and safety regulations. It is the responsibility of a recipient of the data to remain currently informed on chemical hazard information, to design and update its own program and to comply with all national, federal, state and local laws and regulations applicable to safety, occupational health, right-to-know and environmental protection.

**Department issuing SDS:**

GCP Applied Technologies  
62 Whittemore Avenue  
Cambridge, MA 02140 USA  
USA: +1-617-876-1400 (24 hours)  
+1-800-354-5414

Date of preparation / last revision 06/15/2016 / -

The first date of preparation 02/21/2014

Number of revision times and the latest revision date 1.0 / 06/15/2016

USGHS

## Safety Data Sheet

Printing date 03/23/2017

Version Number 1.1

Reviewed on 03/23/2017

### 1 Identification

#### Product identifier

Trade name: V-MAR F100

SDS ID Number: 60184

**Relevant identified uses of the substance or mixture, and uses advised against**  
Specialty construction product. Not intended for other uses

**Product category** Concrete Admixture

#### Details of the supplier of the safety data sheet

**Manufacturer/Supplier:**  
GCP Applied Technologies  
62 Whittemore Avenue  
Cambridge, MA 02140 USA

GCP Canada, Inc.  
294 Clements Road W.  
Ajax, Ontario L1S 3C6 Canada

#### Information department:

Environmental Health & Safety  
USA: +1-617-876-1400 (24 hours)  
+1-800-354-5414 (8AM - 5PM) Not functional within Massachusetts  
CAN: 1-905-683-8561 (24 hours)  
Email address: msds.gcp@gcpat.com

**Transport Emergency:** Chemtrec +1-800-424-9300 (24 hours)

### 2 Hazard(s) identification

#### Classification of the substance or mixture

May cause an allergic skin reaction.

#### Label elements:

##### Hazard pictograms



GHS07

Warning

#### Hazard statements

May cause an allergic skin reaction.

#### Precautionary statements

Avoid breathing dust/fume/gas/mist/vapors/spray

Wear protective gloves.

Contaminated work clothing should not be allowed out of the workplace.

IF ON SKIN: Wash with plenty of water.

If skin irritation or rash occurs: Get medical advice/attention.

Wash contaminated clothing before reuse.

Dispose of contents/container in accordance with local/regional/national/international regulations.

(Cont. on page 2)

USGHS

## Safety Data Sheet

Printing date 03/23/2017

Version Number 1.1

Reviewed on 03/23/2017

Trade name: *V-MAR F100*

(Cont. from page 1)

## NFPA ratings (scale 0 - 4)



Health = 1  
Fire = 1  
Reactivity = 0

## HMIS-ratings (scale 0 - 4)



Health = \*1  
Flammability = 1  
Reactivity = 0

## Other hazards

## Results of PBT and vPvB assessment

PBT: Not applicable.

vPvB: Not applicable.

## \* 3 Composition/information on ingredients

## Chemical characterization: Mixture

Description: Mixture of the hazardous substance(s) listed below with additional nonhazardous ingredients.

## Hazardous components:

26172-55-4 | 5-chloro-2-methyl-2H-isothiazol-3-one

0.0-0.1%

Additional information: Non-hazardous ingredients may be listed in Section 15; Right-To-Know disclosure.

## \* 4 First-aid measures

## Description of first aid measures

General information: Get medical advice/attention if you feel unwell.

After inhalation: IF INHALED: Remove person to fresh air and keep comfortable for breathing.

## After skin contact:

Immediately wash contaminated skin with soap or mild detergent and water. If this chemical soaks clothing, immediately remove clothing and wash skin.

After eye contact: Rinse opened eye for several minutes under running water.

## After swallowing:

Rinse mouth.

Do NOT induce vomiting.

## Information for doctor:

Most important symptoms and effects, both acute and delayed No further relevant information available.

Indication of any immediate medical attention and special treatment needed No further relevant information available.

## \* 5 Fire-fighting measures

## Extinguishing media

Suitable extinguishing agents: CO<sub>2</sub>, extinguishing powder or water spray. Fight larger fires with water spray.

## Special hazards arising from the substance or mixture

Combustion products may include toxic gases such as carbon monoxide and smoke.

(Cont. on page 3)

USGHS

**Trade name:** *V-MAR F100*

(Cont. from page 2)

### Advice for firefighters

**Protective equipment:** Wear personal protective equipment

**Additional information** Collect contaminated fire fighting water separately. It must not enter the sewage system.

## 6 Accidental release measures

### Personal precautions, protective equipment and emergency procedures

Wear protective equipment. Keep unprotected persons away.

### Methods and material for containment and cleaning up:

Contain and/or absorb spill with inert material (i.e. sand, vermiculite) then place in a suitable container.

Dispose contaminated material as waste according to section 13 of the SDS.

### Reference to other sections

See Section 7 for information on safe handling.

See Section 8 for information on personal protection equipment.

See Section 13 for disposal information.

## 7 Handling and storage

### Handling:

#### Precautions for safe handling

Open and handle receptacle with care.

Prevent formation of aerosols.

Avoid contact with eyes, skin and clothing.

Do not take internally.

Practice good personal hygiene to avoid ingestion.

Use only with adequate ventilation.

Wash clothing before reuse.

FOR PROFESSIONAL USE ONLY. KEEP OUT OF CHILDREN'S REACH.

**Information about protection against explosions and fires:** No special measures required.

### Conditions for safe storage, including any incompatibilities

#### Storage:

**Information about storage in one common storage facility:** No special measures required.

**Further information about storage conditions:** Keep receptacle tightly sealed.

**Specific end use(s)** No further relevant information available.

## 8 Exposure controls/personal protection

**Additional information about design of technical systems:** No further data; see item 7.

### Control parameters

#### Components with limit values that require monitoring at the workplace:

The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.

**Additional information:** The lists that were valid during the creation were used as basis.

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**Exposure controls****Personal protective equipment:****General protective and hygienic measures:** The usual precautionary measures for handling chemicals should be followed.**Breathing equipment:**

Control exposure to ingredients with workplace control parameters if mentioned above. If no ingredients are listed, respiratory protection is generally not required.

If exposure limits are listed and may be exceeded, use approved respiratory protective equipment and filter type appropriate for the listed ingredients. (NIOSH, CEN, etc.).

**Protection of hands:** Gloves should be worn to prevent skin contact and should be impermeable and resistant to the product.**Material of gloves** Rubber or other impervious gloves should be worn to prevent skin contact.**Eye protection:**

Safety glasses with side shield protection.



A face shield should also be worn if there is potential exposure to splash or spray.

**Body protection:**

Use personal protective equipment as required.

Take off contaminated clothing.

**9 Physical and chemical properties****Information on basic physical and chemical properties****General Information****Appearance:**

<b>Form:</b>	Liquid
<b>Color:</b>	Brown
<b>Odor:</b>	Odorless
<b>Odor threshold:</b>	Not applicable.

**pH-value (~) at 20 °C (68 °F):** 5**Change in condition**

<b>Melting point/Melting range:</b>	0 °C (32 °F)
<b>Boiling point/Boiling range:</b>	100 °C (212 °F)
<b>Flash point:</b>	A flash point determination is unnecessary due to high water content.

**Flammability (solid, gaseous):** Not applicable.**Decomposition temperature:** Not applicable under normal storage conditions.**Auto igniting:** Product is not self-igniting.**Danger of explosion:** Product does not present an explosion hazard.**Explosion limits:**

<b>Lower:</b>	Not applicable.
<b>Upper:</b>	Not applicable.
<b>VOC Content (max):</b>	Not applicable.

**Vapor pressure:** <18 mm Hg**Density: (~)** Not determined.**Relative density** 1.005

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<b>Vapor density</b>	Not applicable.
<b>Evaporation rate</b>	Not applicable.
<b>Solubility in / Miscibility with Water:</b>	Fully miscible.
<b>Partition coefficient (n-octanol/water):</b>	Not determined.
<b>Viscosity:</b>	
<b>Dynamic at 25 °C (77 °F):</b>	1000 cps (Brookfield)
<b>Kinematic:</b>	Not determined.
<b>Molecular weight</b>	Not applicable.
<b>Other information</b>	No further relevant information available.

**10 Stability and reactivity****Reactivity** Stable under normal conditions.**Chemical stability****Thermal decomposition:** No decomposition if used according to specifications.**Possibility of hazardous reactions** No further relevant information available.**Conditions to avoid** No further relevant information available.**Incompatible materials:** No further relevant information available.**Hazardous decomposition products:** Carbon monoxide and carbon dioxide**Additional information:** See section 7 for information on handling, storage and conditions to be avoided.**11 Toxicological information****Information on toxicological effects****Acute toxicity:****Primary irritant effect:****on the skin:** No irritating effect expected**on the eye:** No irritating effect expected**inhalation:** No irritating effect expected**Sensitization:** May cause an allergic skin reaction.**Additional toxicological information:****Carcinogenic categories****IARC (International Agency for Research on Cancer) Human Carcinogenicity:**  
**Group 1- Positive, Group 2A- Probable, Group 2B- Possible, Group 3- Not Classifiable**

None of the ingredients is listed.

**NTP (National Toxicology Program)****K-Known to be carcinogenic, R-May reasonably be anticipated to be carcinogenic**

None of the ingredients is listed.

**OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients is listed.

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**12 Ecological information****Toxicity**

Aquatic toxicity: No further relevant information available.

**Persistence and degradability** No further relevant information available.**Behavior in environmental systems:****Bioaccumulative potential** No further relevant information available.**Mobility in soil** No further relevant information available.**Additional ecological information:****General notes:** Not known to be hazardous to water.**Results of PBT and vPvB assessment****PBT:** Not applicable.**vPvB:** Not applicable.**Other adverse effects** No further relevant information available.**13 Disposal considerations****Disposal methods:**

Consult all regulations (federal, state, provincial, local) or a qualified waste disposal firm when characterizing product for disposal. Dispose of waste in accordance with all applicable regulations.

**Recommendation:**

Must not be disposed of together with household garbage. Do not allow product to reach sewage system.

**Uncleaned packagings:****Recommendation:** Dispose of contents/container in accordance with local/regional/national/international regulations.**14 Transport information****UN-Number**

DOT, IMDG, IATA

Not applicable.

**UN proper shipping name**

DOT, IMDG, IATA

Not applicable.

**Transport hazard class(es)**

DOT, IMDG, IATA

Class

Not applicable.

**Packing group**

DOT, IMDG, IATA

Not applicable.

**Environmental hazards:****Marine pollutant:**

No

**Special precautions for user**

Not applicable.

**Transport/Additional information:** Not classified as a dangerous good for transport by road, rail or air.

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**DOT****Remarks:** Not Regulated.**UN "Model Regulation":** Not applicable.**15 Regulatory information****SARA (Superfund Amendments and Reauthorization Act)****Section 302/304 (extremely hazardous substances):**

None of the ingredients is listed.

**Section 313 Reportable Ingredients (Chemicals present below reporting threshold are exempt):**

None of the ingredients is listed.

**SARA Section 312/Tier I & II Hazard Categories:** Health Hazard - Respiratory or Skin Sensitization**North America Chemical Inventory Status****TSCA (Toxic Substances Control Act - United States):**

All ingredients are listed or exempt from listing unless otherwise noted below.

**CEPA (Canadian DSL):**

All ingredients are listed or exempt from listing unless otherwise noted below.

**Right to Know Ingredient Disclosure:**

25213-24-5 | vinyl alcohol/vinyl acetate copolymer

7732-18-5 | Water

**California Proposition 65****Chemicals known to cause cancer:**

Ethylene oxide

propylene oxide

**Chemicals known to cause reproductive toxicity for females:**

75-21-8 | Ethylene oxide

**Chemicals known to cause reproductive toxicity for males:**

75-21-8 | Ethylene oxide

**Chemicals known to cause developmental toxicity:**

67-56-1 | Methanol

75-21-8 | Ethylene oxide

**Carcinogenicity Categories****EPA (Environmental Protection Agency)**

None of the ingredients is listed.

**TLV-ACGIH (THE American Conference of Governmental Industrial Hygienists)****Human Carcinogen - A1 Confirmed, A2 Suspected, A3 Unknown Relevance, A4 Not Classifiable**

None of the ingredients is listed.

**NIOSH-Cancer (National Institute for Occupational Safety and Health)**

None of the ingredients is listed.

**Volatile Organic Compounds (VOC) reported per the Emission Standards.**

If no g/L value is provided this product is not subject to above standard.

**16 Other information**

The data included herein are presented in accordance with various environment, health and safety regulations. It is the responsibility of a recipient of the data to remain currently informed on chemical hazard information, to design and update its own program and to comply with all national, federal, state and local laws and regulations applicable to safety, occupational health, right-to-know and environmental protection.

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**Trade name: V-MAR F100**

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**Department issuing SDS:**

GCP Applied Technologies

62 Whittemore Avenue

Cambridge, MA 02140 USA

USA: +1-617-876-1400 (24 hours)

+1-800-354-5414

**Date of preparation / last revision** 03/23/2017 / 1.0**The first date of preparation** 03/29/2012**Number of revision times and the latest revision date** 1.1 / 03/23/2017

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# SAFETY DATA SHEET



## XIAMETER(R) OFS-6020 SILANE

Version 8.0      Revision Date: 09/13/2017      SDS Number: 1045738-00011      Date of last issue: 03/15/2017  
Date of first issue: 01/09/2015

### SECTION 1. IDENTIFICATION

Product name : XIAMETER(R) OFS-6020 SILANE  
Product code : 00000000004088553

#### Manufacturer or supplier's details

Company name of supplier : Dow Corning Corporation  
Address : South Saginaw Road  
Midland Michigan 48686  
Telephone : (989) 496-6000  
Emergency telephone : 24 Hour Emergency Telephone : (989) 496-5900  
CHEMTREC : (800) 424-9300

#### Recommended use of the chemical and restrictions on use

Recommended use : Adhesive, binding agents  
Intermediate

### SECTION 2. HAZARDS IDENTIFICATION

#### GHS classification in accordance with 29 CFR 1910.1200

Flammable liquids : Category 4  
Acute toxicity (Inhalation) : Category 4  
Serious eye damage : Category 1  
Respiratory sensitization : Category 1  
Skin sensitization : Category 1

#### GHS label elements

Hazard pictograms :

Signal Word : Danger

Hazard Statements : H227 Combustible liquid.  
H317 May cause an allergic skin reaction.  
H318 Causes serious eye damage.  
H332 Harmful if inhaled.  
H334 May cause allergy or asthma symptoms or breathing difficulties if inhaled.

Precautionary Statements : **Prevention:**

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P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.  
P261 Avoid breathing mist or vapors.  
P271 Use only outdoors or in a well-ventilated area.  
P272 Contaminated work clothing must not be allowed out of the workplace.  
P280 Wear protective gloves/ eye protection/ face protection.  
P285 In case of inadequate ventilation wear respiratory protection.

**Response:**

P302 + P352 IF ON SKIN: Wash with plenty of soap and water.  
P304 + P340 + P312 IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER/doctor if you feel unwell.  
P305 + P351 + P338 + P310 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.  
P333 + P313 If skin irritation or rash occurs: Get medical advice/ attention.  
P342 + P311 If experiencing respiratory symptoms: Call a POISON CENTER/doctor.  
P363 Wash contaminated clothing before reuse.

**Storage:**

P403 + P235 Store in a well-ventilated place. Keep cool.

**Disposal:**

P501 Dispose of contents/ container to an approved waste disposal plant.

**Other hazards**

|| Vapors may form explosive mixture with air.

**SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS**

Substance / Mixture : Substance  
Chemical nature : Alkoxysilane  
Substance name : N-(3-(Trimethoxysilyl)propyl)ethylenediamine  
CAS-No. : 1760-24-3

**Hazardous ingredients**

Chemical name	CAS-No.	Concentration (% w/w)
N-(3-(Trimethoxysilyl)propyl)ethylenediamine	1760-24-3	>= 72 - <= 89
N, N-Bis(3-(Trimethoxysilyl)propyl)-1,2-ethanediamine	74956-86-8	>= 6 - <= 8
N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine	68845-16-9	>= 6 - <= 8
Oligomers of aminoalkylmethoxysilanes	Not Assigned	>= 3 - <= 5

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Methanol	67-56-1	>= 0.68 - <= 0.92
Ethylenediamine	107-15-3	>= 0.6 - <= 0.81

### SECTION 4. FIRST AID MEASURES

- General advice : In the case of accident or if you feel unwell, seek medical advice immediately.  
When symptoms persist or in all cases of doubt seek medical advice.
- If inhaled : If inhaled, remove to fresh air.  
If not breathing, give artificial respiration.  
If breathing is difficult, give oxygen.  
Get medical attention.
- In case of skin contact : In case of contact, immediately flush skin with plenty of water.  
Remove contaminated clothing and shoes.  
Get medical attention.  
Wash clothing before reuse.  
Thoroughly clean shoes before reuse.
- In case of eye contact : In case of contact, immediately flush eyes with plenty of water for at least 15 minutes.  
If easy to do, remove contact lens, if worn.  
Get medical attention immediately.
- If swallowed : If swallowed, DO NOT induce vomiting.  
Get medical attention.  
Rinse mouth thoroughly with water.
- Most important symptoms and effects, both acute and delayed : May cause an allergic skin reaction.  
Causes serious eye damage.  
Harmful if inhaled.  
May cause allergy or asthma symptoms or breathing difficulties if inhaled.
- Protection of first-aiders : First Aid responders should pay attention to self-protection, and use the recommended personal protective equipment when the potential for exposure exists.
- Notes to physician : Treat symptomatically and supportively.

### SECTION 5. FIRE-FIGHTING MEASURES

- Suitable extinguishing media : Water spray  
Alcohol-resistant foam  
Carbon dioxide (CO<sub>2</sub>)  
Dry chemical
- Unsuitable extinguishing media : High volume water jet
- Specific hazards during fire : Do not use a solid water stream as it may scatter and spread

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- fighting : fire.  
Flash back possible over considerable distance.  
Vapors may form explosive mixtures with air.  
Exposure to combustion products may be a hazard to health.
- Hazardous combustion products : Carbon oxides  
Silicon oxides  
Nitrogen oxides (NO<sub>x</sub>)  
Formaldehyde
- Specific extinguishing methods : Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.  
Use water spray to cool unopened containers.  
Remove undamaged containers from fire area if it is safe to do so.  
Evacuate area.
- Special protective equipment for fire-fighters : In the event of fire, wear self-contained breathing apparatus.  
Use personal protective equipment.
- 

### SECTION 6. ACCIDENTAL RELEASE MEASURES

- Personal precautions, protective equipment and emergency procedures : Remove all sources of ignition.  
Use personal protective equipment.  
Follow safe handling advice and personal protective equipment recommendations.
- Environmental precautions : Discharge into the environment must be avoided.  
Prevent further leakage or spillage if safe to do so.  
Prevent spreading over a wide area (e.g., by containment or oil barriers).  
Retain and dispose of contaminated wash water.  
Local authorities should be advised if significant spillages cannot be contained.
- Methods and materials for containment and cleaning up : Non-sparking tools should be used.  
Soak up with inert absorbent material.  
Suppress (knock down) gases/vapors/mists with a water spray jet.  
For large spills, provide diking or other appropriate containment to keep material from spreading. If diked material can be pumped, store recovered material in appropriate container.  
Clean up remaining materials from spill with suitable absorbent.  
Local or national regulations may apply to releases and disposal of this material, as well as those materials and items employed in the cleanup of releases. You will need to determine which regulations are applicable.  
Sections 13 and 15 of this SDS provide information regarding certain local or national requirements.
- 

### SECTION 7. HANDLING AND STORAGE

**SAFETY DATA SHEET**



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- Technical measures : See Engineering measures under EXPOSURE CONTROLS/PERSONAL PROTECTION section.
- Local/Total ventilation : Use with local exhaust ventilation.
- Advice on safe handling : Do not get on skin or clothing.  
 Do not breathe vapors or spray mist.  
 Do not swallow.  
 Do not get in eyes.  
 Handle in accordance with good industrial hygiene and safety practice, based on the results of the workplace exposure assessment  
 Keep container tightly closed.  
 Keep away from water.  
 Protect from moisture.  
 Keep away from heat and sources of ignition.  
 Take precautionary measures against static discharges.  
 Take care to prevent spills, waste and minimize release to the environment.
- Conditions for safe storage : Keep in properly labeled containers.  
 Keep tightly closed.  
 Keep in a cool, well-ventilated place.  
 Store in accordance with the particular national regulations.  
 Keep away from heat and sources of ignition.
- Materials to avoid : Do not store with the following product types:  
 Strong oxidizing agents  
 Explosives  
 Gases

**SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION**

**Ingredients with workplace control parameters**

Ingredients	CAS-No.	Value type (Form of exposure)	Control parameters / Permissible concentration	Basis
Methanol	67-56-1	TWA	200 ppm	ACGIH
		STEL	250 ppm	ACGIH
		TWA	200 ppm 260 mg/m <sup>3</sup>	NIOSH REL
		ST	250 ppm 325 mg/m <sup>3</sup>	NIOSH REL
		TWA	200 ppm 260 mg/m <sup>3</sup>	OSHA Z-1
Ethylenediamine	107-15-3	TWA	10 ppm	ACGIH
		TWA	10 ppm 25 mg/m <sup>3</sup>	NIOSH REL
		TWA	10 ppm 25 mg/m <sup>3</sup>	OSHA Z-1

**Hazardous components without workplace control parameters**

Ingredients	CAS-No.
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N-(3-(Trimethoxysilyl)propyl)ethylenediamine	1760-24-3
N, N-Bis(3-(Trimethoxysilyl)propyl)-1,2-ethanediamine	74956-86-8
N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine	68845-16-9
Oligomers of aminoalkyl-methoxysilanes	Not Assigned

**Occupational exposure limits of decomposition products**

Ingredients	CAS-No.	Value type (Form of exposure)	Control parameters / Permissible concentration	Basis
Methanol	67-56-1	TWA	200 ppm	ACGIH
		STEL	250 ppm	ACGIH
		TWA	200 ppm 260 mg/m <sup>3</sup>	NIOSH REL
		ST	250 ppm 325 mg/m <sup>3</sup>	NIOSH REL
		TWA	200 ppm 260 mg/m <sup>3</sup>	OSHA Z-1

**Biological occupational exposure limits**

Ingredients	CAS-No.	Control parameters	Biological specimen	Sampling time	Permissible concentration	Basis
Methanol	67-56-1	Methanol	Urine	End of shift (As soon as possible after exposure ceases)	15 mg/l	ACGIH BEI

**Engineering measures** : Processing may form hazardous compounds (see section 10).  
 Minimize workplace exposure concentrations.  
 Use with local exhaust ventilation.

**Personal protective equipment**

**Respiratory protection** : General and local exhaust ventilation is recommended to maintain vapor exposures below recommended limits. Where concentrations are above recommended limits or are unknown, appropriate respiratory protection should be worn. Follow OSHA respirator regulations (29 CFR 1910.134) and use NIOSH/MSHA approved respirators. Protection provided by air purifying respirators against exposure to any hazardous chemical is limited. Use a positive pressure air supplied respirator if there is any potential for uncontrolled

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release, exposure levels are unknown, or any other circumstance where air purifying respirators may not provide adequate protection.

### Hand protection

Material : Chemical-resistant gloves

Remarks : Choose gloves to protect hands against chemicals depending on the concentration specific to place of work. Breakthrough time is not determined for the product. Change gloves often! For special applications, we recommend clarifying the resistance to chemicals of the aforementioned protective gloves with the glove manufacturer. Take note that the product is flammable, which may impact the selection of hand protection. Wash hands before breaks and at the end of workday.

### Eye protection

: Wear the following personal protective equipment:  
Chemical resistant goggles must be worn.  
If splashes are likely to occur, wear:  
Face-shield

### Skin and body protection

: Select appropriate protective clothing based on chemical resistance data and an assessment of the local exposure potential.  
Wear the following personal protective equipment:  
Flame retardant antistatic protective clothing, unless assessment demonstrates that the risk of explosive atmospheres or flash fires is low  
Skin contact must be avoided by using impervious protective clothing (gloves, aprons, boots, etc).

### Hygiene measures

: Ensure that eye flushing systems and safety showers are located close to the working place.  
When using do not eat, drink or smoke.  
Wash contaminated clothing before re-use.  
These precautions are for room temperature handling. Use at elevated temperature or aerosol/spray applications may require added precautions.  
For further information regarding the use of silicones / organic oils in consumer aerosol applications, please refer to the guidance document regarding the use of these type of materials in consumer aerosol applications that has been developed by the silicone industry ([www.SEHSC.com](http://www.SEHSC.com)) or contact the Dow Corning customer service group.

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## SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance : liquid

Color : Colorless to pale yellow

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Odor : No data available

Odor Threshold : No data available

pH : No data available

Melting point/freezing point : No data available

Initial boiling point and boiling range :  $\geq 128.33$  °C

Flash point : 85.0 °C  
Method: Seta closed cup

Evaporation rate : No data available

Flammability (solid, gas) : Not applicable

Flammability (liquids) : Not applicable

Self-ignition : The substance or mixture is not classified as pyrophoric. The substance or mixture is not classified as self heating.

Upper explosion limit / Upper flammability limit : No data available

Lower explosion limit / Lower flammability limit : No data available

Vapor pressure : No data available

Relative vapor density : No data available

Relative density : 1.03

Solubility(ies)  
Water solubility : No data available

Partition coefficient: n-octanol/water : No data available

Autoignition temperature : 310 °C

Decomposition temperature : No data available

Viscosity  
Viscosity, kinematic : 5 cSt (25 °C)

Explosive properties : Not explosive

Oxidizing properties : The substance or mixture is not classified as oxidizing.

Molecular weight : No data available

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Particle size : Not applicable

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### SECTION 10. STABILITY AND REACTIVITY

Reactivity : Not classified as a reactivity hazard.

Chemical stability : Stable under normal conditions.

Possibility of hazardous reactions : Combustible liquid.  
Vapors may form explosive mixture with air.  
Use at elevated temperatures may form highly hazardous compounds.  
Can react with strong oxidizing agents.  
When heated to temperatures above 150 °C (300 °F) in the presence of air, product can form formaldehyde vapors.  
Safe handling conditions may be maintained by keeping vapor concentrations within the occupational exposure limit for formaldehyde.  
See OSHA formaldehyde standard, 29 CFR 1910.1048  
Formaldehyde may cause cancer. It is also toxic by inhalation, skin absorption and ingestion, corrosive to skin and eyes, and may cause skin sensitization and respiratory irritation.  
Hazardous decomposition products will be formed upon contact with water or humid air.  
Hazardous decomposition products will be formed at elevated temperatures.

Conditions to avoid : Exposure to moisture.  
Heat, flames and sparks.

Incompatible materials : Oxidizing agents  
Water

#### **Hazardous decomposition products**

Contact with water or humid air : Methanol

Thermal decomposition : Formaldehyde

---

### SECTION 11. TOXICOLOGICAL INFORMATION

#### **Information on likely routes of exposure**

Inhalation  
Skin contact  
Ingestion  
Eye contact

#### **Acute toxicity**

Harmful if inhaled.

#### **Product:**

Acute oral toxicity : LD50 (Rat): 2,295 mg/kg

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Remarks: On basis of test data.

Acute inhalation toxicity : LC50 (Rat): > 1.49 mg/l  
 Exposure time: 4 h  
 Test atmosphere: dust/mist  
 Remarks: On basis of test data.

Acute dermal toxicity : LD50 (Rabbit): > 2,000 mg/kg  
 Assessment: The substance or mixture has no acute dermal toxicity  
 Remarks: On basis of test data.

**Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Acute oral toxicity : LD50 (Rat): 2,295 mg/kg  
 Remarks: On basis of test data.

Acute inhalation toxicity : LC50 (Rat): > 1.49 mg/l  
 Exposure time: 4 h  
 Test atmosphere: dust/mist  
 Remarks: On basis of test data.

Acute dermal toxicity : LD50 (Rabbit): > 2,000 mg/kg  
 Assessment: The substance or mixture has no acute dermal toxicity  
 Remarks: On basis of test data.

**Methanol:**

Acute oral toxicity : Acute toxicity estimate (Humans): 300 mg/kg  
 Method: Expert judgment

Acute inhalation toxicity : Acute toxicity estimate: 3 mg/l  
 Exposure time: 4 h  
 Test atmosphere: vapor  
 Method: Expert judgment  
 Remarks: Based on harmonised classification in EU regulation 1272/2008, Annex VI

Acute dermal toxicity : Acute toxicity estimate (Humans): 300 mg/kg  
 Method: Expert judgment

**Ethylenediamine:**

Acute oral toxicity : LD50 (Rat): 866 mg/kg

Acute inhalation toxicity : LC50 (Rat): 14.7 mg/l  
 Exposure time: 4 h  
 Test atmosphere: vapor  
 Assessment: Corrosive to the respiratory tract.

Acute dermal toxicity : LD50 (Rabbit): 560 mg/kg

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**Skin corrosion/irritation**

Not classified based on available information.

**Product:**

Species: Rabbit  
Result: Mild skin irritation  
Remarks: On basis of test data.

**Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Species: Rabbit  
Result: Mild skin irritation  
Remarks: On basis of test data.

**N, N-Bis(3-(Trimethoxysilyl)propyl)-1,2-ethanediamine:**

Result: Skin irritation  
Remarks: Based on data from similar materials

**N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine:**

Result: Skin irritation  
Remarks: Information taken from reference works and the literature.

**Oligomers of aminoalkylmethoxysilanes:**

Species: Rabbit  
Result: Mild skin irritation  
Remarks: On basis of test data.

**Methanol:**

Species: Rabbit  
Result: No skin irritation

**Ethylenediamine:**

Species: Rabbit  
Result: Corrosive after 3 minutes to 1 hour of exposure

**Serious eye damage/eye irritation**

Causes serious eye damage.

**Product:**

Species: Rabbit  
Result: Irreversible effects on the eye  
Remarks: On basis of test data.

**Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Species: Rabbit  
Result: Irreversible effects on the eye  
Remarks: On basis of test data.

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**N, N-Bis(3-(Trimethoxysilyl)propyl)-1,2-ethanediamine:**

Result: Irreversible effects on the eye  
 Remarks: Based on data from similar materials

**N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine:**

Result: Irreversible effects on the eye  
 Remarks: Information taken from reference works and the literature.

**Oligomers of aminoalkylmethoxysilanes:**

Species: Rabbit  
 Result: Irreversible effects on the eye  
 Remarks: On basis of test data.

**Methanol:**

Species: Rabbit  
 Result: No eye irritation

**Ethylenediamine:**

Species: Rabbit  
 Result: Irreversible effects on the eye

**Respiratory or skin sensitization****Skin sensitization**

May cause an allergic skin reaction.

**Respiratory sensitization**

May cause allergy or asthma symptoms or breathing difficulties if inhaled.

**Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Assessment: Probability or evidence of skin sensitization in humans  
 Test Type: Maximization Test  
 Species: Guinea pig  
 Result: positive  
 Remarks: Information taken from reference works and the literature.

**N, N-Bis(3-(Trimethoxysilyl)propyl)-1,2-ethanediamine:**

Assessment: Probability or evidence of skin sensitization in humans

**N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine:**

Assessment: Probability or evidence of skin sensitization in humans

**Oligomers of aminoalkylmethoxysilanes:**

Assessment: Probability or evidence of skin sensitization in humans

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Test Type: Maximization Test  
 Species: Guinea pig  
 Remarks: Information taken from reference works and the literature.

**Methanol:**

Test Type: Maximization Test  
 Routes of exposure: Skin contact  
 Species: Guinea pig  
 Result: negative

**Ethylenediamine:**

Test Type: Maximization Test  
 Routes of exposure: Skin contact  
 Species: Guinea pig  
 Result: positive

Assessment: Probability or evidence of low to moderate skin sensitization rate in humans

Assessment: Probability of respiratory sensitization in humans based on animal testing

Remarks: Based on harmonised classification in EU regulation 1272/2008, Annex VI

**Germ cell mutagenicity**

Not classified based on available information.

**Ingredients:****Methanol:**

Genotoxicity in vitro : Test Type: Bacterial reverse mutation assay (AMES)  
 Method: OECD Test Guideline 471  
 Result: negative

Test Type: In vitro mammalian cell gene mutation test  
 Result: negative

Genotoxicity in vivo : Test Type: Mammalian erythrocyte micronucleus test (in vivo  
 cytogenetic assay)  
 Species: Mouse  
 Application Route: Intraperitoneal injection  
 Result: negative

**Ethylenediamine:**

Genotoxicity in vitro : Test Type: Bacterial reverse mutation assay (AMES)  
 Result: positive

Test Type: Chromosome aberration test in vitro  
 Method: OECD Test Guideline 473  
 Result: negative

Genotoxicity in vivo : Test Type: Rodent dominant lethal test (germ cell) (in vivo)  
 Species: Rat  
 Application Route: Ingestion  
 Result: negative

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Remarks: Based on data from similar materials

Germ cell mutagenicity - Assessment : Weight of evidence does not support classification as a germ cell mutagen.

### **Carcinogenicity**

Not classified based on available information.

### **Ingredients:**

#### **Methanol:**

Species: Mouse  
Application Route: inhalation (vapor)  
Exposure time: 18 Months  
Result: negative

#### **Ethylenediamine:**

Species: Mouse  
Application Route: Skin contact  
Exposure time: 2 Years  
Result: negative

#### **IARC**

No ingredient of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

#### **OSHA**

No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

#### **NTP**

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

### **Reproductive toxicity**

Not classified based on available information.

### **Ingredients:**

#### **N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Effects on fertility : Test Type: Combined repeated dose toxicity study with the reproduction/developmental toxicity screening test  
Application Route: Ingestion  
Symptoms: No effects on fertility.  
Remarks: On basis of test data.

Effects on fetal development : Test Type: Combined repeated dose toxicity study with the reproduction/developmental toxicity screening test  
Application Route: Ingestion  
Symptoms: No effects on fetal development.  
Remarks: On basis of test data.

Reproductive toxicity - Assessment : No evidence of adverse effects on sexual function and fertility, or on development, based on animal experiments.

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**Methanol:**

Effects on fertility : Test Type: Fertility/early embryonic development  
Species: Mouse  
Application Route: Ingestion  
Result: negative

Effects on fetal development : Test Type: Embryo-fetal development  
Species: Mouse  
Application Route: Ingestion  
Result: positive  
Remarks: The effects were seen only at maternally toxic doses.

**Ethylenediamine:**

Effects on fertility : Test Type: Two-generation reproduction toxicity study  
Species: Rat  
Application Route: Ingestion  
Result: negative

Effects on fetal development : Test Type: Embryo-fetal development  
Species: Rat  
Application Route: Ingestion  
Result: negative  
Remarks: Based on data from similar materials

**STOT-single exposure**

Not classified based on available information.

**Ingredients:****Methanol:**

Target Organs: Eyes, Central nervous system  
Assessment: Causes damage to organs.

**STOT-repeated exposure**

Not classified based on available information.

**Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Routes of exposure: Ingestion  
Assessment: No significant health effects observed in animals at concentrations of 100 mg/kg bw or less.

**Ethylenediamine:**

Assessment: No significant health effects observed in animals at concentrations of 100 mg/kg bw or less.

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**Repeated dose toxicity****Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Application Route: Ingestion  
Remarks: On basis of test data.

**Methanol:**

Species: Rat  
NOAEL: 1.06 mg/l  
Application Route: inhalation (vapor)  
Exposure time: 90 Days

**Ethylenediamine:**

Species: Rat  
NOAEL: 22 mg/kg  
LOAEL: 114 mg/kg  
Application Route: Ingestion  
Exposure time: 90 Days

**Aspiration toxicity**

Not classified based on available information.

**SECTION 12. ECOLOGICAL INFORMATION****Ecotoxicity****Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Toxicity to fish	:	LC50 (Danio rerio (zebra fish)): 597 mg/l Exposure time: 96 h Method: Directive 67/548/EEC, Annex V, C.1.
Toxicity to daphnia and other aquatic invertebrates	:	EC50 (Daphnia sp. (Water flea)): 81 mg/l Exposure time: 48 h Method: Directive 67/548/EEC, Annex V, C.2.
		EC50 (Daphnia magna (Water flea)): 90 mg/l Exposure time: 48 h Method: OECD Test Guideline 202 Remarks: On basis of test data.
Toxicity to algae	:	ErC50 (Selenastrum capricornutum (green algae)): 8.8 mg/l Exposure time: 72 h Method: OECD Test Guideline 201
		NOEC (Selenastrum capricornutum (green algae)): 3.1 mg/l Exposure time: 72 h Method: OECD Test Guideline 201
Toxicity to microorganisms	:	EC50 (Pseudomonas putida): 67 mg/l

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Exposure time: 16 h  
Method: DIN 38 412 Part 8

**Oligomers of aminoalkylmethoxysilanes:**

Toxicity to fish	:	LC50 (Danio rerio (zebra fish)): 597 mg/l Exposure time: 96 h Remarks: Based on data from similar materials
Toxicity to daphnia and other aquatic invertebrates	:	EC50 (Daphnia sp. (Water flea)): 37 mg/l Exposure time: 48 h Remarks: Based on data from similar materials
Toxicity to algae	:	ErC50 (Pseudokirchneriella subcapitata (green algae)): 8.8 mg/l Exposure time: 72 h Remarks: Based on data from similar materials
		NOEC (Pseudokirchneriella subcapitata (green algae)): 3.1 mg/l Exposure time: 72 h Remarks: Based on data from similar materials
Toxicity to daphnia and other aquatic invertebrates (Chronic toxicity)	:	NOEC (Daphnia sp. (Water flea)): > 1 mg/l Exposure time: 21 d Remarks: Based on data from similar materials

**Methanol:**

Toxicity to fish	:	LC50 (Lepomis macrochirus (Bluegill sunfish)): 15,400 mg/l Exposure time: 96 h
Toxicity to daphnia and other aquatic invertebrates	:	EC50 (Daphnia magna (Water flea)): > 10,000 mg/l Exposure time: 48 h
Toxicity to algae	:	EC50 (Pseudokirchneriella subcapitata (green algae)): 22,000 mg/l Exposure time: 96 h Method: OECD Test Guideline 201
Toxicity to fish (Chronic toxicity)	:	NOEC (Oryzias latipes (Orange-red killifish)): 15,800 mg/l Exposure time: 200 h
Toxicity to microorganisms	:	IC50: > 1,000 mg/l Exposure time: 3 h

**Ethylenediamine:**

Toxicity to fish	:	LC50 (Poecilia reticulata (guppy)): 640 mg/l Exposure time: 96 h Method: Directive 67/548/EEC, Annex V, C.1.
Toxicity to daphnia and other aquatic invertebrates	:	EC50 (Daphnia magna (Water flea)): 16.7 mg/l Exposure time: 48 h Method: Directive 67/548/EEC, Annex V, C.2.

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Toxicity to algae	: ErC50 (Pseudokirchneriella subcapitata (green algae)): 645 mg/l Exposure time: 72 h Method: Directive 67/548/EEC, Annex V, C.3.
	NOEC (Pseudokirchneriella subcapitata (green algae)): 3.2 mg/l Exposure time: 72 h Method: Directive 67/548/EEC, Annex V, C.3.
Toxicity to fish (Chronic toxicity)	: NOEC (Gasterosteus aculeatus (threespine stickleback)): > 10 mg/l Exposure time: 28 d Method: OECD Test Guideline 210
Toxicity to daphnia and other aquatic invertebrates (Chronic toxicity)	: NOEC (Daphnia magna (Water flea)): 0.16 mg/l Exposure time: 21 d
Toxicity to microorganisms	: EC50: 3.2 mg/l Exposure time: 2 h

**Persistence and degradability****Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Biodegradability	: Result: Not readily biodegradable. Biodegradation: 39 % Method: OECD Test Guideline 301A
Stability in water	: Degradation half life: 0.025 h (24.7 °C) pH: 7 Method: OECD Test Guideline 111

**Oligomers of aminoalkylmethoxysilanes:**

Biodegradability	: Result: Not readily biodegradable.
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**Methanol:**

Biodegradability	: Result: Readily biodegradable. Biodegradation: 95 % Exposure time: 20 d
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**Ethylenediamine:**

Biodegradability	: Result: Readily biodegradable. Biodegradation: 95 % Exposure time: 28 d Method: Directive 67/548/EEC Annex V, C.4.E.
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**Bioaccumulative potential****Ingredients:****N-(3-(Trimethoxysilyl)propyl)ethylenediamine:**

Partition coefficient: n-octanol/water	:	log Pow: -0.3
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**Methanol:**

Bioaccumulation	:	Species: Leuciscus idus (Golden orfe) Bioconcentration factor (BCF): < 10
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Partition coefficient: n-octanol/water	:	log Pow: -0.77
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**Ethylenediamine:**

Partition coefficient: n-octanol/water	:	log Pow: -2 - -1.3
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**Mobility in soil**

No data available

**Other adverse effects**

No data available

**SECTION 13. DISPOSAL CONSIDERATIONS****Disposal methods**

Resource Conservation and Recovery Act (RCRA)	:	This product has been evaluated for RCRA characteristics and does not meet the criteria of hazardous waste if discarded in its purchased form.
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Waste from residues	:	Dispose of in accordance with local regulations.
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Contaminated packaging	:	Empty containers should be taken to an approved waste handling site for recycling or disposal. Empty containers retain residue and can be dangerous. Do not pressurize, cut, weld, braze, solder, drill, grind, or expose such containers to heat, flame, sparks, or other sources of ignition. They may explode and cause injury and/or death. If not otherwise specified: Dispose of as unused product.
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**SECTION 14. TRANSPORT INFORMATION****International Regulations****UNRTDG**

Not regulated as a dangerous good

**IATA-DGR**

Not regulated as a dangerous good

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**IMDG-Code**

Not regulated as a dangerous good

**Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code**

Not applicable for product as supplied.

**Domestic regulation**

**49 CFR**

UN/ID/NA number : NA 1993  
 Proper shipping name : Combustible liquid, n.o.s.  
 (N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine)  
 Class : CBL  
 Packing group : III  
 Labels : None  
 ERG Code : 128  
 Marine pollutant : no  
 Remarks : Above applies only to containers over 119 gallons or 450 liters. Not regulated if shipped in packages less than or equal to 119 gallons (450 liters).

**SECTION 15. REGULATORY INFORMATION**

**EPCRA - Emergency Planning and Community Right-to-Know**

**CERCLA Reportable Quantity**

Ingredients	CAS-No.	Component RQ (lbs)	Calculated product RQ (lbs)
Methanol	67-56-1	5000	*
Ethylenediamine	107-15-3	5000	*

\*: Calculated RQ exceeds reasonably attainable upper limit.

**SARA 304 Extremely Hazardous Substances Reportable Quantity**

Ingredients	CAS-No.	Component RQ (lbs)	Calculated product RQ (lbs)
Ethylenediamine	107-15-3	5000	*

\*: Calculated RQ exceeds reasonably attainable upper limit.

**SARA 302 Extremely Hazardous Substances Threshold Planning Quantity**

This material does not contain any components with a section 302 EHS TPQ.

**SARA 311/312 Hazards** : Flammable (gases, aerosols, liquids, or solids)  
 Acute toxicity (any route of exposure)  
 Serious eye damage or eye irritation  
 Respiratory or skin sensitization

**SARA 313** : This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

**US State Regulations**

**Pennsylvania Right To Know**

N-(3-(Trimethoxysilyl)propyl)ethylenediamine      1760-24-3

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N, N'-bis(3-(trimethoxysilyl)propyl)-1,2-ethanediamine	68845-16-9
N, N-Bis(3-(Trimethoxysilyl)propyl)-1,2-ethanediamine	74956-86-8
Oligomers of aminoalkylmethoxysilanes	Not Assigned
Methanol	67-56-1
Ethylenediamine	107-15-3

### California Prop. 65

WARNING: This product can expose you to chemicals including Methanol, which is/are known to the State of California to cause birth defects or other reproductive harm. For more information go to [www.P65Warnings.ca.gov](http://www.P65Warnings.ca.gov).

### The ingredients of this product are reported in the following inventories:

NZIoC : All ingredients listed or exempt.

REACH : For purchases from Dow Corning EU legal entities, all ingredients are currently pre/registered or exempt under REACH. Please refer to section 1 for recommended uses. For purchases from non-EU Dow Corning legal entities with the intention to export into EEA please contact your DC representative/local office.

TSCA : All chemical substances in this product are either listed on the TSCA Inventory or are in compliance with a TSCA Inventory exemption.

PICCS : All ingredients listed or exempt.

KECI : All ingredients listed, exempt or notified.

ENCS/ISHL : All components are listed on ENCS/ISHL or exempted from inventory listing.

IECSC : All ingredients listed or exempt.

AICS : All ingredients listed or exempt.

DSL : All chemical substances in this product comply with the CEPA 1999 and NSNR and are on or exempt from listing on the Canadian Domestic Substances List (DSL).

TCSI : All ingredients listed or exempt.

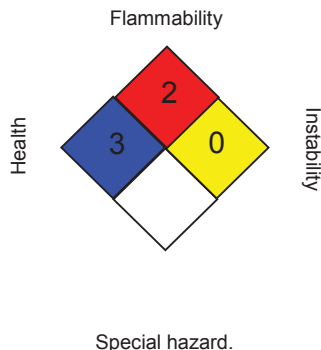
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## SECTION 16. OTHER INFORMATION

## Further information

## NFPA:



## HMIS® IV:

HEALTH	*	3
FLAMMABILITY		2
PHYSICAL HAZARD		0

HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. The "\*" represents a chronic hazard, while the "/" represents the absence of a chronic hazard.

## Full text of other abbreviations

ACGIH	:	USA. ACGIH Threshold Limit Values (TLV)
ACGIH BEI	:	ACGIH - Biological Exposure Indices (BEI)
NIOSH REL	:	USA. NIOSH Recommended Exposure Limits
OSHA Z-1	:	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
ACGIH / TWA	:	8-hour, time-weighted average
ACGIH / STEL	:	Short-term exposure limit
NIOSH REL / TWA	:	Time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek
NIOSH REL / ST	:	STEL - 15-minute TWA exposure that should not be exceeded at any time during a workday
OSHA Z-1 / TWA	:	8-hour time weighted average

AICS - Australian Inventory of Chemical Substances; ASTM - American Society for the Testing of Materials; bw - Body weight; CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act; CMR - Carcinogen, Mutagen or Reproductive Toxicant; DIN - Standard of the German Institute for Standardisation; DOT - Department of Transportation; DSL - Domestic Substances List (Canada); ECx - Concentration associated with x% response; EHS - Extremely Hazardous Substance; ELx - Loading rate associated with x% response; EmS - Emergency Schedule; ENCS - Existing and New Chemical Substances (Japan); ErCx - Concentration associated with x% growth rate response; ERG - Emergency Response Guide; GHS - Globally Harmonized System; GLP - Good Laboratory Practice; HMIS - Hazardous Materials Identification System; IARC - International Agency for Research on Cancer; IATA - International Air Transport Association; IBC - International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk; IC50 - Half maximal inhibitory concentration; ICAO - International Civil Aviation Organization; IECSC - Inventory of Existing Chemical Substances in China; IMDG - International Maritime Dangerous Goods; IMO - International Maritime Organization; ISHL - Industrial Safety and Health Law (Japan); ISO - International Organisation for Standardization; KECI - Korea Existing Chemicals Inventory; LC50 - Lethal Concentration to 50 % of a test population; LD50 - Lethal Dose to 50% of a test population (Median Lethal Dose); MARPOL - International Convention for the Prevention of Pollution from Ships; MSHA - Mine Safety and Health Administration; n.o.s. - Not Otherwise Specified; NFPA - National Fire Protection Association; NO(A)EC - No Observed (Adverse)

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Effect Concentration; NO(A)EL - No Observed (Adverse) Effect Level; NOELR - No Observable Effect Loading Rate; NTP - National Toxicology Program; NZIoC - New Zealand Inventory of Chemicals; OECD - Organization for Economic Co-operation and Development; OPPTS - Office of Chemical Safety and Pollution Prevention; PBT - Persistent, Bioaccumulative and Toxic substance; PICCS - Philippines Inventory of Chemicals and Chemical Substances; (Q)SAR - (Quantitative) Structure Activity Relationship; RCRA - Resource Conservation and Recovery Act; REACH - Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals; RQ - Reportable Quantity; SADT - Self-Accelerating Decomposition Temperature; SARA - Superfund Amendments and Reauthorization Act; SDS - Safety Data Sheet; TCSI - Taiwan Chemical Substance Inventory; TSCA - Toxic Substances Control Act (United States); UN - United Nations; UNRTDG - United Nations Recommendations on the Transport of Dangerous Goods; vPvB - Very Persistent and Very Bioaccumulative

Sources of key data used to compile the Material Safety Data Sheet : Internal technical data, data from raw material SDSs, OECD eChem Portal search results and European Chemicals Agency, <http://echa.europa.eu/>

Revision Date : 09/13/2017

Items where changes have been made to the previous version are highlighted in the body of this document by two vertical lines.

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and shall not be considered a warranty or quality specification of any type. The information provided relates only to the specific material identified at the top of this SDS and may not be valid when the SDS material is used in combination with any other materials or in any process, unless specified in the text. Material users should review the information and recommendations in the specific context of their intended manner of handling, use, processing and storage, including an assessment of the appropriateness of the SDS material in the user's end product, if applicable.

US / Z8

# SAFETY DATA SHEET



## XIAMETER(R) OFS-6040 SILANE

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Date of first issue: 01/05/2015

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### SECTION 1. IDENTIFICATION

Product name : XIAMETER(R) OFS-6040 SILANE  
Product code : 000000000004088617

#### Manufacturer or supplier's details

Company name of supplier : Dow Corning Corporation  
Address : South Saginaw Road  
Midland Michigan 48686  
Telephone : (989) 496-6000  
Emergency telephone : 24 Hour Emergency Telephone : (989) 496-5900  
CHEMTREC : (800) 424-9300

#### Recommended use of the chemical and restrictions on use

Recommended use : Adhesive, binding agents


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### SECTION 2. HAZARDS IDENTIFICATION

#### GHS classification in accordance with 29 CFR 1910.1200

Serious eye damage : Category 1

#### GHS label elements

Hazard pictograms : 

Signal Word : Danger

Hazard Statements : H318 Causes serious eye damage.

Precautionary Statements : **Prevention:**  
P280 Wear eye protection/ face protection.  
**Response:**  
P305 + P351 + P338 + P310 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.

#### Other hazards

None known.

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### SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

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Substance / Mixture : Substance  
Chemical nature : Organosilane  
Substance name : Glycidoxypropyl trimethoxysilane  
CAS-No. : 2530-83-8

### Hazardous ingredients

Chemical name	CAS-No.	Concentration (% w/w)
Glycidoxypropyl trimethoxysilane	2530-83-8	>= 99 - <= 100

### SECTION 4. FIRST AID MEASURES

General advice : In the case of accident or if you feel unwell, seek medical advice immediately.  
When symptoms persist or in all cases of doubt seek medical advice.

If inhaled : If inhaled, remove to fresh air.  
Get medical attention if symptoms occur.

In case of skin contact : In case of contact, immediately flush skin with plenty of water.  
Remove contaminated clothing and shoes.  
Get medical attention.  
Wash clothing before reuse.  
Thoroughly clean shoes before reuse.

In case of eye contact : In case of contact, immediately flush eyes with plenty of water for at least 15 minutes.  
If easy to do, remove contact lens, if worn.  
Get medical attention immediately.

If swallowed : If swallowed, DO NOT induce vomiting.  
Get medical attention if symptoms occur.  
Rinse mouth thoroughly with water.

Most important symptoms and effects, both acute and delayed : Causes serious eye damage.

Protection of first-aiders : First Aid responders should pay attention to self-protection, and use the recommended personal protective equipment when the potential for exposure exists.

Notes to physician : Treat symptomatically and supportively.

### SECTION 5. FIRE-FIGHTING MEASURES

Suitable extinguishing media : Water spray  
Alcohol-resistant foam  
Carbon dioxide (CO<sub>2</sub>)

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- Dry chemical
- Unsuitable extinguishing media : None known.
- Specific hazards during fire fighting : Exposure to combustion products may be a hazard to health.
- Hazardous combustion products : Carbon oxides  
Silicon oxides  
Formaldehyde
- Specific extinguishing methods : Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.  
Use water spray to cool unopened containers.  
Remove undamaged containers from fire area if it is safe to do so.  
Evacuate area.
- Special protective equipment for fire-fighters : In the event of fire, wear self-contained breathing apparatus.  
Use personal protective equipment.
- 

### SECTION 6. ACCIDENTAL RELEASE MEASURES

- Personal precautions, protective equipment and emergency procedures : Use personal protective equipment.  
Follow safe handling advice and personal protective equipment recommendations.
- Environmental precautions : Discharge into the environment must be avoided.  
Prevent further leakage or spillage if safe to do so.  
Prevent spreading over a wide area (e.g., by containment or oil barriers).  
Retain and dispose of contaminated wash water.  
Local authorities should be advised if significant spillages cannot be contained.
- Methods and materials for containment and cleaning up : Soak up with inert absorbent material.  
For large spills, provide diking or other appropriate containment to keep material from spreading. If diked material can be pumped, store recovered material in appropriate container.  
Clean up remaining materials from spill with suitable absorbent.  
Local or national regulations may apply to releases and disposal of this material, as well as those materials and items employed in the cleanup of releases. You will need to determine which regulations are applicable.  
Sections 13 and 15 of this SDS provide information regarding certain local or national requirements.
- 

### SECTION 7. HANDLING AND STORAGE

- Technical measures : See Engineering measures under EXPOSURE
-

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## CONTROLS/PERSONAL PROTECTION section.

- Local/Total ventilation : Use only with adequate ventilation.
- Advice on safe handling : Do not get on skin or clothing.  
 Avoid inhalation of vapor or mist.  
 Do not swallow.  
 Do not get in eyes.  
 Handle in accordance with good industrial hygiene and safety practice, based on the results of the workplace exposure assessment  
 Keep container tightly closed.  
 Keep away from water.  
 Protect from moisture.  
 Take care to prevent spills, waste and minimize release to the environment.
- Conditions for safe storage : Keep in properly labeled containers.  
 Keep tightly closed.  
 Store in accordance with the particular national regulations.
- Materials to avoid : Do not store with the following product types:  
 Strong oxidizing agents

## SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

## Ingredients with workplace control parameters

Ingredients	CAS-No.	Value type (Form of exposure)	Control parameters / Permissible concentration	Basis
Glycidoxypropyl trimethoxysilane	2530-83-8	TWA	0.5 ppm	DCC OEL

## Occupational exposure limits of decomposition products

Ingredients	CAS-No.	Value type (Form of exposure)	Control parameters / Permissible concentration	Basis
Methanol	67-56-1	TWA	200 ppm	ACGIH
		STEL	250 ppm	ACGIH
		TWA	200 ppm 260 mg/m <sup>3</sup>	NIOSH REL
		ST	250 ppm 325 mg/m <sup>3</sup>	NIOSH REL
		TWA	200 ppm 260 mg/m <sup>3</sup>	OSHA Z-1

- Engineering measures : Processing may form hazardous compounds (see section 10).  
 Ensure adequate ventilation, especially in confined areas.  
 Minimize workplace exposure concentrations.

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### Personal protective equipment

Respiratory protection : General and local exhaust ventilation is recommended to maintain vapor exposures below recommended limits. Where concentrations are above recommended limits or are unknown, appropriate respiratory protection should be worn. Follow OSHA respirator regulations (29 CFR 1910.134) and use NIOSH/MSHA approved respirators. Protection provided by air purifying respirators against exposure to any hazardous chemical is limited. Use a positive pressure air supplied respirator if there is any potential for uncontrolled release, exposure levels are unknown, or any other circumstance where air purifying respirators may not provide adequate protection.

### Hand protection

Material : Chemical-resistant gloves

Remarks : Choose gloves to protect hands against chemicals depending on the concentration specific to place of work. Breakthrough time is not determined for the product. Change gloves often! For special applications, we recommend clarifying the resistance to chemicals of the aforementioned protective gloves with the glove manufacturer. Wash hands before breaks and at the end of workday.

Eye protection : Wear the following personal protective equipment:  
Chemical resistant goggles must be worn.  
If splashes are likely to occur, wear:  
Face-shield

Skin and body protection : Select appropriate protective clothing based on chemical resistance data and an assessment of the local exposure potential.  
Skin contact must be avoided by using impervious protective clothing (gloves, aprons, boots, etc).

Hygiene measures : Ensure that eye flushing systems and safety showers are located close to the working place.  
When using do not eat, drink or smoke.  
Wash contaminated clothing before re-use.  
These precautions are for room temperature handling. Use at elevated temperature or aerosol/spray applications may require added precautions.  
For further information regarding the use of silicones / organic oils in consumer aerosol applications, please refer to the guidance document regarding the use of these type of materials in consumer aerosol applications that has been developed by the silicone industry ([www.SEHSC.com](http://www.SEHSC.com)) or contact the Dow Corning customer service group.

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### SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

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Appearance : liquid

Color : Colorless to pale yellow

Odor : aromatic

Odor Threshold : No data available

pH : No data available

Melting point/freezing point : No data available

Initial boiling point and boiling range :  $\geq 250$  °C

Flash point :  $> 94$  °C  
Method: Seta closed cup

Evaporation rate : No data available

Flammability (solid, gas) : Not applicable

Flammability (liquids) : Not applicable

Self-ignition : The substance or mixture is not classified as pyrophoric. The substance or mixture is not classified as self heating.

Upper explosion limit / Upper flammability limit : No data available

Lower explosion limit / Lower flammability limit : No data available

Vapor pressure : No data available

Relative vapor density : No data available

Relative density : 1.07

Solubility(ies)  
Water solubility : No data available

Partition coefficient: n-octanol/water : No data available

Autoignition temperature : No data available

Decomposition temperature : No data available

Viscosity  
Viscosity, kinematic : 3.09 mm<sup>2</sup>/s (25 °C)

Explosive properties : Not explosive

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Oxidizing properties : The substance or mixture is not classified as oxidizing.  
Molecular weight : No data available  
Particle size : Not applicable

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### SECTION 10. STABILITY AND REACTIVITY

Reactivity : Not classified as a reactivity hazard.  
Chemical stability : Stable under normal conditions.  
Possibility of hazardous reactions : Use at elevated temperatures may form highly hazardous compounds.  
Can react with strong oxidizing agents.  
When heated to temperatures above 150 °C (300 °F) in the presence of air, product can form formaldehyde vapors.  
Safe handling conditions may be maintained by keeping vapor concentrations within the occupational exposure limit for formaldehyde.  
See OSHA formaldehyde standard, 29 CFR 1910.1048  
Formaldehyde may cause cancer. It is also toxic by inhalation, skin absorption and ingestion, corrosive to skin and eyes, and may cause skin sensitization and respiratory irritation.  
Hazardous decomposition products will be formed upon contact with water or humid air.  
Hazardous decomposition products will be formed at elevated temperatures.  
Conditions to avoid : Exposure to moisture.  
Incompatible materials : Oxidizing agents  
Water

#### **Hazardous decomposition products**

Contact with water or humid air : Methanol  
Thermal decomposition : Formaldehyde

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### SECTION 11. TOXICOLOGICAL INFORMATION

#### **Information on likely routes of exposure**

Inhalation  
Skin contact  
Ingestion  
Eye contact

#### **Acute toxicity**

Not classified based on available information.

#### **Product:**

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Acute inhalation toxicity : LC50: > 5.3 mg/l  
Exposure time: 4 h  
Test atmosphere: dust/mist  
Remarks: On basis of test data.

Acute dermal toxicity : Acute toxicity estimate: 4,276 mg/kg  
Method: Calculation method

### Ingredients:

#### **Glycidoxypropyl trimethoxysilane:**

Acute oral toxicity : LD50 (Rat): 7.5 ml/kg  
Assessment: The substance or mixture has no acute oral toxicity  
Remarks: On basis of test data.

Acute inhalation toxicity : LC50 (Rat): > 5.3 mg/l  
Exposure time: 4 h  
Test atmosphere: dust/mist  
Remarks: On basis of test data.

Acute dermal toxicity : LD50 (Rabbit): 3.97 ml/kg  
Remarks: On basis of test data.

#### **Skin corrosion/irritation**

Not classified based on available information.

### Product:

Species: Rabbit  
Result: Mild skin irritation  
Remarks: On basis of test data.

### Ingredients:

#### **Glycidoxypropyl trimethoxysilane:**

Species: Rabbit  
Result: Mild skin irritation  
Remarks: On basis of test data.

#### **Serious eye damage/eye irritation**

Causes serious eye damage.

### Product:

Species: Rabbit  
Result: Irreversible effects on the eye  
Remarks: On basis of test data.

### Ingredients:

#### **Glycidoxypropyl trimethoxysilane:**

Species: Rabbit  
Result: Irreversible effects on the eye

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Remarks: On basis of test data.

### Respiratory or skin sensitization

#### Skin sensitization

Not classified based on available information.

#### Respiratory sensitization

Not classified based on available information.

#### Product:

Assessment: Does not cause skin sensitization.

Test Type: Human repeat insult patch test (HRIPT)

Species: Humans

Result: negative

Remarks: On basis of test data.

Test Type: Maximization Test

Species: Guinea pig

Result: negative

Remarks: On basis of test data.

#### Ingredients:

#### Glycidoxypropyl trimethoxysilane:

Assessment: Does not cause skin sensitization.

Test Type: Maximization Test

Species: Guinea pig

Result: negative

Remarks: On basis of test data.

Test Type: Human repeat insult patch test (HRIPT)

Species: Humans

Result: negative

Remarks: On basis of test data.

#### Germ cell mutagenicity

Not classified based on available information.

#### Product:

Genotoxicity in vitro : Test Type: Bacterial reverse mutation assay (AMES)  
 Result: positive  
 Remarks: On basis of test data.

Genotoxicity in vivo : Test Type: sister chromatid exchange assay  
 Species: Rabbit  
 Application Route: Intravenous injection  
 Result: negative  
 Remarks: On basis of test data.

Germ cell mutagenicity - Assessment : Animal testing did not show any mutagenic effects.

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**Ingredients:****Glycidoxypropyl trimethoxysilane:**

Genotoxicity in vitro : Test Type: In vitro sister chromatid exchange assay in mammalian cells  
 Result: positive  
 Remarks: On basis of test data.

Test Type: Bacterial reverse mutation assay (AMES)  
 Result: positive  
 Remarks: On basis of test data.

Test Type: Mutagenicity (in vitro mammalian cytogenetic test)  
 Result: positive  
 Remarks: On basis of test data.

Genotoxicity in vivo : Test Type: sister chromatid exchange assay  
 Species: Rabbit  
 Application Route: Intraperitoneal injection  
 Result: negative  
 Remarks: On basis of test data.

Germ cell mutagenicity - Assessment : Animal testing did not show any mutagenic effects.

**Carcinogenicity**

Not classified based on available information.

**Ingredients:****Glycidoxypropyl trimethoxysilane:**

Species: Mouse  
 Application Route: Skin contact  
 Result: negative  
 Remarks: On basis of test data.

Carcinogenicity - Assessment : Animal testing did not show any carcinogenic effects.

**IARC**

No ingredient of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

**OSHA**

No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

**NTP**

No ingredient of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

**Reproductive toxicity**

Not classified based on available information.

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**Ingredients:****Glycidoxypropyl trimethoxysilane:**

Effects on fertility	:	Test Type: One-generation reproduction toxicity study Species: Rat, male and female Application Route: Ingestion Symptoms: No effects on fertility. Remarks: On basis of test data.
Effects on fetal development	:	Test Type: Prenatal development toxicity study (teratogenicity) Species: Rat, female Application Route: Ingestion Symptoms: No effects on fetal development. Remarks: On basis of test data.
Reproductive toxicity - Assessment	:	No evidence of adverse effects on sexual function and fertility, or on development, based on animal experiments.

**STOT-single exposure**

Not classified based on available information.

**STOT-repeated exposure**

Not classified based on available information.

**Ingredients:****Glycidoxypropyl trimethoxysilane:**

Routes of exposure: inhalation (dust/mist/fume)	Assessment: No significant health effects observed in animals at concentrations of 0.2 mg/l/6h/d or less.
Routes of exposure: Ingestion	Assessment: No significant health effects observed in animals at concentrations of 100 mg/kg bw or less.

**Repeated dose toxicity****Ingredients:****Glycidoxypropyl trimethoxysilane:**

Species: Rat	Application Route: inhalation (dust/mist/fume)	Remarks: On basis of test data.
Species: Rat	Application Route: Ingestion	Remarks: On basis of test data.

**Aspiration toxicity**

Not classified based on available information.

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**Further information****Ingredients:****Glycidoxypropyl trimethoxysilane:**

Remarks: Glycidoxypropyltrimethoxysilane was found to be genetically active in Ames reverse mutation assays, In Vitro sister chromatid exchange assays, and an In Vivo mouse micronucleus assay. This ingredient was not genetically active in an In Vivo cytogenetic assay (mice) or in an In Vivo sister chromatid exchange assay (rabbits, rats). The potential relevance of these data to humans is not known.

**SECTION 12. ECOLOGICAL INFORMATION****Ecotoxicity****Ingredients:****Glycidoxypropyl trimethoxysilane:**

Toxicity to fish	:	LC50 (Oncorhynchus mykiss (rainbow trout)): 237 mg/l
		Exposure time: 96 h
		LC50 (Cyprinus carpio (Carp)): 276 mg/l
		Exposure time: 96 h
Toxicity to daphnia and other aquatic invertebrates	:	EC50 (Simocephalus vetulus): 324 mg/l
		Exposure time: 48 h
		EC50 (Daphnia magna (Water flea)): 710 mg/l
		Exposure time: 48 h
		Method: OECD Test Guideline 202 Remarks: On basis of test data.
Toxicity to algae	:	ErC50 (Anabaena flos-aquae): 119 mg/l
		Exposure time: 72 h
Toxicity to daphnia and other aquatic invertebrates (Chronic toxicity)	:	NOEC (Daphnia magna (Water flea)): > 100 mg/l
		Exposure time: 21 d
Toxicity to microorganisms	:	EC50: > 100 mg/l
		Method: OECD Test Guideline 209

**Persistence and degradability****Ingredients:****Glycidoxypropyl trimethoxysilane:**

Biodegradability	:	Result: Not readily biodegradable.
		Biodegradation: 37 %
		Exposure time: 28 d
		Method: OECD Test Guideline 301A
Stability in water	:	Degradation half life: 6.5 h (24.5 °C) pH: 7
		Method: OECD Test Guideline 111

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II

### Bioaccumulative potential

#### Ingredients:

#### Glycidoxypropyl trimethoxysilane:

Partition coefficient: n-octanol/water : log Pow: -2.6

#### Mobility in soil

No data available

#### Other adverse effects

No data available

---

### SECTION 13. DISPOSAL CONSIDERATIONS

#### Disposal methods

Resource Conservation and Recovery Act (RCRA) : This product has been evaluated for RCRA characteristics and does not meet the criteria of hazardous waste if discarded in its purchased form.

Waste from residues : Dispose of in accordance with local regulations.

Contaminated packaging : Empty containers should be taken to an approved waste handling site for recycling or disposal.  
If not otherwise specified: Dispose of as unused product.

---

### SECTION 14. TRANSPORT INFORMATION

#### International Regulations

##### UNRTDG

Not regulated as a dangerous good

##### IATA-DGR

Not regulated as a dangerous good

##### IMDG-Code

Not regulated as a dangerous good

#### Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

Not applicable for product as supplied.

#### Domestic regulation

##### 49 CFR

Not regulated as a dangerous good

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### SECTION 15. REGULATORY INFORMATION

#### EPCRA - Emergency Planning and Community Right-to-Know

#### CERCLA Reportable Quantity

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Ingredients	CAS-No.	Component RQ (lbs)	Calculated product RQ (lbs)
Methanol	67-56-1	5000	*

\*: Calculated RQ exceeds reasonably attainable upper limit.

### SARA 304 Extremely Hazardous Substances Reportable Quantity

This material does not contain any components with a section 304 EHS RQ.

### SARA 302 Extremely Hazardous Substances Threshold Planning Quantity

This material does not contain any components with a section 302 EHS TPQ.

**SARA 311/312 Hazards** : Serious eye damage or eye irritation

**SARA 313** : This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

### US State Regulations

#### Pennsylvania Right To Know

Glycidoxypropyl trimethoxysilane	2530-83-8
Methanol	67-56-1

#### California Prop. 65

WARNING: This product can expose you to chemicals including Methanol, which is/are known to the State of California to cause birth defects or other reproductive harm. For more information go to [www.P65Warnings.ca.gov](http://www.P65Warnings.ca.gov).

### The ingredients of this product are reported in the following inventories:

- NZIoC : All ingredients listed or exempt.
- REACH : For purchases from Dow Corning EU legal entities, all ingredients are currently pre/registered or exempt under REACH. Please refer to section 1 for recommended uses. For purchases from non-EU Dow Corning legal entities with the intention to export into EEA please contact your DC representative/local office.
- TSCA : All chemical substances in this product are either listed on the TSCA Inventory or are in compliance with a TSCA Inventory exemption.
- AICS : All ingredients listed or exempt.
- IECSC : All ingredients listed or exempt.
- ENCS/ISHL : All components are listed on ENCS/ISHL or exempted from inventory listing.
- KECI : All ingredients listed, exempt or notified.
- PICCS : All ingredients listed or exempt.
- DSL : All chemical substances in this product comply with the CEPA 1999 and NSNR and are on or exempt from listing on the

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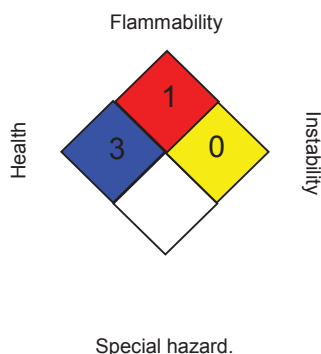
Canadian Domestic Substances List (DSL).

TCSI : All ingredients listed or exempt.

### SECTION 16. OTHER INFORMATION

#### Further information

##### NFPA:



##### HMIS® IV:

HEALTH	/	3
FLAMMABILITY		1
PHYSICAL HAZARD		0

HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. The "\*" represents a chronic hazard, while the "/" represents the absence of a chronic hazard.

#### Full text of other abbreviations

- ACGIH : USA. ACGIH Threshold Limit Values (TLV)
- DCC OEL : Dow Corning Guide
- NIOSH REL : USA. NIOSH Recommended Exposure Limits
- OSHA Z-1 : USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
- ACGIH / TWA : 8-hour, time-weighted average
- ACGIH / STEL : Short-term exposure limit
- DCC OEL / TWA : Time weighted average
- NIOSH REL / TWA : Time-weighted average concentration for up to a 10-hour workday during a 40-hour workweek
- NIOSH REL / ST : STEL - 15-minute TWA exposure that should not be exceeded at any time during a workday
- OSHA Z-1 / TWA : 8-hour time weighted average

AICS - Australian Inventory of Chemical Substances; ASTM - American Society for the Testing of Materials; bw - Body weight; CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act; CMR - Carcinogen, Mutagen or Reproductive Toxicant; DIN - Standard of the German Institute for Standardisation; DOT - Department of Transportation; DSL - Domestic Substances List (Canada); ECx - Concentration associated with x% response; EHS - Extremely Hazardous Substance; ELx - Loading rate associated with x% response; EmS - Emergency Schedule; ENCS - Existing and New Chemical Substances (Japan); ErCx - Concentration associated with x% growth rate response; ERG - Emergency Response Guide; GHS - Globally Harmonized System; GLP - Good Laboratory Practice; HMIS - Hazardous Materials Identification System; IARC - International Agency for Research on Cancer; IATA - International Air Transport Association; IBC - International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk; IC50 - Half maximal inhibitory concentration; ICAO - International Civil Aviation Organiza-

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tion; IECSC - Inventory of Existing Chemical Substances in China; IMDG - International Maritime Dangerous Goods; IMO - International Maritime Organization; ISHL - Industrial Safety and Health Law (Japan); ISO - International Organisation for Standardization; KECI - Korea Existing Chemicals Inventory; LC50 - Lethal Concentration to 50 % of a test population; LD50 - Lethal Dose to 50% of a test population (Median Lethal Dose); MARPOL - International Convention for the Prevention of Pollution from Ships; MSHA - Mine Safety and Health Administration; n.o.s. - Not Otherwise Specified; NFPA - National Fire Protection Association; NO(A)EC - No Observed (Adverse) Effect Concentration; NO(A)EL - No Observed (Adverse) Effect Level; NOELR - No Observable Effect Loading Rate; NTP - National Toxicology Program; NZIoC - New Zealand Inventory of Chemicals; OECD - Organization for Economic Co-operation and Development; OPPTS - Office of Chemical Safety and Pollution Prevention; PBT - Persistent, Bioaccumulative and Toxic substance; PICCS - Philippines Inventory of Chemicals and Chemical Substances; (Q)SAR - (Quantitative) Structure Activity Relationship; RCRA - Resource Conservation and Recovery Act; REACH - Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals; RQ - Reportable Quantity; SADT - Self-Accelerating Decomposition Temperature; SARA - Superfund Amendments and Reauthorization Act; SDS - Safety Data Sheet; TCSI - Taiwan Chemical Substance Inventory; TSCA - Toxic Substances Control Act (United States); UN - United Nations; UNRTDG - United Nations Recommendations on the Transport of Dangerous Goods; vPvB - Very Persistent and Very Bioaccumulative

Sources of key data used to compile the Material Safety Data Sheet : Internal technical data, data from raw material SDSs, OECD eChem Portal search results and European Chemicals Agency, <http://echa.europa.eu/>

Revision Date : 09/13/2017

Items where changes have been made to the previous version are highlighted in the body of this document by two vertical lines.

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and shall not be considered a warranty or quality specification of any type. The information provided relates only to the specific material identified at the top of this SDS and may not be valid when the SDS material is used in combination with any other materials or in any process, unless specified in the text. Material users should review the information and recommendations in the specific context of their intended manner of handling, use, processing and storage, including an assessment of the appropriateness of the SDS material in the user's end product, if applicable.

US / Z8

## APPENDIX B

# XIAMETER® OFS-6020 Silane

### Diaminofunctional silane

#### FEATURES

- Coupling agent
- Improved adhesion
- Increased wet and dry tensile strength and modulus to the composite
- Increased wet and dry flexural strength and modulus to the composite
- Increased wet and dry compressive strength
- Improved compatibility between inorganic filler and organic polymer

#### APPLICATIONS

- XIAMETER® OFS-6020 Silane has been found to be an effective coupling agent for clay reinforced elastomers such as natural and nitrile rubber. The silane-treated clay provides improvement in both physical and dynamic properties compared to similar cured elastomers containing untreated clay.
- XIAMETER OFS-6020 Silane has been reported to be an effective coupling agent for mineral reinforced nylon 6, nylon 6/6 and polybutyleneterephthalate.
- Fiberglass reinforced phenolic, melamine and epoxy thermoset composites, either as fiberglass finish or as resinous additive.
- As an additive to improve the performance of these types of thermoset resins when they are used as mineral binders in foundry and abrasive composite applications.
- Coupling agent for phenolic, melamine and other organic resins used as binders for glass and mineral wood insulation, abrasives and molding components.

#### TYPICAL PROPERTIES

Specification Writers: These values are not intended for use in preparing specifications. Please contact your local XIAMETER® sales representative prior to writing specifications on this product.

Property	Unit	Value
Appearance		Clear liquid
Flash point – closed cup	°C (°F)	85 (185)
Specific gravity at 25°C (77°F)	g/cm <sup>3</sup>	1.03
Refractive index		1.445
Neutral equivalents	g/eq	115
Color		Light straw
Viscosity	mm <sup>2</sup> /s	5

#### DESCRIPTION

XIAMETER OFS-6020 Silane possesses both organic and inorganic reactivity. XIAMETER OFS-6020 Silane can react with organic polymers and glass or other inorganic mineral surfaces.

For each specific application, the optimum level of additive should be determined by testing several concentrations. When used as an additive to epoxy coatings, this product improves adhesion of the coating, particularly in a very humid environment.

#### HOW TO USE

When used as a resin additive, generally the silane is added at a level of less than 1% based on the weight of the resin solids.

XIAMETER OFS-6020 Silane can be applied to inorganic surfaces, like other silanes, as a dilute aqueous solution (0.1% to 0.5% silane concentration).

Aqueous solutions can be prepared by simply adding the silane to water with stirring. However, poor agitation when adding XIAMETER OFS-6020 Silane to water can result in locally high concentration which may form gel particles. It is normally recommended that the silane solution be acidified to a pH of 3.0 to 4.5 with an organic acid, such as acetic acid, to obtain optimum performance of reinforcing material such as fiberglass.

Inorganic surfaces can be treated with the aqueous solution by either dipping or padding. In the case of siliceous mineral fillers, the mineral can be treated by slurring in the aqueous solution or mixed with the silane at very high shear without any additional solvent.

After applying the silane, the glass or mineral surface can be air dried or dried briefly at 105° to 120°C (221° to 248°F) to effect complete condensation of silanol groups at the surface and to remove water and/or traces of methanol. Optimum application and drying conditions, such as time and temperature, should be determined for each application prior to use in a commercial process.

## PRODUCT SAFETY INFORMATION

PRODUCT SAFETY INFORMATION REQUIRED FOR SAFE USE IS NOT INCLUDED IN THIS DOCUMENT. BEFORE HANDLING, READ PRODUCT AND SAFETY DATA SHEETS AND CONTAINER LABELS FOR SAFE USE, PHYSICAL, ENVIRONMENTAL, AND HEALTH HAZARD INFORMATION. THE SAFETY DATA SHEET IS AVAILABLE ON THE XIAMETER WEBSITE AT [WWW.XIAMETER.COM](http://WWW.XIAMETER.COM).

## STORAGE

Product should be stored at or below 25°C (77°F) in original, unopened containers. The most up-to-date shelf life information can be found on the XIAMETER Web site in the Product Detail page under Sales Specification.

Keep away from heat and open flame.

## LIMITATIONS

This product is neither tested nor represented as suitable for medical or pharmaceutical uses. Not intended for human injection.

## LIMITED WARRANTY INFORMATION – PLEASE READ CAREFULLY

The information contained herein is offered in good faith and is believed to be accurate. However, because conditions and methods of use of our products are beyond our control, this information should not be used in substitution for customer's tests to ensure that our products are safe, effective, and fully satisfactory for the intended end use. Suggestions of use shall not be taken as inducements to infringe any patent.

Dow Corning's sole warranty is that our products will meet the sales specifications in effect at the time of shipment.

Your exclusive remedy for breach of such warranty is limited to refund of purchase price or replacement of any product shown to be other than as warranted.

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**DOW CORNING DISCLAIMS LIABILITY FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES.**

# XIAMETER® OFS-6040 Silane

**Coupling agent to improve adhesion of organic resins to inorganic surfaces**

## FEATURES

- Epoxy reactivity
- Methoxysilyl inorganic reactivity

## BENEFITS

- Improves adhesion
- Increases composite strength properties
- Increased composite wet and dry tensile strength and modulus
- Increased composite wet and dry flexural strength and modulus
- Increased wet and dry compressive strength
- Better appearance
- Better filler wet-out and dispersion
- Lower viscosity of filled liquid resins
- Improved processability

## COMPOSITION

- $\gamma$ -Glycidoxypropyltrimethoxysilane

## APPLICATIONS

- Used in a wide variety of surface treatment and coupling agent applications
- Used as an adhesion promoter for many types of resins
- Compatible with a broad range of resins and fillers

## TYPICAL PROPERTIES

Specification Writers: These values are not intended for use in preparing specifications. Please contact your local XIAMETER sales representative prior to writing specifications on this product.

Test	Unit	Value
Appearance		Clear liquid
Color	APHA	50
Viscosity	cst	3
Specific gravity at 25°C (77°F)		1.07
Refractive index		1.428
Flash point-closed cup	°C (°F)	>101 (>213)
Purity by GC	%	>98.5
Chloride	ppm	<10
Molecular weight	g/mol	236.34
CAS #		2530-83-8

## DESCRIPTION

XIAMETER® OFS-6040 Silane is a bifunctional silane containing a glycidoxy reactive organic group and a trimethoxysilyl inorganic group. It is designated  $\gamma$ -glycidoxypropyltrimethoxysilane. This glycidoxy functional silane is reactive with many different types of organic polymers.

## USES

XIAMETER® OFS-6040 Silane possesses both organic and inorganic reactivity that allows it to react with or “couple” organic polymers and inorganic surface. This dual reactivity should be considered when using XIAMETER® OFS-6040 Silane in specific applications.

XIAMETER® OFS-6040 Silane is particularly recommended as:

- A treatment on glass fiber for use in reinforced plastics
- A treatment on mineral surfaces for use in mineral filled plastics
- An adhesion promoter to enhance the bonding of a polymer coating, paint or adhesive to glass, metals or other polymer surfaces.

For example, XIAMETER® OFS-6040 Silane is used in the finish on fiberglass rovings. Uses include fiberglass reinforced epoxy resin composites with benefits such as improved physical properties, especially the wet strength, of the composite.

XIAMETER® OFS-6040 Silane is effective in improving the physical properties of a mineral-filled polymer such as silica-filled epoxy resins.

XIAMETER® OFS-6040 Silane is also recommended as an additive to improve the adhesion of acrylic latex caulks.

Other polymers that are receptive to XIAMETER® OFS-6040 Silane are urethanes, acrylics, polysulfides and nylon.

## HOW TO USE

XIAMETER® OFS-6040 Silane can be applied to inorganic surfaces as a dilute aqueous solution (0.1 to 0.5% silane concentration). Aqueous solutions are prepared by adjusting the pH of the water to about 4.5 with acetic acid and then adding the silane and stirring. After adding the silane to the acidified water, it is necessary to stir the mixture for about 15 minutes before it hydrolyses and forms a clear homogeneous solution. Higher concentrations of XIAMETER® OFS-6040 Silane in water are not stable indefinitely and after standing several days may deposit an oily phase of condensed polysiloxane. It is recommended that aqueous solutions of XIAMETER® OFS-6040 Silane be used within 24 hours of preparation. Old solutions will begin to haze – an indication of a significant amount of siloxane condensation.

XIAMETER® OFS-6040 Silane can also be applied as a solution in many common organic solvents. Solubility and stability of a specific organic solvent should, however, be verified before use in a commercial process.

In the case of mineral fillers, the mineral can be treated by mixing with the silane at very low shear for several minutes without any additional solvent. The silane can be diluted in water or a solvent as described above.

After applying the silane, the glass or mineral surface should be dried for 5 to 15 minutes at 104°C to 121°C (220°F to 250°F) to drive the condensation of silanol groups at the surface and to remove traces of methanol from hydrolysis of the methoxysilane. Optimum application and drying

Conditions such as time and temperature should be determined for each application prior to use in a commercial process.

For use as a primer, a typical formulation includes 49.5 parts of XIAMETER® OFS-6040 Silane and 0.5 parts of an organic amine, such as benzyldimethylamine, (mixture A) are diluted with about 950 parts methanol, isopropanol or ether glycol.

Alternatively, a prehydrolyzed primer may be prepared by adding 5 parts water and 1,000 parts of the above primer solution. In both cases, the primer solution is applied to a solid surface such as glass or metal, and a polymer is heat pressed or cured on the surface.

XIAMETER® OFS-6040 Silane can be added directly to a resin system at 0.5 to 2.0 pph to promote unprimed adhesion.

## Epoxy Reactivity

The epoxy group of XIAMETER® OFS-6040 Silane has a reactivity similar to that of organic epoxides. That is, it will undergo ring-opening reactions with acids, amines, alcohols, thiols and other epoxides. The presence of acid or basic catalysts facilitates this reactivity.

## Trimethoxysilyl Reactivity

The trimethoxysilyl portion of XIAMETER® OFS-6040 Silane undergoes the typical chemistry of alkoxyxilanes. The methoxysilyl group is subject to hydrolysis in water or water/alcohol solutions. The initial product of hydrolysis is a silanetriol. Silanetriols are moderately stable at dilute concentrations in polar solvents such as water and alcohols. Dispersions of XIAMETER® OFS-6040 Silane are more stable and have more favorable orientation on siliceous surfaces if they are applied from a slightly acid solution. Silanol groups are capable of condensing with hydroxyl groups at the surface of glass and siliceous minerals.

After condensing with the mineral surface, the remaining silanol groups are capable of hydrogen bonding or condensing with adjacent silanol groups. By this combination of covalent and hydrogen bonding, the coupling agent is bonded to the inorganic surface, and modifies it so that it is organoreactive.

## PRODUCT SAFETY INFORMATION

PRODUCT SAFETY INFORMATION REQUIRED FOR SAFE USE IS NOT INCLUDED IN THIS DOCUMENT. BEFORE HANDLING, READ PRODUCT AND MATERIAL SAFETY DATA SHEETS AND CONTAINER LABELS FOR SAFE USE, PHYSICAL, ENVIRONMENTAL, AND HEALTH HAZARD INFORMATION. THE MATERIAL SAFETY DATA SHEET IS AVAILABLE ON THE XIAMETER WEBSITE AT [WWW.XIAMETER.COM](http://WWW.XIAMETER.COM).

## USABLE LIFE AND STORAGE

When stored at or below 25oC (77oF) in the original unopened containers, this product has a usable life of 36 months from the date of production.

After opening, XIAMETER® OFS-6040 Silane should be protected from atmospheric moisture to prevent gelation.

## LIMITATIONS

This product is neither tested nor represented as suitable for medical or Pharmaceutical uses.

**LIMITED WARRANTY  
INFORMATION – PLEASE  
READ CAREFULLY**

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Dow Corning's sole warranty is that *Dow Corning* or XIAMETER products will meet the sales specifications in effect at the time of shipment.

Your exclusive remedy for breach of such warranty is limited to refund of purchase price or replacement of any product shown to be other than as warranted.

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DISCLAIMS ANY OTHER  
EXPRESS OR IMPLIED  
WARRANTY OF FITNESS FOR A  
PARTICULAR PURPOSE OR  
MERCHANTABILITY.**

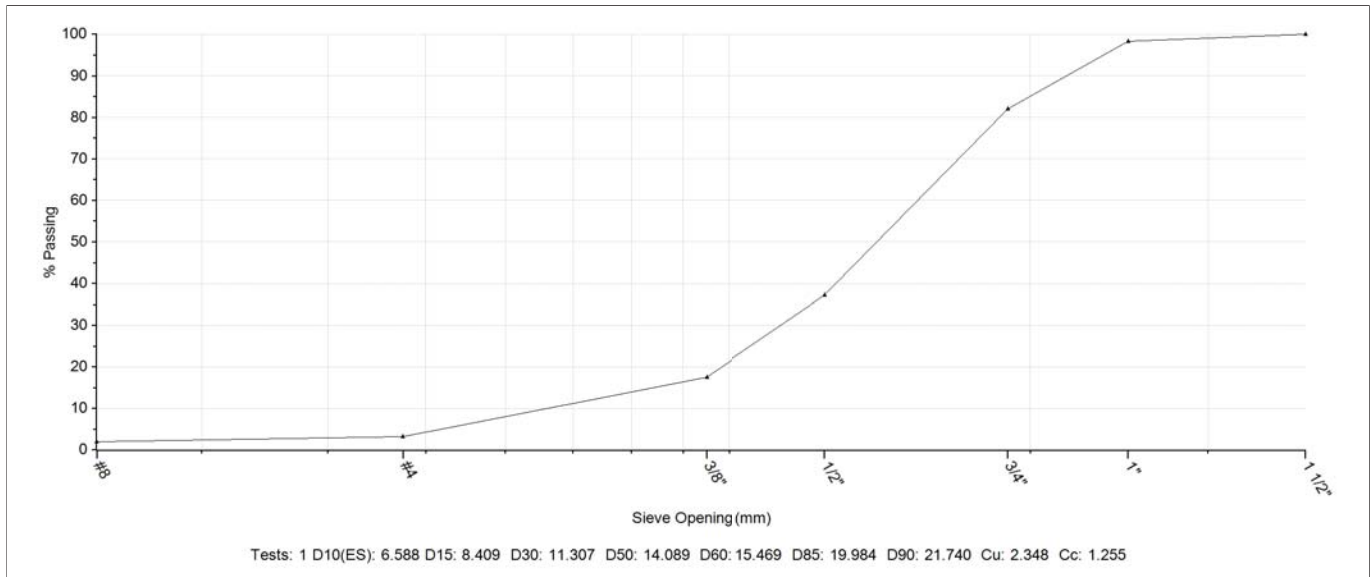
**DOW CORNING DISCLAIMS  
LIABILITY FOR ANY  
INCIDENTAL OR  
CONSEQUENTIAL DAMAGES.**

## APPENDIX C

# Basic Quality Statistical Summary Report

Plant E103-ATHENS GEORGIA  
 Product 030007-#57  
 Specification GADOT 57  
 Period 01/01/2016 - 11/02/2016

Sieve/Test	Tests	Average	St Dev	Target	Specification
1 1/2" (37.5mm)	287	100.0	0.00	100-100\100	100-100
1" (25mm)	287	98.3	0.77	97-100\97	95-100
3/4" (19mm)	287	82.0	4.96		
1/2" (12.5mm)	287	37.2	4.44	32-48\34	25-60
3/8" (9.5mm)	287	17.5	4.49		
#4 (4.75mm)	287	3.3	1.06	0-5\4	0-10
#8 (2.36mm)	287	2.0	0.48	0-2.6\2.6	0-5
Pan	286	0.00	0.000		



Query Query Selections  
 Date Created 11/02/2016  
 Date Range 01/01/2016 - 11/02/2016  
 Plant ATHENS GEORGIA  
 Sample Type Shipping  
 Sample Method Stockpile

## APPENDIX D

### Concrete Mixture Design Spreadsheet

Volume Replacement of Rock with Tire Rubber Chips	0%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	0.00	0.00

#### Mix Proportion (SSD)

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	611.0	13.68%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	40.29%	10.89	0.403	18	16.20
Sand	1135.81	25.42%	6.87	0.254	18	10.22
New Rock Qty.	1800.00	40.29%	10.89	0.403	18	16.20
Tire Chip Rubber	0.00	0.00%	0.00	0.000	400	0.00
Water	256.62	5.74%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4467.62		27.00	1.00	-	-
					Total Cost =	79.36

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Moisture Content			
sand mc (%)	0.18	mc-ssd	-0.01
rock mc (%)	0.13	mc-ssd	-0.0036

#### Mix Characteristics

w/c	0.42
Unit Weight (pcf)	165.5
Cementitious material (lbs)	611

#### Material Properties

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

#### Batch Weights (yd<sup>3</sup>)

Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1794	lb
Crumb Rubber	0	lb
Sand	1120	lb
Water	278	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml

#### Testing Specimens Required

Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
	Total	0.96
	x 1.15	1.11

#### Batch Weights (ft<sup>3</sup>)

Batch size	1.11	cf
Cement	25.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock Qty.	73.6	lb
Crumb Rubber	0.0	lb
Sand	46.0	lb
Water	11.4	lb
AEA	0.0	mL
HRWRA	51.9	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	10%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	180.00	76.08

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Correction	Unit Cost (\$/td)	Amount (\$)
Cement	611.0	14.00%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	41.25%	10.89	0.403	18	16.20
Sand	1135.81	26.03%	6.87	0.254	18	10.22
New Rock	1620.00	37.12%	9.80	0.363	18	14.58
Tire Chip R	76.08	1.74%	1.09	0.040	400	15.22
Water	256.62	5.88%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4363.70		27.00	1.00	-	-
					Total Cost =	92.95

**ONLY CHANGE YELLOW BOXES**

Moisture Content		
sand mc (%)	0.18	mc-ssd -0.01
rock mc (%)	0.13	mc-ssd -0.0036

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	161.6
Cementitious material (C)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Material	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight (lb)	Unit
Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	1614	lb
Crumb Rub	76	lb
Sand	1120	lb
Water	278	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml

**Testing Specimens Required**

Specimen Type	Quantity	Weight (lb)
Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Pounding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Material	Weight (lb)	Unit
Batch size	1.11	cf
Cement	25.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock	66.2	lb
Crumb Rub	3.1	lb
Sand	46.0	lb
Water	11.4	lb
AEA	0.0	mL
HRWRA	51.9	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	20%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	360.00	152.15

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	611.0	14.34%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	42.26%	10.89	0.403	18	16.20
Sand	1135.81	26.66%	6.87	0.254	18	10.22
New Rock	1440.00	33.80%	8.71	0.323	18	12.96
Tire Chip R	152.15	3.57%	2.18	0.081	400	30.43
Water	256.62	6.02%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4259.77		27.00	1.00	-	-
Total Cost =					106.55	

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Moisture Content			
sand mc (%)	0.18	mc-ssd	-0.01
rock mc (%)	0.13	mc-ssd	-0.0036

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	157.8
Cementitious material (C)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Material	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	1435	lb
Crumb Rub	152	lb
Sand	1120	lb
Water	278	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml

**Testing Specimens Required**

Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.11	cf
Cement	25.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock	58.9	lb
Crumb Rub	6.2	lb
Sand	46.0	lb
Water	11.4	lb
AEA	0.0	mL
HRWRA	51.9	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	30%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	540.00	228.23

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	611.0	14.70%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	43.31%	10.89	0.403	18	16.20
Sand	1135.81	27.33%	6.87	0.254	18	10.22
New Rock	1260.00	30.32%	7.62	0.282	18	11.34
Tire Chip R	228.23	5.49%	3.27	0.121	400	45.65
Water	256.62	6.17%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4155.85		27.00	1.00	-	-
Total Cost =					120.14	

**ONLY CHANGE YELLOW BOXES**

Moisture Content			
sand mc (%)	0.18	mc-ssd	-0.01
rock mc (%)	0.13	mc-ssd	-0.0036

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	153.9
Cementitious material (C)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Ma	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	1255	lb
Crumb Rub	227	lb
Sand	1120	lb
Water	278	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	5.5	fl oz./cwt
HRWRA	994	ml

**Testing Specimens Rec**

Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.11	cf
Cement	25.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock	51.5	lb
Crumb Rub	9.3	lb
Sand	46.0	lb
Water	11.4	lb
AEA	0.0	mL
HRWRA	40.8	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	40%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	720.00	304.30

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	611.0	15.08%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	44.42%	10.89	0.403	18	16.20
Sand	1135.81	28.03%	6.87	0.254	18	10.22
New Rock	1080.00	26.65%	6.53	0.242	18	9.72
Tire Chip R	304.30	7.51%	4.35	0.161	400	60.86
Water	256.62	6.33%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4051.92		27.00	1.00	-	-
Total Cost =					133.74	

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Moisture Content			
sand mc (%)	0.18	mc-ssd	-0.01
rock mc (%)	0.13	mc-ssd	-0.0036

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	150.1
Cementitious material (C)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Ma	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	1076	lb
Crumb Rub	303	lb
Sand	1120	lb
Water	278	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml

**Testing Specimens Rec**

Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.11	cf
Cement	25.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock	44.2	lb
Crumb Rub	12.4	lb
Sand	46.0	lb
Water	11.4	lb
AEA	0.0	mL
HRWRA	51.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	50%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	900.00	380.38

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**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/tc)	Amount (\$)
Cement	611.0	15.48%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	45.59%	10.89	0.403	18	16.20
Sand	1135.81	28.77%	6.87	0.254	18	10.22
New Rock	900.00	22.80%	5.44	0.202	18	8.10
Tire Chip R	380.38	9.63%	5.44	0.202	400	76.08
Water	256.62	6.50%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
#####			27.00	1.00	-	-
Total Cost =						147.33

**Moisture Content**

sand mc (%)	0.18	mc-ssd	-0.01
rock mc (%)	0.13	mc-ssd	-0.0036

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	146.2
Cementitious material (lbs)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	897	lb
Crumb Rub	379	lb
Sand	1120	lb
Water	278	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml

**Testing Specimens Rec**

Specimen Type	Quantity	Unit
Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	0.96
x 1.15	1.11

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	1.11	cf
Cement	25.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock	36.8	lb
Crumb Rub	15.6	lb
Sand	46.0	lb
Water	11.4	lb
AEA	0.0	mL
HRWRA	51.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	0%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	0.00	0.00

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	660.0	14.55%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	39.67%	10.89	0.403	18	16.20
Sand	1040.05	22.92%	6.29	0.233	18	9.36
New Rock Qty.	1800.00	39.67%	10.89	0.403	18	16.20
Tire Chip Rubber	0.00	0.00%	0.00	0.000	400	0.00
Water	277.20	6.11%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4537.20		27.00	1.00	-	-
					Total Cost =	81.44

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**Moisture Content**

sand mc (%)	0.4	mc-ssd	-0.01
rock mc (%)	0	mc-ssd	-0.0049

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	168.0
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

	Weight	Unit
Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1791	lb
Crumb Rubber	0	lb
Sand	1028	lb
Water	298	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1366	ml

**Testing Specimens Required**

	Count	Volume
Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

	Weight	Unit
Batch size	1.11	cf
Cement	27.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock Qty.	73.5	lb
Crumb Rubber	0.0	lb
Sand	42.2	lb
Water	12.2	lb
AEA	0.0	mL
HRWRA	56.1	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	10%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	180.00	76.08

**ONLY CHANGE YELLOW BOXES**

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	660.0	14.89%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	40.60%	10.89	0.403	18	16.20
Sand	1040.05	23.46%	6.29	0.233	18	9.36
New Rock Qty.	1620.00	36.54%	9.80	0.363	18	14.58
Tire Chip Rubber	76.08	1.72%	1.09	0.040	400	15.22
Water	277.20	6.25%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4433.28		27.00	1.00	-	-
					Total Cost =	95.04

**Moisture Content**

sand mc (%)	0.7	mc-ssd	-0.01
rock mc (%)	0.2	mc-ssd	-0.0029

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	164.2
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1615	lb
Crumb Rubber	76	lb
Sand	1031	lb
Water	291	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1366	ml

**Testing Specimens Required**

Specimen Type	Quantity	Unit
Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		1.02
x 1.15		1.18

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock Qty.	70.3	lb
Crumb Rubber	3.3	lb
Sand	44.9	lb
Water	12.7	lb
AEA	0.0	mL
HRWRA	59.5	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	20%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	360.00	152.15

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**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	660.0	15.24%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	41.58%	10.89	0.403	18	16.20
Sand	1040.05	24.02%	6.29	0.233	18	9.36
New Rock Qty.	1440.00	33.26%	8.71	0.323	18	12.96
Tire Chip Rubber	152.15	3.51%	2.18	0.081	400	30.43
Water	277.20	6.40%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4329.35		27.00	1.00	-	-
Total Cost =					108.63	

**Moisture Content**

sand mc (%)	0.1	mc-ssd	-0.01
rock mc (%)	0.1	mc-ssd	-0.0039

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	160.3
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1434	lb
Crumb Rubber	152	lb
Sand	1025	lb
Water	299	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1366	ml

**Testing Specimens Required**

Specimen Type	Quantity	Volume
Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	1.11	cf
Cement	27.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock Qty.	58.9	lb
Crumb Rubber	6.2	lb
Sand	42.1	lb
Water	12.3	lb
AEA	0.0	mL
HRWRA	56.1	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	30%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	540.00	228.23

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**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	660.0	15.62%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	42.60%	10.89	0.403	18	16.20
Sand	1040.05	24.61%	6.29	0.233	18	9.36
New Rock Qty.	1260.00	29.82%	7.62	0.282	18	11.34
Tire Chip Rubber	228.23	5.40%	3.27	0.121	400	45.65
Water	277.20	6.56%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4225.43		27.00	1.00	-	-
Total Cost =					122.23	

**Moisture Content**

sand mc (%)	0.4	mc-ssd	-0.01
rock mc (%)	0	mc-ssd	-0.0049

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	156.5
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1254	lb
Crumb Rubber	227	lb
Sand	1028	lb
Water	298	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1366	ml

**Testing Specimens Required**

Specimen Type	Quantity	Volume
Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	1.11	cf
Cement	27.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock Qty.	51.5	lb
Crumb Rubber	9.3	lb
Sand	42.2	lb
Water	12.2	lb
AEA	0.0	mL
HRWRA	56.1	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	40%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	720.00	304.30

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Cost (\$/td)	Amount (\$)
Cement	660.0	16.01%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	43.67%	10.89	0.403	18	16.20
Sand	1040.05	25.23%	6.29	0.233	18	9.36
New Rock C	1080.00	26.20%	6.53	0.242	18	9.72
Tire Chip R	304.30	7.38%	4.35	0.161	400	60.86
Water	277.20	6.73%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4121.50		27.00	1.00	-	-
					Total Cost =	135.82

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Moisture Content			
sand mc (%)	0.4	mc-ssd	-0.01
rock mc (%)	0	mc-ssd	-0.0049

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	152.6
Cementitious material (C)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Material	Percent (%)	Weight (lb)	Class F only
Fly Ash replacement (%)	0.0%	0.0	
BFS replacement (%)	0.0%	0.0	
Micron 3 (%)	0.0%	0.0	
Silica Fume (%)	0.0%	0.0	

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock C	1075	lb
Crumb Rub	303	lb
Sand	1028	lb
Water	298	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1366	ml

**Testing Specimens Required**

Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.11	cf
Cement	27.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock C	44.1	lb
Crumb Rub	12.4	lb
Sand	42.2	lb
Water	12.2	lb
AEA	0.0	mL
HRWRA	56.1	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	50%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	900.00	380.38

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Credit	Cost (\$/td)	Amount (\$)
Cement	660.0	16.43%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	44.80%	10.89	0.403	18	16.20
Sand	1040.05	25.89%	6.29	0.233	18	9.36
New Rock C	900.00	22.40%	5.44	0.202	18	8.10
Tire Chip R	380.38	9.47%	5.44	0.202	400	76.08
Water	277.20	6.90%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4017.58		27.00	1.00	-	-
					Total Cost =	149.42

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Moisture Content			
sand mc (%)	0.4	mc-ssd	-0.01
rock mc (%)	0	mc-ssd	-0.0049

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	148.8
Cementitious material (C)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Material	Percent (%)	Weight (lb)	Class F only
Fly Ash replacement (%)	0.0%	0.0	
BFS replacement (%)	0.0%	0.0	
Micron 3 (%)	0.0%	0.0	
Silica Fume (%)	0.0%	0.0	

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock C	896	lb
Crumb Rub	379	lb
Sand	1028	lb
Water	298	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1366	ml

**Testing Specimens Required**

Compressive cylinders	9	0.52
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		0.96
x 1.15		1.11

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.11	cf
Cement	27.1	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	73.9	lb
New Rock C	36.8	lb
Crumb Rub	15.5	lb
Sand	42.2	lb
Water	12.2	lb
AEA	0.0	mL
HRWRA	56.1	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	0%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	0.00	0.00

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	705.0	15.32%	3.59	0.133	120	42.30
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	39.12%	10.89	0.403	18	16.20
Sand	952.11	20.69%	5.76	0.213	18	8.57
New Rock C	1800.00	39.12%	10.89	0.403	18	16.20
Tire Chip R	0.00	0.00%	0.00	0.000	400	0.00
Water	296.10	6.44%	4.75	0.176	0.6	0.09
Air	0.075		2.03	0.075	-	-
4601.10			27.00	1.00	-	-
					Total Cost =	83.36

**ONLY CHANGE YELLOW BOXES**

Moisture Content			
sand mc (%)	3.5	mc-ssd	0.02
rock mc (%)	1	mc-ssd	0.0051

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	170.4
Cementitious material (C)	705

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Material	Percent (%)	Weight (lb)	Class F only
Fly Ash replacement (%)	0.0%	0.0	
BFS replacement (%)	0.0%	0.0	
Micron 3 (%)	0.0%	0.0	
Silica Fume (%)	0.0%	0.0	

**Batch Weights (yd<sup>3</sup>)**

Cement	705	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock C	1809	lb
Crumb Rub	0	lb
Sand	971	lb
Water	268	lb
AEA	1.0	fl oz./cwt
AEA	208	ml
HRWRA	8.0	fl oz./cwt
HRWRA	1668	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		1.02
x 1.15		1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	30.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock C	78.7	lb
Crumb Rub	0.0	lb
Sand	42.3	lb
Water	11.7	lb
AEA	9.1	mL
HRWRA	72.6	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	10%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	180.00	76.08

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	705.0	15.68%	3.59	0.133	120	42.30
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	40.03%	10.89	0.403	18	16.20
Sand	952.11	21.17%	5.76	0.213	18	8.57
New Rock (	1620.00	36.02%	9.80	0.363	18	14.58
Tire Chip R	76.08	1.69%	1.09	0.040	400	15.22
Water	296.10	6.58%	4.75	0.176	0.6	0.09
Air	0.075		2.03	0.075	-	-
	4497.18		27.00	1.00	-	-
<b>Total Cost =</b>						96.95

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Moisture Content			
sand mc (%)	3.5	mc-ssd	0.02
rock mc (%)	1	mc-ssd	0.0051

0.010101

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	166.6
Cementitious material (lb)	705

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Ma	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	705	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock (	1628	lb
Crumb Rub	76	lb
Sand	971	lb
Water	268	lb
AEA	0.0	fl oz./cwt
AEA	0	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1459	ml

**Testing Specimens Rec**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	30.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock (	70.9	lb
Crumb Rub	3.3	lb
Sand	42.3	lb
Water	11.7	lb
AEA	0.0	mL
HRWRA	63.5	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	20%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	360.00	152.15

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	705.0	16.05%	3.59	0.133	120	42.30
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	40.97%	10.89	0.403	18	16.20
Sand	952.11	21.67%	5.76	0.213	18	8.57
New Rock C	1440.00	32.78%	8.71	0.323	18	12.96
Tire Chip R	152.15	3.46%	2.18	0.081	400	30.43
Water	296.10	6.74%	4.75	0.176	0.6	0.09
Air	0.075		2.03	0.075	-	-
	4393.25		27.00	1.00	-	-
					Total Cost =	110.55

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Moisture Content			
sand mc (%)	4.4	mc-ssd	0.03
rock mc (%)	0.8	mc-ssd	0.0031

0.0438413  
0.0080645

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	162.7
Cementitious material (C)	705

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Material	Percent (%)	Weight (lb)	Class F only
Fly Ash replacement (%)	0.0%	0.0	
BFS replacement (%)	0.0%	0.0	
Micron 3 (%)	0.0%	0.0	
Silica Fume (%)	0.0%	0.0	

**Batch Weights (yd<sup>3</sup>)**

Cement	705	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock C	1444	lb
Crumb Rub	153	lb
Sand	979	lb
Water	263	lb
AEA	1.3	fl oz./cwt
AEA	261	ml
HRWRA	4.5	fl oz./cwt
HRWRA	938	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		1.02
x 1.15		1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	30.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock C	62.9	lb
Crumb Rub	6.6	lb
Sand	42.6	lb
Water	11.5	lb
AEA	11.3	mL
HRWRA	40.8	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	30%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	540.00	228.23

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	705.0	16.44%	3.59	0.133	120	42.30
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	41.96%	10.89	0.403	18	16.20
Sand	952.11	22.20%	5.76	0.213	18	8.57
New Rock	1260.00	29.38%	7.62	0.282	18	11.34
Tire Chip R	228.23	5.32%	3.27	0.121	400	45.65
Water	296.10	6.90%	4.75	0.176	0.6	0.09
Air	0.075		2.03	0.075	-	-
	4289.33		27.00	1.00	-	-
Total Cost =					124.14	

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Moisture Content			
sand mc (%)	4.8	mc-ssd	0.03
rock mc (%)	3.2	mc-ssd	0.0271

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	158.9
Cementitious material (C)	705

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

0.0319917  
0.048218

Suppl. Cementitious Ma	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	705	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	1294	lb
Crumb Rub	234	lb
Sand	983	lb
Water	216	lb
AEA	1.3	fl oz./cwt
AEA	261	ml
HRWRA	4.0	fl oz./cwt
HRWRA	834	ml

**Testing Specimens Rec**

Specimen Type	Quantity	Weight
Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		1.02
x 1.15		1.18

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	1.18	cf
Cement	30.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock	56.3	lb
Crumb Rub	10.2	lb
Sand	42.8	lb
Water	9.4	lb
AEA	11.3	mL
HRWRA	36.3	mL

**Concrete Mixture Design Spreads**

Volume Replacement of Rock with Tire Rubber Chips	40%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	720.00	304.30

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/td)	Amount (\$)
Cement	705.0	16.84%	3.59	0.133	120	42.30
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	43.01%	10.89	0.403	18	16.20
Sand	952.11	22.75%	5.76	0.213	18	8.57
New Rock	1080.00	25.80%	6.53	0.242	18	9.72
Tire Chip R	304.30	7.27%	4.35	0.161	400	60.86
Water	296.10	7.07%	4.75	0.176	0.6	0.09
Air	0.075		2.03	0.075	-	-
	4185.40		27.00	1.00	-	-
Total Cost =					137.74	

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Moisture Content			
sand mc (%)	4.9	mc-ssd	0.03
rock mc (%)	4.2	mc-ssd	0.0371

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	155.0
Cementitious material (C)	705

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rub	1.12	0.2

Suppl. Cementitious Ma	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	705	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock	1120	lb
Crumb Rub	316	lb
Sand	984	lb
Water	197	lb
AEA	1.3	fl oz./cwt
AEA	261	ml
HRWRA	5.5	fl oz./cwt
HRWRA	1147	ml

Testing Specimens Rec		
Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	30.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock	48.7	lb
Crumb Rub	13.7	lb
Sand	42.8	lb
Water	8.6	lb
AEA	11.3	mL
HRWRA	49.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	50%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	900.00	380.38

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weigh	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	705.0	17.27%	3.59	0.133	120	42.30
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	44.10%	10.89	0.403	18	16.20
Sand	952.11	23.33%	5.76	0.213	18	8.57
New Rock Qty.	900.00	22.05%	5.44	0.202	18	8.10
Tire Chip Rubber	380.38	9.32%	5.44	0.202	400	76.08
Water	296.10	7.25%	4.75	0.176	0.6	0.09
Air	0.075		2.03	0.075	-	-
	4081.48		27.00	1.00	-	-
					Total Cost =	151.33

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Moisture Content		
sand mc (%)	4.7	mc-ssd 0.03
rock mc (%)	1.5	mc-ssd 0.0101

0.0471204  
0.0152284

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	151.2
Cementitious material (lbs)	705

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	705	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	909	lb
Crumb Rubber	384	lb
Sand	982	lb
Water	248	lb
AEA	1.3	fl oz./cwt
AEA	261	ml
HRWRA	5.5	fl oz./cwt
HRWRA	1147	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00
Total		1.02
x 1.15		1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	30.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.3	lb
New Rock Qty.	39.6	lb
Crumb Rubber	16.7	lb
Sand	42.7	lb
Water	10.8	lb
AEA	11.3	mL
HRWRA	49.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	10%	Sand (lbs)	CR (lbs)
Fraction of Replacement	42/100	104.00	43.96

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weigh	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	17.76%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	48.42%	10.89	0.403	18	16.20
Sand	1040.05	27.98%	6.29	0.233	18	9.36
<b>New Sand Quantity</b>	<b>936.04</b>	<b>25.18%</b>	<b>5.66</b>	<b>0.210</b>	<b>18</b>	<b>8.42</b>
Tire Chip Rubber	43.96	1.18%	0.63	0.023	400	8.79
Water	277.20	7.46%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	3717.20		27.00	0.83	-	-
					Total Cost =	82.46

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Moisture Content			
sand mc (%)	0.7	mc-ssd	-0.01
rock mc (%)	0.2	mc-ssd	-0.0029

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	137.7
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1795	lb
<b>New Sand Quantity</b>	<b>928</b>	<b>lb</b>
Crumb Rubber	44	lb
Sand	1031	lb
Water	291	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.1	lb
<b>New Sand Quantity</b>	<b>40.4</b>	<b>lb</b>
Crumb Rubber	1.9	lb
Sand	44.9	lb
Water	12.7	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	20%	Sand (lbs)	CR (lbs)
Fraction of Replacement	42/100	208.01	87.91

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	18.05%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	49.22%	10.89	0.403	18	16.20
Sand	1040.05	28.44%	6.29	0.233	18	9.36
<b>New Sand Quantity</b>	<b>832.04</b>	<b>22.75%</b>	<b>5.03</b>	<b>0.186</b>	<b>18</b>	<b>7.49</b>
Tire Chip Rubber	87.91	2.40%	1.26	0.047	400	17.58
Water	277.20	7.58%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	3657.15		27.00	0.83	-	-
					Total Cost =	90.31

ONLY CHANGE YELLOW BOXES

Moisture Content			
sand mc (%)	6.7	mc-ssd	0.05
rock mc (%)	1	mc-ssd	0.0051

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	135.5
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1809	lb
<b>New Sand Quantity</b>	<b>875</b>	<b>lb</b>
Crumb Rubber	88	lb
Sand	1094	lb
Water	214	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.7	lb
<b>New Sand Quantity</b>	<b>38.1</b>	<b>lb</b>
Crumb Rubber	3.8	lb
Sand	47.6	lb
Water	9.3	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	30%	Sand (lbs)	CR (lbs)
Fraction of Replacement	42/100	312.01	131.87

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weigh	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	18.35%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	50.04%	10.89	0.403	18	16.20
Sand	1040.05	28.91%	6.29	0.233	18	9.36
<b>New Sand Quantity</b>	<b>728.03</b>	<b>20.24%</b>	<b>4.40</b>	<b>0.163</b>	<b>18</b>	<b>6.55</b>
Tire Chip Rubber	131.87	3.67%	1.89	0.070	400	26.37
Water	277.20	7.71%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	3597.10		27.00	0.83	-	-
					Total Cost =	98.17

ONLY CHANGE YELLOW BOXES

Moisture Content		
sand mc (%)	6.7	mc-ssd 0.05
rock mc (%)	1	mc-ssd 0.0051

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	133.2
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1809	lb
<b>New Sand Quantity</b>	<b>766</b>	<b>lb</b>
Crumb Rubber	133	lb
Sand	1094	lb
Water	214	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.7	lb
<b>New Sand Quantity</b>	<b>33.3</b>	<b>lb</b>
Crumb Rubber	5.8	lb
Sand	47.6	lb
Water	9.3	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	40%	Sand (lbs)	CR (lbs)
Fraction of Replacement	42/100	416.02	175.83

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	18.66%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	50.89%	10.89	0.403	18	16.20
Sand	1040.05	29.40%	6.29	0.233	18	9.36
<b>New Sand Quantity</b>	<b>624.03</b>	<b>17.64%</b>	<b>3.77</b>	<b>0.140</b>	<b>18</b>	<b>5.62</b>
Tire Chip Rubber	175.83	4.97%	2.52	0.093	400	35.17
Water	277.20	7.84%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	3537.06		27.00	0.83	-	-
					Total Cost =	106.03

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Moisture Content			
sand mc (%)	4	mc-ssd	0.02
rock mc (%)	1	mc-ssd	0.0051

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	131.0
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1809	lb
<b>New Sand Quantity</b>	<b>639</b>	<b>lb</b>
Crumb Rubber	177	lb
Sand	1066	lb
Water	242	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.7	lb
<b>New Sand Quantity</b>	<b>27.8</b>	<b>lb</b>
Crumb Rubber	7.7	lb
Sand	46.4	lb
Water	10.5	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	50%	Sand (lbs)	CR (lbs)
Fraction of Replacement	42/100	520.02	219.78

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	18.98%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	51.77%	10.89	0.403	18	16.20
Sand	1040.05	29.91%	6.29	0.233	18	9.36
<b>New Sand Quantity</b>	<b>520.02</b>	<b>14.96%</b>	<b>3.14</b>	<b>0.116</b>	<b>18</b>	<b>4.68</b>
<b>Tire Chip Rubber</b>	<b>219.78</b>	<b>6.32%</b>	<b>3.14</b>	<b>0.116</b>	<b>400</b>	<b>43.96</b>
Water	277.20	7.97%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
	3477.01		27.00	1.00	-	-
					Total Cost =	113.88

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Moisture Content			
sand mc (%)	4	mc-ssd	0.02
rock mc (%)	1	mc-ssd	0.0051

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	128.8
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1809	lb
<b>New Sand Quantity</b>	<b>533</b>	<b>lb</b>
<b>Crumb Rubber</b>	<b>221</b>	<b>lb</b>
Sand	1066	lb
Water	242	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.7	lb
<b>New Sand Quantity</b>	<b>23.2</b>	<b>lb</b>
<b>Crumb Rubber</b>	<b>9.6</b>	<b>lb</b>
Sand	46.4	lb
Water	10.5	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Sand with Crumb Rubber	10%	Aggregate (lbs)	CR (lbs)
Fraction of Replacement	42/100	104.00	43.96
Volume Replacement of Rock with Tire Chips	5%		
Fraction of Replacement	42/100	90.00	38.04

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	18.20%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	49.63%	10.89	0.403	18	16.20
New Rock Quantity	1710.00	47.14%	10.34	0.383	18	
Tire Chip Quantity	38.04	1.05%	0.54	0.020	400	
Sand	1040.05	28.67%	6.29	0.233	18	9.36
New Sand Quantity	936.04	25.81%	5.66	0.210	18	8.42
Crumb Rubber	43.96	1.21%	0.63	0.023	400	8.79
Water	277.20	7.64%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
#####			27.00	1.00	-	-
Total Cost =						82.46

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Moisture Content		
sand mc (%)	0.7	mc-ssd -0.01
rock mc (%)	0.2	mc-ssd -0.0029

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	202.4
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1795	lb
New Rock Quantity	1705	lb
Tire Chips	38	lb
New Sand Quantity	928	lb
Crumb Rubber	44	lb
Sand	1031	lb
Water	291	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.1	lb
New Rock Quantity	74.2	lb
Tire Chips	1.7	lb
New Sand Quantity	40.4	lb
Crumb Rubber	1.9	lb
Sand	44.9	lb
Water	12.7	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Sand with Crumb Rubber	20%	Aggregate (lbs)	CR (lbs)
Fraction of Replacement	42/100	208.01	87.91
Volume Replacement of Rock with Tire Chips	10%		
Fraction of Replacement	42/100	180.00	76.08

**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weigh	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	660.0	18.98%	3.36	0.124	120	39.60
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	51.77%	10.89	0.403	18	16.20
New Rock Quantity	1620.00	46.59%	9.80	0.363	18	
Tire Chip Quantity	76.08	2.19%	1.09	0.040	400	
Sand	1040.05	29.91%	6.29	0.233	18	9.36
New Sand Quantity	832.04	23.93%	5.03	0.186	18	7.49
Crumb Rubber	87.91	2.53%	1.26	0.047	400	17.58
Water	277.20	7.97%	4.44	0.165	0.6	0.08
Air	0.075		2.03	0.075	-	-
#####			27.00	1.00	-	-
Total Cost =						90.31

**ONLY CHANGE YELLOW BOXES**

Moisture Content		
sand mc (%)	0.7	mc-ssd -0.01
rock mc (%)	0.2	mc-ssd -0.0029

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	198.3
Cementitious material (lbs)	660

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight (lb)	Unit
Cement	660	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1795	lb
New Rock Quantity	1615	lb
Tire Chips	76	lb
New Sand Quantity	825	lb
Crumb Rubber	88	lb
Sand	1031	lb
Water	291	lb
AEA	1.3	fl oz./cwt
AEA	244	ml
HRWRA	4.0	fl oz./cwt
HRWRA	781	ml
VMA	8.0	fl oz./cwt
VMA	1561	ml

**Testing Specimens Required**

Specimen	Quantity	Notes
Compressive cylinders	10	0.58
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds	0	0.00
Split Cylinder	0	0.00

Total	1.02
x 1.15	1.18

**Batch Weights (ft<sup>3</sup>)**

Material	Weight (lb)	Unit
Batch size	1.18	cf
Cement	28.7	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	78.1	lb
New Rock Quantity	70.3	lb
Tire Chips	3.3	lb
New Sand Quantity	35.9	lb
Crumb Rubber	3.8	lb
Sand	44.9	lb
Water	12.7	lb
AEA	10.6	mL
HRWRA	34.0	mL
VMA	67.9	mL

## APPENDIX E

### Concrete Mixture Design Spreadsheet

Volume Replacement of Rock with Tire Rubber Chips	0%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	0.00	0.00

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#### Mix Proportion (SSD)

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	611.0	13.68%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	40.29%	10.89	0.403	18	16.20
Sand	1135.81	25.42%	6.87	0.254	18	10.22
New Rock Qty.	1800.00	40.29%	10.89	0.403	18	16.20
Tire Chip Rubber	0.00	0.00%	0.00	0.000	400	0.00
Water	256.62	5.74%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4467.62		27.00	1.00	-	-
					Total Cost =	79.36

Moisture Content			
sand mc (%)	7	mc-ssd	0.05
rock mc (%)	1.5	mc-ssd	0.0101

#### Mix Characteristics

w/c	0.42
Unit Weight (pcf)	165.5
Cementitious material (lbs)	611

#### Material Properties

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

#### Batch Weights (yd<sup>3</sup>)

Material	Weight	Unit
Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1818	lb
Crumb Rubber	0	lb
Sand	1198	lb
Water	176	lb
AEA	1.3	fl oz./cwt
AEA	235	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml
VMA	8.0	fl oz./cwt
VMA	1445	ml

#### Testing Specimens Required

Specimen Type	Quantity	Notes
Compressive cylinders	30	1.75
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds (Static Load Displacement)	3	1.25
Split Cylinder	6	0.35
Drop Weight	3	0.10

\*Includes permeability and CTE (6 cylinders each)

\*\*\*use freeze thaw beams instead

Total	3.88
x 1.15	4.46

#### Batch Weights (ft<sup>3</sup>)

Material	Weight	Unit
Batch size	4.46	cf
Cement	101.0	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	297.7	lb
New Rock Qty.	300.7	lb
Crumb Rubber	0.0	lb
Sand	198.1	lb
Water	29.2	lb
AEA	38.8	mL
HRWRA	209.1	mL
VMA	239.0	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	10%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	180.00	76.08

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**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	611.0	14.00%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	41.25%	10.89	0.403	18	16.20
Sand	1135.81	26.03%	6.87	0.254	18	10.22
New Rock Qty.	1620.00	37.12%	9.80	0.363	18	14.58
Tire Chip Rubber	76.08	1.74%	1.09	0.040	400	15.22
Water	256.62	5.88%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4363.70		27.00	1.00	-	-
					Total Cost =	92.95

Moisture Content			
sand mc (%)	7	mc-ssd	0.05
rock mc (%)	1.5	mc-ssd	0.0101

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	161.6
Cementitious material (lbs)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1636	lb
Crumb Rubber	77	lb
Sand	1198	lb
Water	176	lb
AEA	1.3	fl oz./cwt
AEA	235	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml
VMA	8.0	fl oz./cwt
VMA	1445	ml

**Testing Specimens Required**

Specimen	Quantity	Notes
Compressive cylinders	30	1.75
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds (Static Load Displacement)	3	1.25
Split Cylinder	6	0.35
Drop Weight	3	0.10
Total		3.88
x 1.15		4.46

\*Includes permeability and CTE (6 cylinders each)

\*\*\*use freeze thaw beams instead

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	4.46	cf
Cement	101.0	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	297.7	lb
New Rock Qty.	270.6	lb
Crumb Rubber	12.7	lb
Sand	198.1	lb
Water	29.2	lb
AEA	38.8	mL
HRWRA	209.1	mL
VMA	239.0	mL

**Concrete Mixture Design Spreadsheet**

Volume Replacement of Rock with Tire Rubber Chips	20%	Rock (lbs)	TR (lbs)
Fraction of Replacement	42/100	360.00	152.15

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**Mix Proportion (SSD)**

Material	Weight (lbs)	% by Weight	Volume (cf)	Volume Check	Unit Cost (\$/ton)	Amount (\$)
Cement	611.0	14.34%	3.11	0.115	120	36.66
Fly Ash	0.0	0.00%	0.00	0.000	100	0.00
BFS	0.0	0.00%	0.00	0.000	85	0.00
Micron 3	0.0	0.00%	0.00	0.000	500	0.00
Silica Fume	0.0	0.00%	0.00	0.000	500	0.00
Rock	1800.00	42.26%	10.89	0.403	18	16.20
Sand	1135.81	26.66%	6.87	0.254	18	10.22
New Rock Qty.	1440.00	33.80%	8.71	0.323	18	12.96
Tire Chip Rubber	152.15	3.57%	2.18	0.081	400	30.43
Water	256.62	6.02%	4.11	0.152	0.6	0.08
Air	0.075		2.03	0.075	-	-
	4259.77		27.00	1.00	-	-
					Total Cost =	106.55

Moisture Content			
sand mc (%)	7	mc-ssd	0.05
rock mc (%)	1.5	mc-ssd	0.0101

**Mix Characteristics**

w/c	0.42
Unit Weight (pcf)	157.8
Cementitious material (lbs)	611

**Material Properties**

Material	S.G.	A.C
Cement	3.15	-
Fly Ash	2.67	-
BFS	2.90	-
Micron 3	2.53	-
Silica Fume	2.20	-
Rock	2.65	0.49
Sand	2.65	1.53
Crumb Rubber	1.12	0.2

Suppl. Cementitious Mat.	Percent (%)	Weight (lb)
Fly Ash replacement (%)	0.0%	0.0
BFS replacement (%)	0.0%	0.0
Micron 3 (%)	0.0%	0.0
Silica Fume (%)	0.0%	0.0

Class F only

**Batch Weights (yd<sup>3</sup>)**

Material	Weight	Unit
Cement	611	lb
Fly Ash	0	lb
Micron 3	0	lb
Silica Fume	0	lb
Rock	1800	lb
New Rock Qty.	1455	lb
Crumb Rubber	154	lb
Sand	1198	lb
Water	176	lb
AEA	1.3	fl oz./cwt
AEA	235	ml
HRWRA	7.0	fl oz./cwt
HRWRA	1265	ml
VMA	8.0	fl oz./cwt
VMA	1445	ml

**Testing Specimens Required**

Specimen	Quantity	Notes
Compressive cylinders	30	1.75
RCIP cylinders	0	0.00
MOR	0	0.00
Unit weight	1	0.25
Permeameter slabs	0	0.00
Salt Ponding	0	0.00
MOE	0	0.19
Beam Molds (Static Load Displacement)	3	1.25
Split Cylinder	6	0.35
Drop Weight	3	0.10
Total		3.88
x 1.15		4.46

\*Includes permeability and CTE (6 cylinders each)

\*\*\*use freeze thaw beams instead

**Batch Weights (ft<sup>3</sup>)**

Material	Weight	Unit
Batch size	4.46	cf
Cement	101.0	lb
Fly Ash	0.0	lb
Micron 3	0.0	lb
Silica Fume	0.0	lb
Rock	297.7	lb
New Rock Qty.	240.5	lb
Crumb Rubber	25.4	lb
Sand	198.1	lb
Water	29.2	lb
AEA	38.8	mL
HRWRA	209.1	mL
VMA	239.0	mL