Use of Recycled Tires as Partial Replacement of Coarse Aggregate in the Production of Concrete

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Student Paper Abstract

It is estimated that more than 270 million scrap-tires weighing more than 3 million tons are produced in the United States each year. This waste being non-biodegradable poses severe fire, environmental and health risks. Aside from tire derived fuel, the most promising use of recycled tires is in engineering applications as artificial reefs, erosion control and aggregates for asphalt and concrete.

The use of recycled tire rubber as partial aggregate in concrete has great potential to positively affect the properties of concrete in a wide spectrum. Concrete is one of the most popular construction materials. Due to this fact, the construction industry is always trying to increase its uses and applications and improving its properties, while reducing cost. In general, concrete has low tensile strength, low ductility, and low energy absorption. Concrete also tends to shrink and crack during the hardening and curing process. These limitations are constantly being tested with hopes of improvement by the introduction of new admixtures and aggregates used in the mix. One such method may be the introduction of rubber to the concrete mix. It is a perfect way to modify the properties of concrete and recycle rubber tires at the same time.

The objective of this research is to test the properties of concrete when recycled rubber from automotive tires is used as a partial aggregate. Special attention is being given to the use of modified surface rubber. Pre-treating the rubber with a sodium hydroxide (NaOH) solution modifies its surface, affecting the interfacial transition zone (ITZ) and allowing the rubber to better adhere with the cement paste. For this research, the recycled tires were surface-treated with a NaOH saturated aqueous solution for 20 minutes, then washed under running water and left to air dry. Compressive, splitting tensile and flexural strength was measured in concrete mixes with 10%, 15% and 20% substitution of natural aggregate by recycled rubber with no pretreatment and with surface modification.

Key Words

Student Paper, Technology, Human Resources, Construction Management and Engineering Technology

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Introduction

It is estimated that more than 270 million scrap-tires weighing more than 3 million tons are produced in the United States each year, this quantity is in addition to the more than 300 million scrap-tires that are stockpiled already [1]. Those stockpiles represent a severe fire risk due to lightning, spontaneous combustion, or just plain carelessness. They also pose other health hazards including diseases due to rodent and mosquito infestation and pollution to land, water, and air. Most landfills are refusing to take anymore tires due to the fact that they are harmful to the environment and are not bio-degradable. New means of disposal or recycling must be used. Aside from tire derived fuel (TDF), the most promising use of recycled tires is in engineering applications [1]. Some of those innovative and promising applications are as artificial reefs, erosion control, and as aggregate in asphalt and concrete.

The use of recycled tires as partial aggregate in concrete has been considered for several years. Previous research conducted show dramatic changes in the mechanical properties of concrete when rubber is introduced to the mix [2-11]. A tire is a composite of complex elastomer formulations, fibers and steel/fiber cord [1]. Rubber is the principal element of tire, making up about 85% of the tire where both synthetic and natural rubbers may be used. Natural rubber is an elastic hydrocarbon polymer which occurs as a milky colloidal secretion in the sap of several varieties of plants. Rubber can also be produced synthetically, as a thermoset polymeric material in which individual monomer chains are chemically linked by covalent bonds during polymerization [12].

Previous research has shown that the use of rubber particles in concrete mixes decreases the compressive strength of hardened concrete [2-11It has been reported that the mechanical properties of concrete rubber containing concrete takes place due to the weak adhesion between the rubber particles and the cement paste. In order to address this issue, the modification of the rubber particles surface has been suggested [2].

Sodium hydroxide (NaOH), also known as lye or caustic soda, is a caustic metallic base [13] due to its causticity; it is a perfect substance to modify the surface of rubber in order to improve the interfacial transition zone (ITZ) in the concrete matrix.

Much debate is still raging on whether recycled rubber is better used as a fine aggregate or a coarse aggregate. However, one thing is clear; the introduction of recycled rubber aggregate changes the properties of concrete.

Rubber filled concrete tends to have a reduction in slump and density compared to ordinary Portland cement concrete (OPC). Reduction of around 85% on slump has been reported when comparing traditional aggregate concrete with mixes containing recycled rubber [2, 3]. These values include mixes prepared using partial replacement of natural aggregates by rubber particles treated with sodium hydroxide (NaOH) solution.

Also, higher air content in concrete mixtures containing rubber when compared to control mixtures, even without any air-entrainment admixtures being introduced, has been reported [4, 5]. This behavior may be due to the non-polar nature of rubber particles and their tendency to entrap air on the particles surface.

Several studies has shown that the compressive and tensile strength of rubber containing concrete is affected by the size, shape, and surface textures of the aggregate along with the volume being used indicating that the strength of concretes decreases as the volume of rubber aggregate increases. However, discrepancies have been reported on the effect of recycled rubber size aggregate on the compressive strength of concrete [2-11].

Concrete containing rubber aggregate has a higher energy absorbing capacity referred to as toughness. Rostami [5] reported investigation on the comparison of the toughness of a control concrete mixture with that of a rubber containing concrete mixture. Data showed that the presence of rubber in concrete increases toughness.

Thus far the use of recycled rubber as aggregate in concrete has not given results that could indicate the possibility of its use as structural material. It is thought that the main cause of the decrease of strength in rubber concrete is due to the weak bond between the recycled rubber particles and the cement. This investigation intents to further explore this issue by comparing a OPC control mix with three mixes with different amount of natural coarse aggregate replacement (10, 15 and 20%) by untreated shredded rubber and with three concrete mixes (10, 15 and 20%) with the surface modified shredded rubber tire particles. Additionally, the effect of pozzolans, chemical admixtures and synthetic fiber on the mechanical properties of the concrete mixes is being investigated.

This investigation consists of three initial tests programs, two of which have been completed with the third test program currently being executed. The experimentation and results shown in this paper correspond to data obtained from the first two test programs.

Experimentation

All mixes prepared for testing had a water to cement ratio of 0.45. The same natural aggregates and rubber were used for two test programs. Test program I consisted of four concrete mixes: one control mix with no recycled shredded tire and three mixes with 10%, 15% and 20% replacement of natural aggregate by volume. The recycled shredded tire used in test program I was not subjected to any surface modification treatment. Test program two consisted of three concrete mixes prepared with partial replacement of natural aggregate on the amount of 10%, 15%, and 20% by volume. The recycled tire aggregate used for this test program was of the same origin as test program I, but it was pretreated with a saturated sodium hydroxide (NaOH) solution to modify the surface of the particles and improve the adhesion between the cement paste and the rubber particles. Pretreatment consisted of soaking the recycled tire particles in a NaOH solution for a period of 20 minutes, then washed under running water and left to air dry at room temperature.

Analysis of the physical properties of the natural aggregates was performed according to ASTM standards [14-18]. All aggregates met the specification of ASTM standard C-33 [14]. The characteristics of the control mix are shown in table 3. The proportions for the rest of the mixes partial substitution of coarse aggregate was done by volume and the quantities are shown in table 4.

Table 1. Mix characteristics.

Water to cement Ratio	0.45
Maximum size of Coarse Aggregate	¾”
Slump	2 in.
Air content	6%
Water	280 lbs/cu.yd
Cement	622 lbs/cu.yd
Coarse Aggregate (limestone)	1741 lbs/cu.yd
Fine Aggregate (sand)	1197 lbs/cu.yd
Portland Cement	Type I

Mixing and casting of cylindrical test specimens was performed in accordance with ASTM Designation: C 192 [15]. All specimens were wet cure by submersion in water.

Cylinders were tested for compressive strength at an age of 7, 14, and 28 days. For compression testing the cylinders were loaded at a constant rate of 20 pounds per square inch per second in accordance with ASTM standard test method C39 [16]. Splitting tensile strength was tested at ages 14 and 28 days after casting. The cylinders were loaded at a rate of 100 pounds per square inch per minute until failure; in accordance with ASTM standard test method C 496 [17]. Three beams were cast and tested for each mix of both test programs to measure modulus of rupture as an indication of flexural strength. All three beams were tested at an age of 28 days. The dimensions of the beams were 5 ⅞" x 5 ⅞' x 23 ½" (nominal measurement of 6' x 6' x 24"). Testing was performed according to ASTM standard method C 293 [18].

<u>Results</u>

Physical properties of Aggregates

Table 2 shows results of analysis of the physical properties of natural coarse and fine aggregates used in both tests programs.

Table 2. Physical properties of aggregates

Property	**Aggregate**	
	Coarse	**Fine**
Apparent Specific Gravity	**2.74**	**2.70**
Bulk Specific Gravity	**2.14**	**2.64**
Absorption	**1.62**	**1.52**
Moisture Content	**0.62**	**0.2**
Fineness Modulus		**2.40**

Compressive strength versus age for all mixes and test programs are shown in figures 1, 2, 3 and 4. Tables 3 and 4 show the percentage change in compressive strength with respect to control mix, by addition of untreated and treated shredded recycled tire respectively. Table 5 shows the percentage increase in compressive strength for each mix by modifying surface treatment of the rubber particles compared to concrete containing untreated rubber particles.

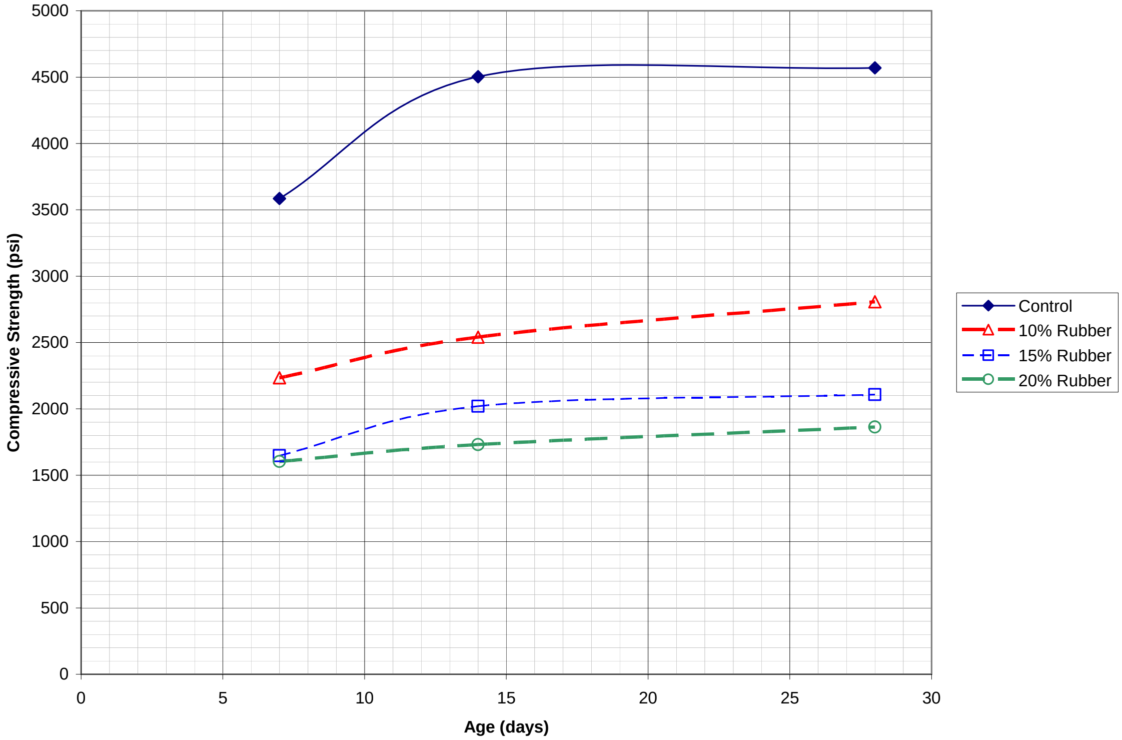

Figure 1. Compressive Strength versus Age. Test Program I.

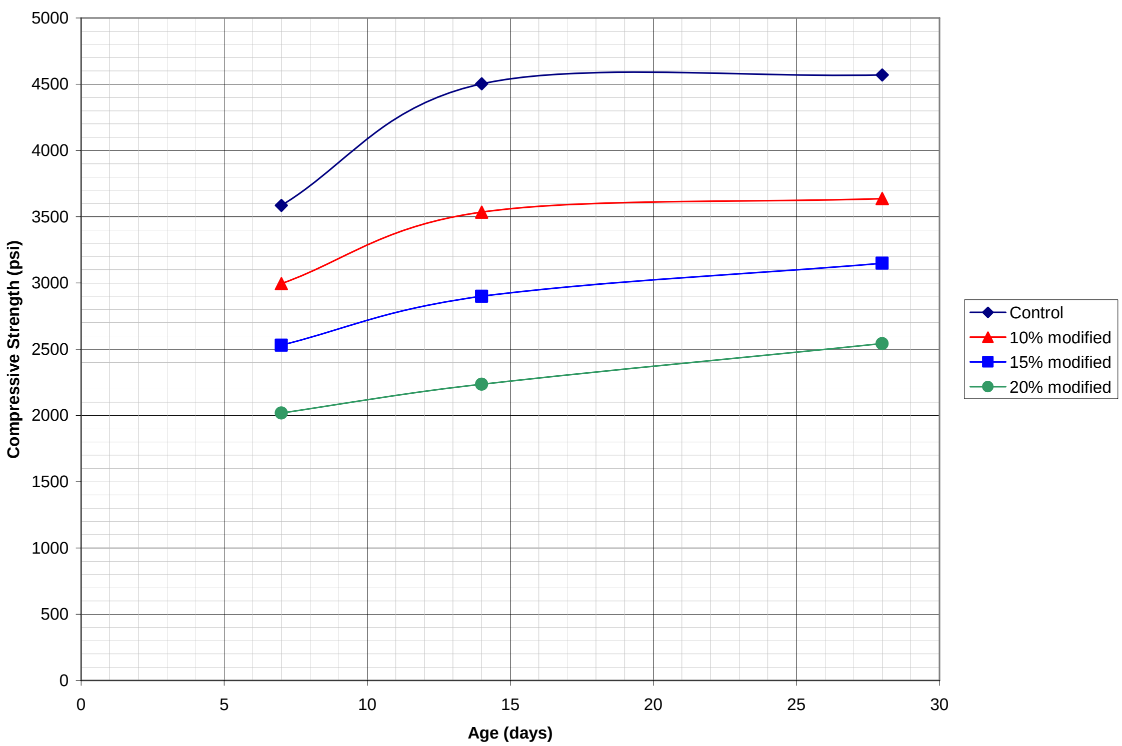

Figure 2. Compressive Strength versus Age. Test Program II.

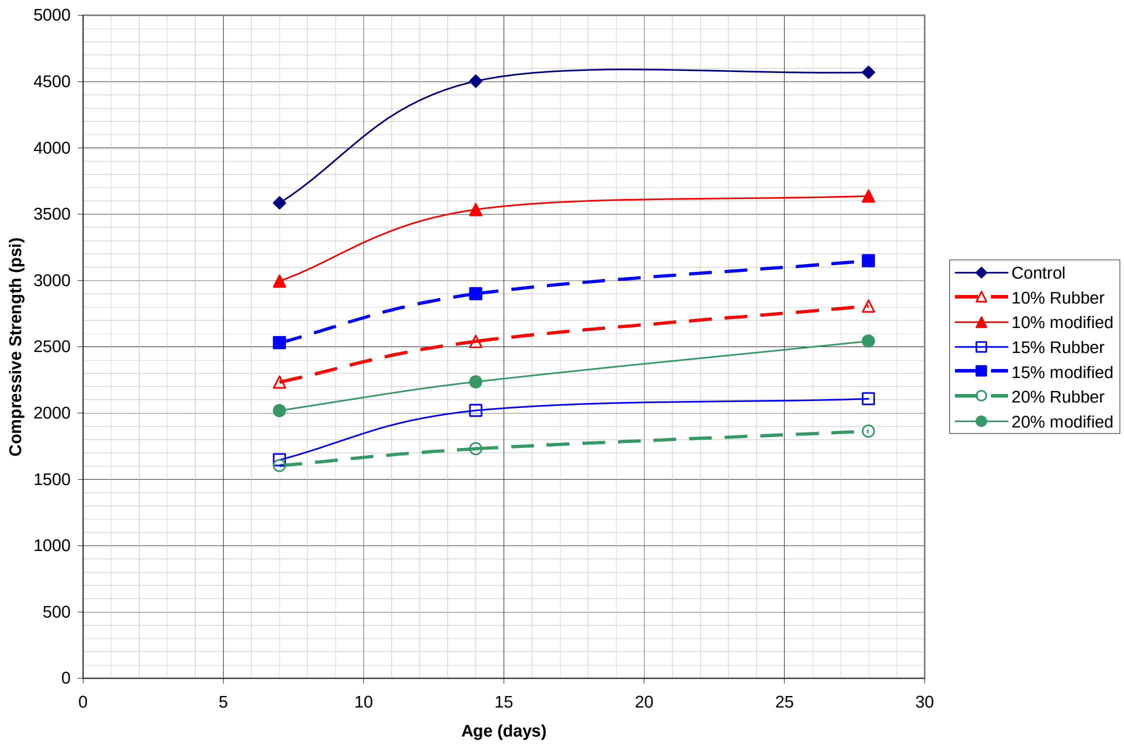

Figure 3. Compressive Strength versus Age. Test Programs I and II.

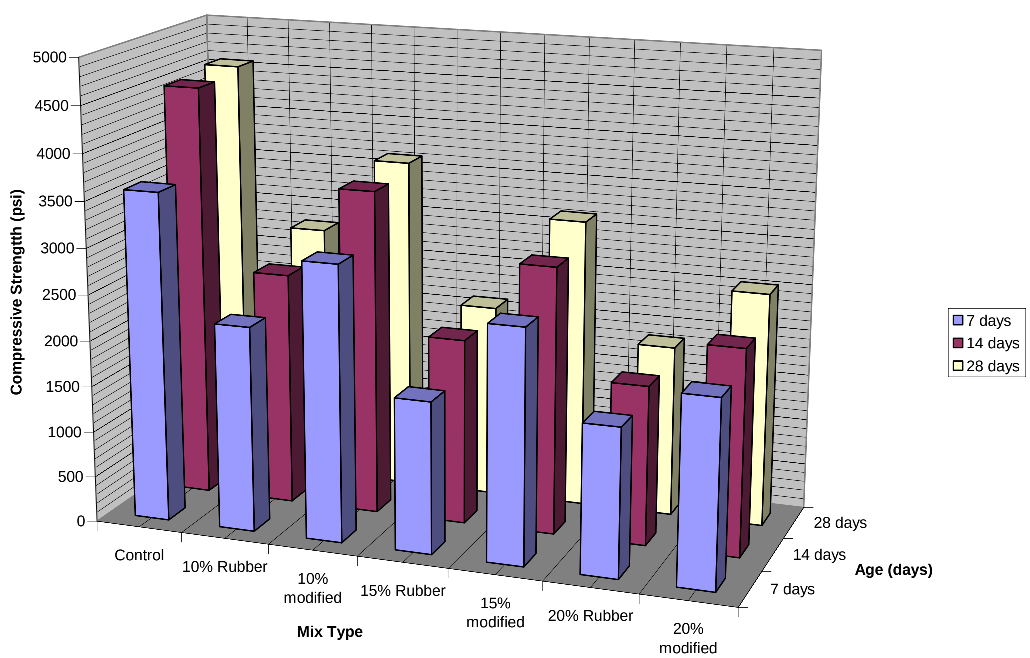

Figure 4. Comparison of compressive strength for test program I and II according to percentage aggregate substitution.

Table 3. Percentage decrease of compressive strength for concrete mixes used in test program I

Age (days)	Percentage shredded rubber tire (by volume)		
	10%	15%	20%
7	-37.68	-54.03	-55.29
14	-43.59	-55.17	-61.57
28	-38.58	-53.87	-59.22

Table 4. Percentage decrease of compressive strength for concrete mixes used in test program II.

Age (days)	Percentage shredded rubber tire (by volume)		
	10%	15%	20%
7	-16.43	-29.43	-43.70
14	-21.51	-35.61	-50.37
28	-20.40	-31.09	-44.35

Table 5. Percentage increase in compressive strength by modifying surface treatment on rubber tire particles.

Age (days)	Percentage shredded rubber tire (by volume)		
	10%	15%	20%
7	34.11	53.52	25.92
14	39.15	43.64	29.15
28	29.59	49.38	36.46

Figures 5 and 6 show the splitting tensile strength results for ages 14 and 28 days. Tables 6 and 7 show the percentage change in splitting tensile strength with respect to the control mix for test program I and II respectively. Table 8 shows the change in percentage for each mix as comparison of untreated and treated rubber aggregate particles.

Table 9 shows the results of the modulus of rupture for beams of test program I and II respectively. Additionally, this table shows the percentage change on deflection due to the replacement of untreated and treated rubber tire, as well as the impact of surface modification treatment expressed in terms of percentage.

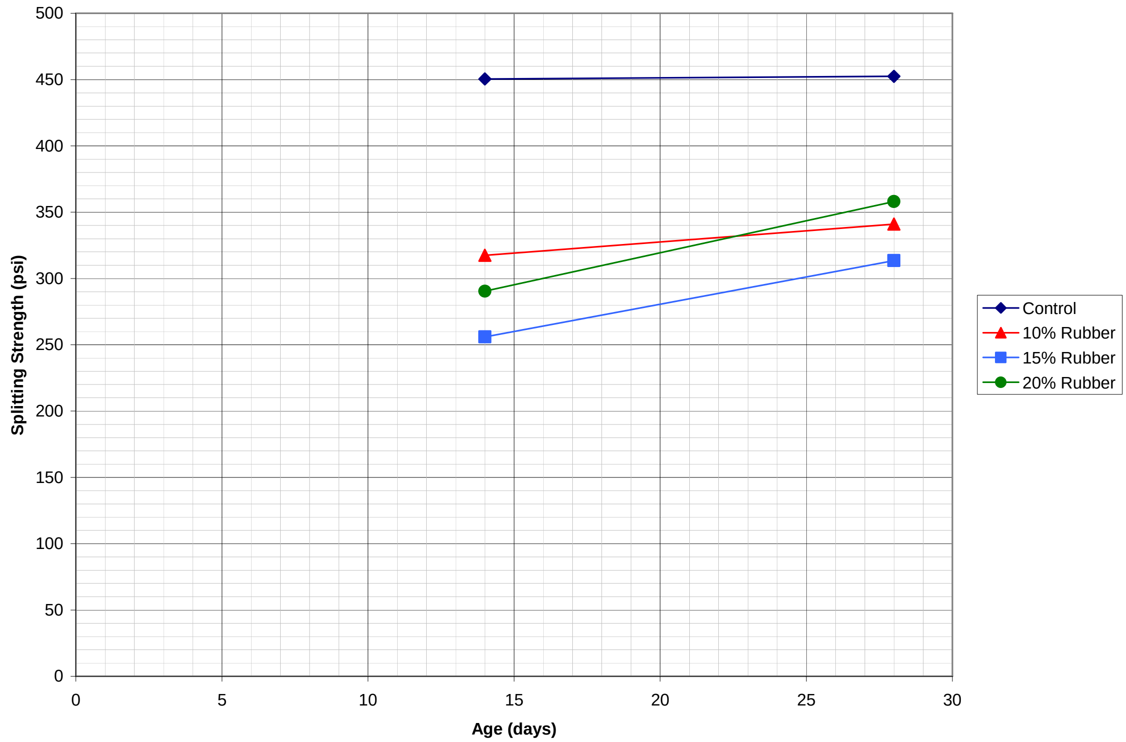

Figure 5. Splitting tensile strength versus age. Test Program I.

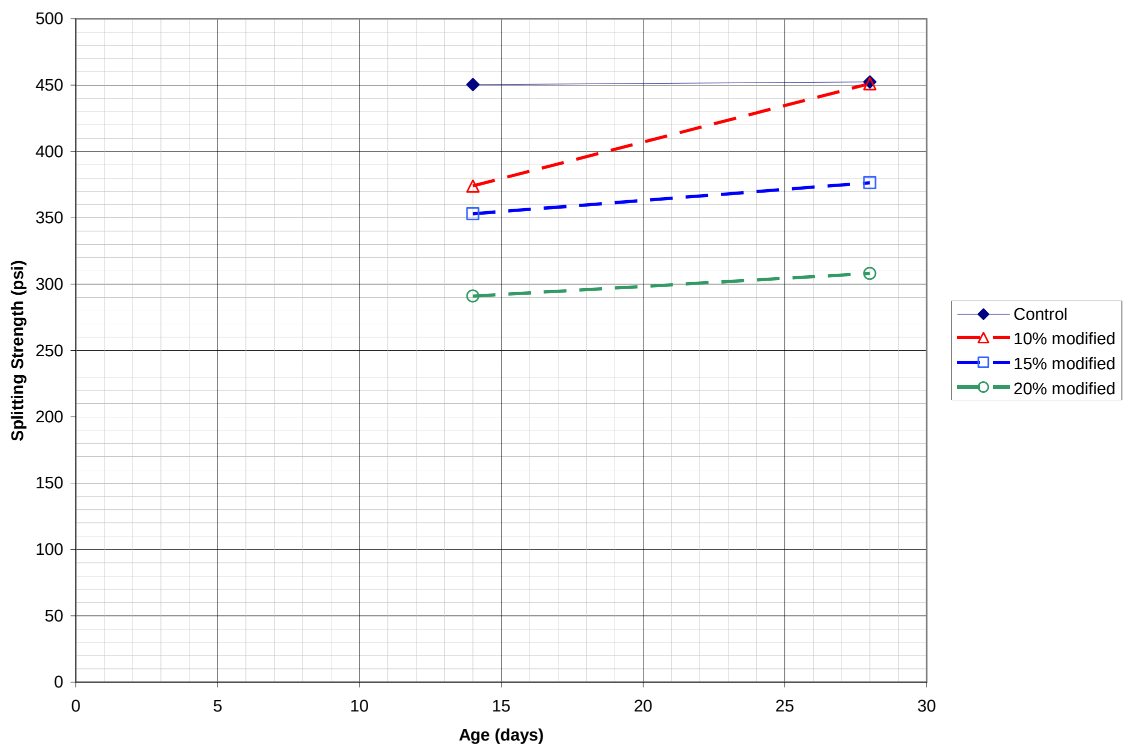

Figure 6. Splitting tensile strength versus age. Test Program II.

Table 6. Percentage decrease of splitting tensile strength on concrete for test program I.

Age (days)	Percentage shredded rubber tire (by volume)		
	10%	15%	20%
14	-29.52	-43.17	-35.52
28	-24.64	-30.72	-20.88

Table 7. Percentage decrease of splitting tensile strength on concrete for test program II.

Age (days)	Percentage shredded rubber tire (by volume)		
	10%	15%	20%
14	-16.98	-21.64	-35.41
28	-0.33	-16.80	-31.93

Table 8. Percentage change in splitting tensile strength by modifying surface treatment on rubber tire particles.

Age (days)	Percentage shredded rubber tire (by volume)		
	10%	15%	20%
14	17.80	37.89	0.17
28	32.26	20.10	-13.97

Table 9: Modulus of rupture testing results

Mix Type	**Modulus of Rupture (psi)**	**Deflection (inch)**	**% deflections change with respect to control mix**	**% deflection change from untreated to treated rubber**
Control Mix	865	0.0691	6.80	NA
10% Shredded Tire Untreated	720	0.0738	34.59	26.02
10% Shredded Tire Modified Surface	775	0.0930	37.05	
15% Shredded Tire Untreated	538	0.0947	48.19	8.13
15% Shredded Tire Modified Surface	582	0.1024	49.64	
20% Shredded Tire Untreated	492	0.1034	52.24	1.74
20% Shredded Tire Modified Surface	511	0.1052	6.80	

Discussion

The introduction of recycled rubber tires to concrete significantly reduced the slump and workability. All concrete mixes were designed to have a slump of 2 inches; however all of the mixes had a slump of much less. It was noted that the slump was reduced as the percentage of rubber was increased. The mix consisting of 10% rubber had a slump of 5/8 in., followed by the 15% rubber mix having a ½ in. slump while the mix with 20% replacement of aggregate by rubber had a slump of just under 1/8 of an inch regardless of the rubber having modified surface or not. In general, as the percentage amount of rubber increased the amount of energy required for casting specimens increased substantially.

Results from Test Program I show a significant decrease in the compressive strength as the rubber replacement amount increases (Figures 1 and 3). Upon examination of broken cylinders containing recycled tire, it could be seen that the concrete broke around the rubber particles and through the interfacial transition zone (ITZ) which has been considered in the literature [19] as the weakest zone in concrete. Table 3 shows the percentage change in compressive strength for each mix and age.

Test program II show also show a decrease in the compressive strength as the amount of recycled tire substitution increased; however, the compressive strength for all mixes was higher when the recycled tire particles where treated with the sodium hydroxide solution (Table 4). This increase in strength with respect to the concrete containing untreated rubber particles is thought to be attributed to the surface modification of the recycled particles which ameliorates the adhesion of the rubber with the cement paste, improving the quality and reducing the thickness of the ITZ. The saturated sodium hydroxide solution had an effect on the hydrophilicity of the rubber allowing it to adhere better to the cement paste that surrounded it. The ITZ refers to the zone that surrounds the aggregate particles. It is generally found that as the paste-aggregate bond increases so does the strength of the concrete whether in tension, flexure or compression [2-4, 9]. Table 5 shows the percentage improvement of compressive strength due to surface modification when compared with concrete containing untreated rubber particles. Upon visual inspection of the untreated rubber concrete particles after testing, the low quality and high porosity of the ITZ was observed, however, the same observation showed improvement on the quality and size of the same area.

In general, it was observed that the stress strain curves (not shown) for each test show an increase in the plastic deformation which translates into an increase of the toughness with a gradual failure, where the pieces of concrete tested tend to stay together linked through the rubber particles (figure 7).

Figure 7: Cylinder specimen held together by recycled aggregate fibers

The NaOH pretreatment seem to have similar effect on the splitting tensile strength of the concrete. Overall the 10% mix had the highest strength improvement decreasing as the percentage of rubber increased.

Similar to compressive and tensile testing, the flexural test showed an increase in strength when the rubber aggregate was pretreated with the NaOH solution but a decreased with respect to the control mix. Just like the cylindrical specimens, the beams showed larger amounts of plastic deformation. Table 9 shows the general increase in deflection as the amount of rubber increased; this trend was corroborated by the shape of the stress-strain curves and the calculations of the modules of elasticity. It is clear the increase in toughness calculated as the area under the stress-strain curves. In general, for all testing the specimens did not shattered as the OPC control mix, the rubber containing specimens cracked but the cracks were arrested by the rubber fibers.

Conclusions

The results of the present research highlight positive effects on the compressive, tensile, and flexural properties of concrete containing surface modified recycled rubber when compared to concrete mixes containing untreated rubber particles. However, the decrease in mechanical properties with respect to OPC concrete is still evident.

Based on results for tests programs I and II, concrete containing shredded rubber particles (untreated or treated) is still not recommended for structural uses; However, the increase in toughness and ductility of the material indicates that further testing is necessary in order to increase the strength while maintaining ductility. Currently, test program III is being executed exploring the use of pozzolans, chemical admixtures, micro fibers and further surface treatment to determine if this objective may be achieved, keeping in mind that as this point, recycled rubber tires use as aggregate could be successful in its use as lightweight concrete in non-structural applications, and it represents a viable alternative to recycle tires helping the conservation of the environment in the process.

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