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THE PROPERTIES OF RUBBERIZED CONCRETES

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ABSTRACT

Utilization of industrial waste products in concrete has attracted attention both with the energy crisis in the 70s and the rise of environmental consciousness. Most of the concrete properties can be improved by incorporating different kinds of industrial wastes. In this study, the changes of the properties for the rubberized concretes were investigated in terms of both size and amount of the rubber chips. The concretes are postulated to be a potential material especially for construction applications which are subjected to impact effects such as crash barriers, bridges and roads. With the cylindrical and cubic specimens produced by adding rubbers of volume ratios of 15, 30 and 45 % into C 20 quality concrete, the physical and mechanical tests were conducted at the end of 7, 28-day and 6-month, and σ–ε diagrams were drawn. From the diagrams the toughness values and plastic and elastic energy capacities of these rubberized concretes were determined. It was observed that plastic energy capacities began to increase when the high elastic energy capacity of normal concrete was reduced by adding rubber. Due to their high plastic energy capacities these concretes showed high strains especially under impact effects.

1. INTRODUCTION

In some application of concrete, it is desired that concrete should have low unit weight, high toughness and impact resistance. Although concrete is the most commonly used construction material, it does not always fulfill these requirements. To improve elastic properties of concrete and recycle the waste materials recently new applications have been realized (1,6). One of these applications is the utilization of discarded tires to replace a part of the aggregate. For this purpose, this research was conducted to investigate the physical and mechanical properties of the concrete which was obtained by incorporating pieces of discarded tires. It is thought that rubberized concrete would be an ideal material for jersey barriers which are subjected to immediate effects of impact and very high strength is not sought for. Rubberized concrete could prevent life casulties and damage to vehicles by absorbing the impact energy.

2. EXPERIMENTAL WORK

2.1. Material Used and Experiment Done

In preparation of the specimens for the experiments, ASTM C 150 type I portland cement (28-day compressive strength of 32.5 MPa) was used. In all concrete series river sand was used, which has 4 mm maximum size, 1.640 kg/dm^3 unit weight, 2.640 specific gravity, 1 % water absorption, and 2.00 fineness modulus. In concrete, crushed limestone of 4 to 16 mm was used as coarse aggregate. The crushed stone has 1.425 kg/dm^3 unit weight, 2.681 specific gravity, 0.3 % water absorption, and 5.04 fineness modulus. The rubber aggregate, obtained by mechanical grinding from the outer surface of scrap tires, was seived and separated into two grain sizes of 0/1 (fine) and 1/4 mm (coarse). The fine and coarse rubber chips had specific gravity of 0.650, unit weights of 0.472 and 0.410, fineness moduli of 1.58 and 1.91, respectively.

2.2. Concrete Mixes

In this study, C 20 control concrete without rubber and six series of concrete with rubber chips of 0/1 and 1/4 mm were used. The mix proportioning of the control concrete series was done using the absolute volume method. The other six series were prepared by replacing same volume of fine and coarse aggregates by rubber chips. The water-cement ratio of the batches were around 0.60 to get an average slump of 40-50 mm and a flow value of 420 mm. The weights and absolute volumes of the materials in 1 m^3 of the control concrete were as follows:

	Cement	Sand	Crashed Stone	Water	Air
Weight (kg)	357.5	609.0	1148.1	222.4	0
Volume (dm^3)	113.5	230.7	428.4	222.4	5

The fine and coarse rubber chips were included by replacing 15, 30, and 45 % of the aggregate in the control concrete. The resulting concretes were designeted as follows: NC (control concrete), FRC-15, FRC-30, FRC-45 (15, 30, and 45 %, by volume, 0/1 mm rubber chips replacing the aggregate), CRC-15, CRC-30, and CRC-45 (15, 30, and 45 %, by volume, 1/4 mm rubber chips replacing the aggregate).

2.3. Tests Conducted

Three 150x300 mm cylindrical and 150 mm cube specimens were prepared for 7, 28 and 180-day compression testing. Before the compression tests, unit weights of the specimens were determined. Then, on each specimen non-destructive tests such as ultrasound velocity and resonance frequency were conducted. For the compressive test (according to ASTM C 39) a 250 ton press with 100-kg sensitivity was used. To measure the deformations, a compressometer with 0.01 mm sensitivity was used. The loading rate was 2 kg/cm^2-sec. and with one-ton load intervals, longitudinal deformations were recorded. During the tests of cube specimens, the machine was stopped at 4 ton load and the surface hardness was found with Schmidt hammer. The σ–ε diagrams of the cylindrical specimens were drawn. Splitting-tensile test (Brazilian) was done and indirect tensile strengths of the cylindrical specimens were determined according to ASTM C 496. The values obtained are the average of at least three specimens.

3. EVALUATION OF THE TEST RESULTS

3.1. Physical Properties of Rubberized Concrete

There is a systematic decrease in the unit weight of the concrete (of 7, 28 days and 6 months), with increasing amount of tire chips. The average unit weight, 2.30 kg/dm^3, of control concrete decreased to 2.22 kg/dm^3, 2.14 kg/dm^3 and 2.01 kg/dm^3 by the using 15, 30 and 45 % tire chips, respectively. Likewise, the values of Schmidt hardness and ultrasound velocity for the concretes decrease with increasing amount of tire chips added. The rebound value of 28-day old control concrete was 29, whereas it decreased to 19 and 16 with addition of fine and co-arse tire chips, respectively. Similarly, the value of Schmidt hardness for 6-month old concrete was 30, which reduced to 19 and 22 for the 45 % of fine and coarse rubber chips. For 28-day old control concrete, ultrasound velocity was determined as 4.30 km/sec, whereas it decreased to 3.60 and to 2.85 km/sec. with addition of 45 % fine and coarse rubber chips, respectively.

3.2. Mechanical Properties of Rubberized Concretes

The values of compressive strength for rubberized concrete are given in Figures 1 and 2. As shown in these figures, the strength values of the rubberized concrete are considerably decreased

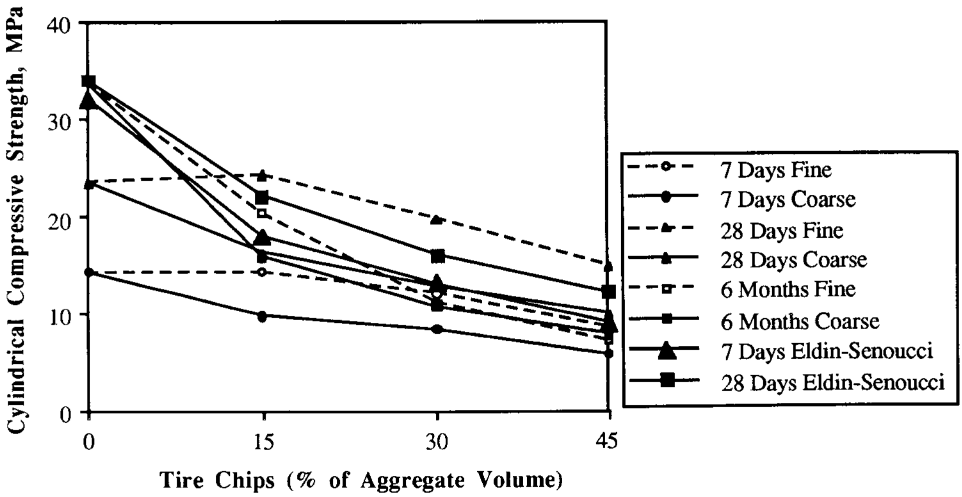

Figure 1. Changes in Compressive Strength with the amount of Rubber Mixture

with increasing amount of tire chips at the end of 7, 28-day and 6-month. As seen in Figure 1, the compressive strength of the control concrete at 7 days is 14.27 MPa. However, this reduces to 14.16, 12.00, and 8.54 MPa with addition of 15, 30, and 45 % of fine rubber chips, respectively. Likewise, it decreases to 9.68, 8.38 and 5.80 MPa with addition of the above stated percentages of coarse tire chips.While the cylindrical compressive strength of 28-day old concrete was determined as 23.48 MPa, it was determined as 24.22, 19.70 and 14.77 MPa with the addition of above stated fine rubber. Furthermore, it was decreased to 16.18, 12.62, and 9.90 MPa with the addition of the coarse rubber chips.

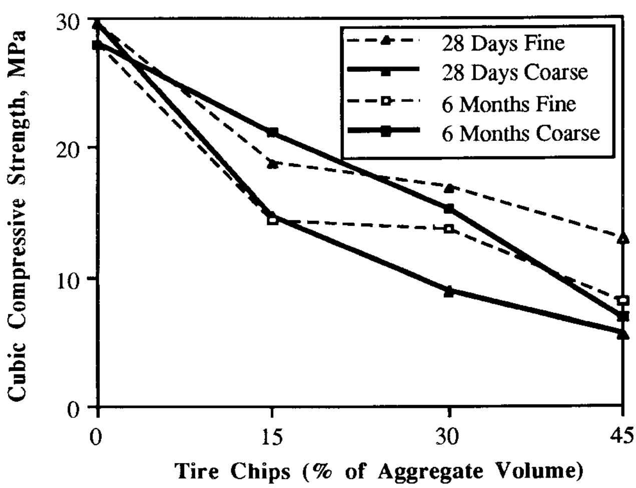

Figure 2. Changes in Cubic Strength With the Amount of Rubber Mixture

For the 6-month old specimens, the strength value of the normal concrete was determined as 33.67 MPa.However, it was found as 20.23, 11.06, and 7.16 MPa with the mixture of fine rubber chips, and 15.75, 10.82, and 7.72 MPa with the mixture of coarse rubber chips.

As seen in Figure 1, there is no substantial change in the strength of 7 and 28-day with respect to tire chips (0 to 15 % aggregate volume of fine tire chips); however, there is a linear inverse relationship between strength and the tire chips for the same amount of the volume of 6-month. On the other hand, there is about a linear inverse relationship between the same components for the coarse rubber chips. To make C 20 rubberized concrete, about 35 % fine and 15 % coarse rubber tire chips should be suitable.

Figure 2 shows the compressive strength of the cubic specimens with respect to the tire chips amounts added. As seen in the figure, the compressive strength of a C 20 normal concrete for 28-day was determined as 29.50 MPa. However, it was determined as 18.80, 16.90, and 12.90 MPa with the addition of the ratio of 15, 30 and 45 % of fine rubber chips, and as 14.60, 8.91, and 5.51 MPa with the addition of the same amount of coarse rubber chips, respectively. For the 6-month, the compressive strength was determined as 28.00 MPa for the normal concrete while it was decreased to 14.40, 13.60 and 8.00 MPa, and 21.00, 15.27, and 6.87 MPa with the addition of fine and coarse rubber chips, respectively. This suggests that the coarse tire chips lower the compressive strengths more than the fine tire chips. This could be caused by weak interfacial bonds between the cement paste and tire chips.

The specimens withstood measurable post-failure compression loads and underwent significant displacement without full disintegration. Displacements and deformations were partially recoverable upon loading. Rubber particles having low modulus of elasticity produce high internal tensile stresses that are perpendicular to the direction of the compression load applied. Cement paste shows early failure because of its weakness against tension. Rubber chips behaving like springs delay the widening of the existing cracks. Continuous application of compressive load generates more cracks and widens the already present ones. When the bond between cement paste and rubber is overcome, fracture occurs.

For the splitting-tensile test, the C 20 normal concrete is yielded 3.21 MPa, while it is determined 2.17, 1.53, and 1.13 MPa with the fine rubber chips and, 1.50, 1.06, and 0.82 MPa with the coarse rubber chips for the addition of 15, 30, and 45 % ratios, successively. In the splitting-tensile strength tests, specimens showed high capacity of absorbing plastic energy as expected. The failed specimens withstood measurable post-failure loads and underwent significant displacement, which was partially recoverable. Thus the concrete mass was able to withstand loads even when it was highly cracked. This should be because the rubber aggregate has the ability to undergo large elastic deformation before failure as reported by Eldin and Senoucci (3). Specimens containing rubber did not exhibit brittle failure under compression due to the rubber's plastic behavior. Splitting was gradual depending on the type and amount of rubber used. Eldin and Senoucci (3), reported losses up to 85 % in compressive strength and up to 50 % in tensile strength at their experimental study. Here, maximum reductions in presented study on the mechanical strengths with the addition of rubber of 45 % are given as follows:

	Cylin.Comp.Strength			**Cubic Compr.Strength**		**Spl.-Tens.Strength**
	7 Days	28 Days	6 Months	28 Days	6 Months	28 Days
FRC	0.40	0.37	0.78	0.56	0.71	0.64
CRC	0.59	0.57	0.77	0.81	0.75	0.74

3.3. σ–ε Diagrams of Rubberized Concretes

Although the σ–ε diagrams of 7, 28-day and 6-month normal and rubberized concretes were tested in this study, because of their similarity only those of 28-day concretes are given in Figure 3 as example. When the σ–ε diagrams of these concretes are analyzed, it can be seen that control concrete reaches the ultimate strain around 0.002. The concrete having 15 % coarse rubber mixture shows similar behavior as normal concrete. With mixture of coarse rubber particles maximum strain points fall while the strain increases at the failure point in rubberized concretes ε-strain values change between 0.003 and 0.005 against maximum strains.

Changes in toughness values with addition of rubber were determined by measuring the areas under the σ–ε diagrams and are given in Figure 4. Here, although decreases in toughness with additions of rubber are observed, some changes are witnessed in the energy capacities consumed during the fracture. Since the rubberized concretes absorb more energy, they can show more strain at the time of fracture. Examination of ε_{max} values obtained from σ–ε diagrams show that these values can reach to 0.007 and 0.008.

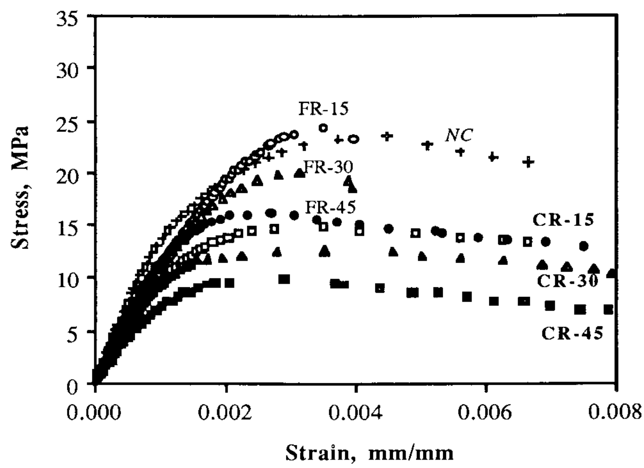

Figure 3. σ–ε Diagram of 28-Day Old Concrete

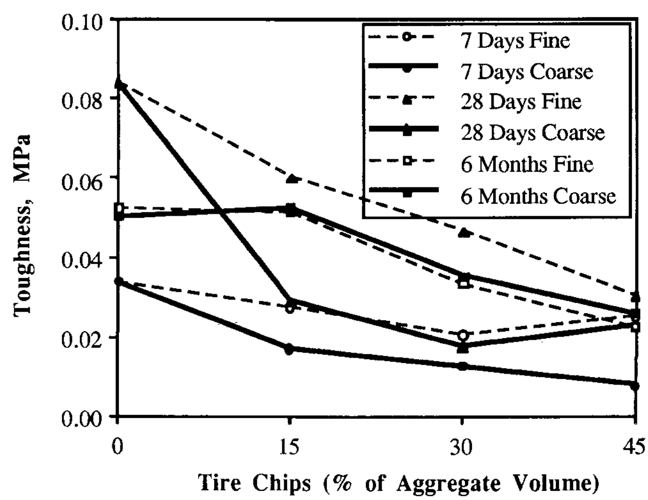

Figure 4. Changes in Toughness Values with Addition of Rubber

Toughness values in terms of energy capacities consumed at the time of fracture were investigated in two different ways as plastic and elastic properties. How the energy capacities are evaluated is explained in Figure 5. As can clearly be seen from Figure 5, in the total area shown as toughness area under σ–ε diagram, A1 area that shows the plastic energy consumed during the failure and never recovered again (plastic energy capacity) and A2 area that shows the recovered deformation energy to be obtained just before fracture (elastic energy capacity) were seperately calculated and investigated. Changes in plastic and elastic energy capacities with addition of rubber shown in Figure 5 are seperately shown in Figures 6 and 7.

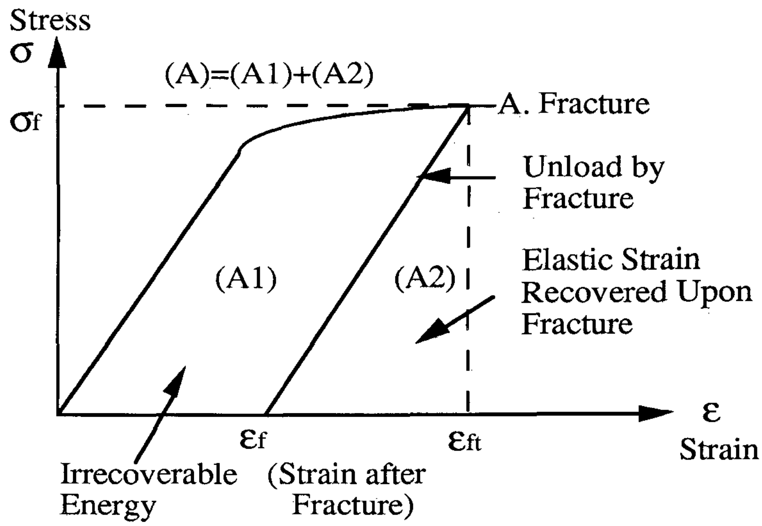

Figure 5. Determination of Elastic and Plastic Energy Capacities (3).

It was observed that the originally high elastic energy capacities of normal concretes begin to decrease with the additon of rubber and originally low plastic energy capacities begin to increase. That a material has high plastic energy implies that it could show higher deformation at the time of fracture and it could absorb more energy. With the rubber mixed into concrete plastic energy capacities of the concretes can be increased.

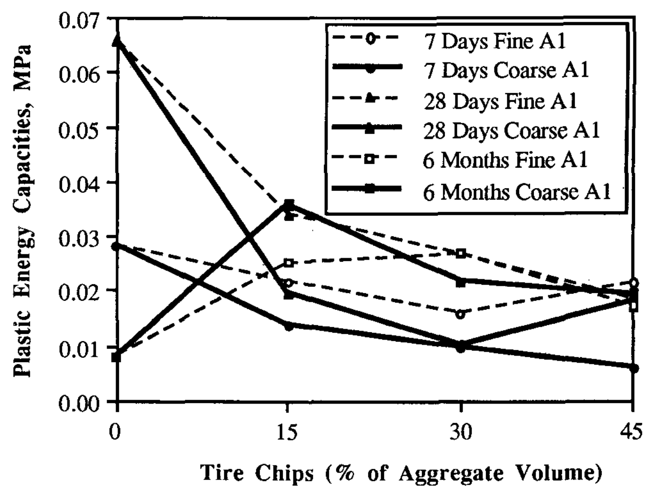

Figure 6. Changes in Plastic Energy Capacities with the Additon of Rubber

4. CONCLUSIONS AND RECOMMENDATIONS

A general reduction in the physical and mechanical properties of rubberized concrete made by using scrap tires was observed. About 50 % decrease in cylinder and cube compressive strengths, 64 % decrease in tensile strengths were observed in concretes mixed with fine rubber particles. On the other hand, using coarse rubber particles caused decreases up to 60 % in cylinder compressive

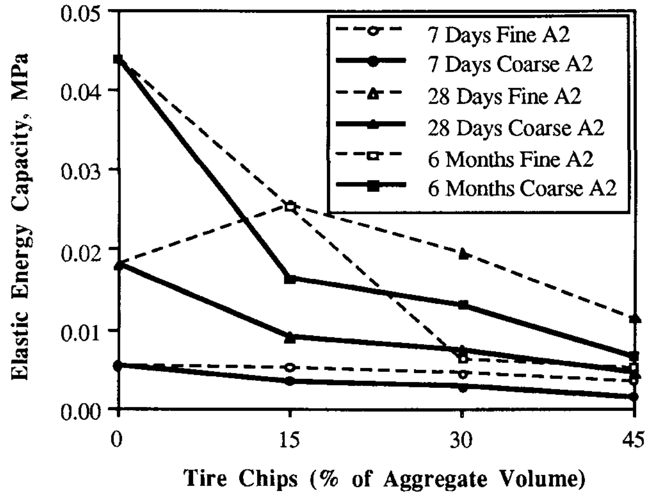

Figure 7. Changes in Elastic Energy Capacities with the Additon of Rubber

strengths, and up to 80% in cube strengths and up to 74 % in tensile strengths. These results indicate that coarse rubber aggregates affect the properties more negatively than fine rubber aggregates. Rubberized concretes in contrast to the normal ones have higher plastic energy capacities. With addition of rubber, which is an elastic material, concrete becomes comparatively ductile and begins to show the behavior of an elastic structure under load. With this new property it is projected that these concretes can be used in architectural applications such as nailing concrete, in road constructions where high strength is not necessary, in wall panels that require low unit weight, in construction elements and Jersey barrires that are subject to impact, in sound barries as sound absorbers, and in rail roads to fix the rails to the ground.

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