Investigation the Physical Properties of Rubber Concrete

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ABSTRACT

Increasing trend for automobile production in recent decades has caused an extensive volume of waste tires, which are not dissolvable in nature, and generates many problems as environmental pollutants. Therefore, the present research with impetus on feasibility of using waste tires in concrete has been accomplished. In order to reach this goal, some laboratory samples were made and tested. The laboratory investigations were compressive strength, modulus of elasticity, tensile strength, and flexural strength. In this research, the effect of different weight percentages (5, 7.5 and 10 percent) of cement and sand replacement by waste tires has been investigated separately. The experiments were divided into two groups. The first one was replacement of sand with rubber chip and in the second group, the replacement of cement with rubber powder. The results indicated that in both groups and up to 5% rubber, no significant change was observed, but when more than 5% rubber was used most of physical properties of concrete varied.

KEYWORDS

Concrete, Waste Tire, Physical Characteristic

1. INTRODUCTION

Scrap tire is composed of ingredients that are non-exhaustible in nature in normal conditions and usually produce environmental mal-effects. Recently, discarded fiber tires have had high profiles as a waste disposal problem, and their stockpiles have produced the potential of environmental damage. This stockpiles are dangerous not only due to potential of fire hazards, but also stockpiled tires catches rain water and become a breeding ground for disease carrying mosquitoes, mice, rats and vermin [10]. Application of rubber in concrete could be a useful solution to meet the challenge associated with disposal problems of waste tire.

According to the official Iranian Industrial Ministry reports, the total production of rubber tires was 205,000 tons in Iran in 2005. It is estimated that the lifetime for each tire is two-years. Therefore, there will be nearly 100,000-tone scrap tire annually. There is no solution for problems associated with this waste tires. If they could be successfully used in concrete, it may solve environmental problems especially in landfills.

The rubber tire is of two general categories: automotive tire and truck tire. They are different in their structure and composition, mainly the amount of carbon black and fiber type. The amount of these materials is varied to attain desirable tire properties: Young modulus, tensile strength, strength of failure and resilience. Automotive tire, because of their large volume of production rather than truck tire is more attended in the recent studies.

The use of waste tire in concrete is very desirable because the resulted material is of high toughness opposed to conventional concrete [1]; but the rubberized concrete shows a remarkable decrease in mechanical properties comparing to normal concrete [2-11].

Eldin and Senouci [2] reported that there is approximately 85% reduction in compressive strength and 50% reduction in splitting tensile strength when coarse aggregate was fully replaced by coarse crumb rubber chips. However, a reduction of about 65% in compressive strength and up to 50% in splitting tensile strength was observed when fine aggregate was fully replaced by fine crumb rubber. Topcu [4] investigated the particle size and content of tire rubbers on the mechanical properties of concrete. He found that, although the strength was reduced, the plastic capacity was enhanced significantly. Khatib and Bayomi [5] in their study concluded that rubberized concrete shows a systematic reduction in strength with increasing rubber content, while its toughness was enhanced. So, they concluded that rubber content in concrete should not exceed 20% volume of aggregate due to severe reduction in the strength of concrete with addition of rubber. Sukontasukkul and Chaikaew [7] studied the use of crumb rubber to replace coarse and fine aggregates in concrete

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pedestrian block. Their results showed that it is possible to manufacture concrete block containing rubber crumb up to about 20% by weight using a conventional plain concrete block manufacturing processes. The resulting blocks, though not as strong as plain concrete block, are lighter and seem to be more flexible with better energy absorption. Papakonstantinou and Tobolski [8] focused on the use of steel beads, a byproduct of the tire recycling process, in concrete mixtures. When 2% steel beads are used in the mixtures the compressive strength reduction is minimal. But, the mixes are workable up to 4% volume fractions although there is a decrease in workability with an increase in steel bead content. Kaloush et al [9] investigative efforts determined that the entrapped air, which caused excessive reductions in compressive strength, could be reduced substantially by adding a deairing agent. The coefficient of thermal expansion test results indicated that rubberized concrete was more resistant to thermal changes. Such behavior besides the higher toughness of rubberized concrete may be beneficial for a structure that requires good impact resistance properties.

The review of these studies shows that replacement of aggregate with rubber leads to weakness in mechanical characteristics but improves toughness and ductility. In addition, there are some differences in their research results. Eldin and Senouci [2] discovered that the compressive strength of concrete decreases when coarse aggregate was fully replaced by rubber, but smaller reduction in compressive strength was observed when sand was fully replaced by fine crumb rubber. This is in contradiction with the results of Fattuhi and Clarlk [6]. By comparison and contrasting of these studies, it is found that these differences in their results are due to the quality of aggregate material and cement as well as various procedures used for attaining concrete mix design. On the other hand, the related studies were conducted to solve the environmental problems associates with the stockpiling of waste tire, and no attempt was made to improve the properties of modified concrete with waste tire. The main part of concrete is composed of aggregate and their effect on the mechanical properties of concrete matrix is smaller than cement. So, the main focus on these studies was made to replace aggregate with rubber. It seems that replacement of cement particles with rubber may be an alternative. Replacement of cement by waste tire powders will reduce the amount of cementitious materials but it was believed that the rubber powder could fill pores of concrete, and in this way, it may compensate the deficiencies associated with reduction of cement as adhesive material.

The objective of this study is not only to follow the trend of past studies which was the replacement of aggregate by waste rubber but replacement of cement by waste tire is also investigated.

2. Experimental Program

In order to review the impact of concrete material (coarse aggregates, fine aggregates and cement) characteristics and the possibility of replacing them with waste tire rubber, various specimens were designed, prepared and tested after curing in standard conditions.

A. Raw Materials and Specimens Preparations

Material used to make concrete specimens were fine aggregate, coarse aggregate, cement, tire chips, tire powder and water. The properties of fine and coarse aggregates were determined according to ASTM standard test methods C 127, C 128, C 129 and C 136. The coarse aggregate was selected from crush stone, which was maximum 25 mm in size. The grading distribution curves for coarse and fine aggregate with the Iranian standard's limits are given in Figures 1 and 2.

In these figures, standard ranges (Iran National Standard-No.302) have been shown in dotted lines. To make chip rubber, at first, automobile tire was shredded by a mill to 50–100 mm in dimension. Then its wires were isolated, and after that to achieve the same size as the coarse aggregate, rubber particles were converted into small dimensions (10-20 mm) by cutters. The grading of the rubber chips is depicted by continuous solid line in Figure 2.

The concrete specimens were prepared with 380 kg/m^3 of Type II Portland cement and water/cement ratio of 0.5. The amounts of fine and coarse aggregate were 858 and 927 kg/m^3, respectively. In this research, two groups of specimens were made and tested:

First group: In this group, coarse aggregates were replaced by shredded rubber in 3, 5, 7.5 and 10, weight percentages. The specimens were identified as RAx, which is an abbreviation for aggregate replacement by x percent. The large rubber parts were reduced in size with cutter (Figure. 3).

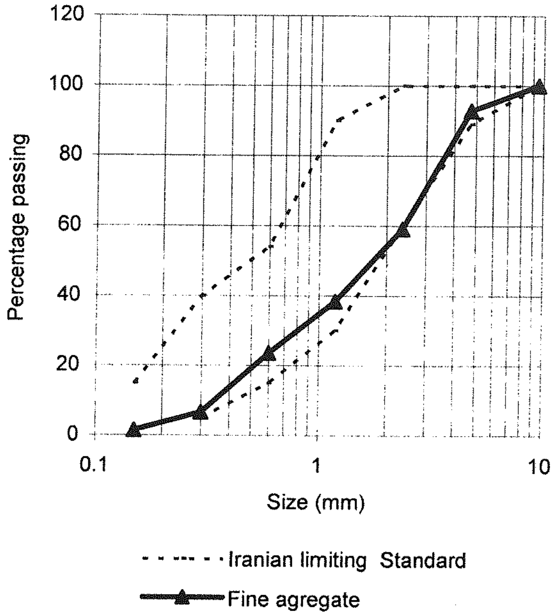


Figure 1: The grading curve of the fine aggregate according to Iranian standard.

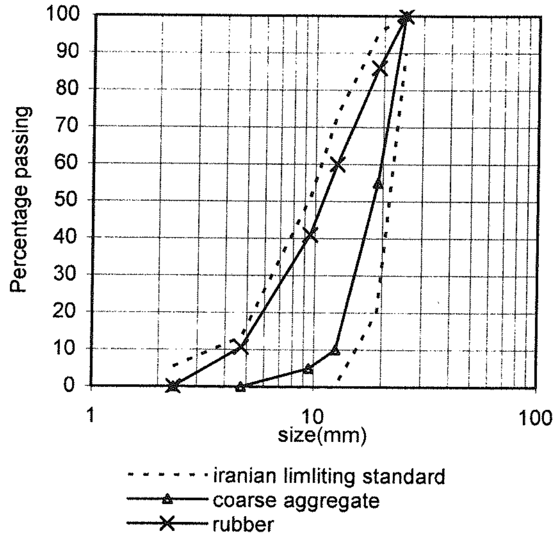


Figure 2: The grading curve of the coarse aggregate according to Iranian standard.

Second group: In this group, cement was replaced by powder rubber in 5, 7.5 and 10 weight percentages. The specimens were identified as RCx, representing, x percent replacement for cement. The size of rubber particles was 400-500 μm (Figure 4.).

The control sample in this research is named CS. The names of specimens and their mix design specifications are given in Table 1.

Specimens (which included 3 samples) were demolded after 24 hours of casting the concrete into moulds, and were kept in a concrete curing chamber for 28 days.

B. Testing

The compressive strength was determined using 150×150 mm cubic specimens, and was tested according to the BS 1881: part 116: 1993 standard. In addition, the tensile strength and Young modulus were determined

Figure 3: Rubber shredded (Chip rubber particles) as replacement for coarse aggregates.

Figure 4. Rubber powder as replacement for cement.

according to BS 1881: part 117: 1983 and BS 1881: part 121: 1983 with cylindrical samples of 150 × 300 mm. Flexural strength test was also carried out according to BS 188: part 118: 1983 by making prismatic specimens of 100 × 100× 500 mm dimensions.

TABLE 1. MIX DESIGN DETAILS OF THE PREPARED MIXES.

Sample ID	Weight of the materials used (kg/m^3) Rubber		Cement (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)	Description
	Shredded	Shredded				
CS	0.0	0.0	380	858	927	Control
RA5	46.4	0.0	380	858	884	Replacing 5 percent by weight rubber particles for aggregates
RA7.5	69.5	0.0	380	858	461	Replacing 7.5percent by weight rubber particles for aggregates
RA10	93	0.0	380	858	839	Replacing 10 percent by weight rubber particles for aggregates
RC5	0.0	19.0	361	858	927	Replacing 5 percent by weight cement with rubber powder
RC7.5	0.0	28.5	351.5	858	927	Replacing 7.5percent by weight cement with rubber powder
RC10	0.0	38.0	342	858	927	Replacing 10 percent by weight cement with rubber powder

3. RESULTS AND DISCUSSION

A. Compressive Strength

Results of the 28-Day compressive strength are presented in Figure. 5. As it can be seen, by replacing rubber content up to 5% of coarse aggregate, about 5% increase in compressive strength was obtained. However, with increasing rubber to 7.5 and 10%, a reduction of 10 and 23% in compressive strength was resulted compared to control specimen.

In the second group, the compressive strength of concrete shows the same trends similar to that observed in the first group, but the compressive strength in this group is slightly lower than the first one. This may be related to the decrease of cementitious material by replacing cement with the rubber powder.

The reasons for reduction in the compressive strength of concrete in both groups are related to different characteristics of rubber particles and its role in concrete. These factors may be attributed to the following issues:

1- As rubber particles are much softer than hardened cement paste surrounding them, the cracks would quickly develop around the rubber particles during loading and propagate rapidly throughout the matrix. So, the failure of concrete would be accelerated.

2- Due to lack of proper bonding between rubber particles and the cement paste (as compared to cement paste and aggregates), a homogeneous and integrated matrix of concrete is not available. Therefore, during loading, applied stresses cannot uniformly distributed in the paste and causing cracks initiating at the interfaces of rubber aggregates and cement paste.

3- Because a portion of the cement or aggregates is replaced by rubber particles, their volumes will reduce in

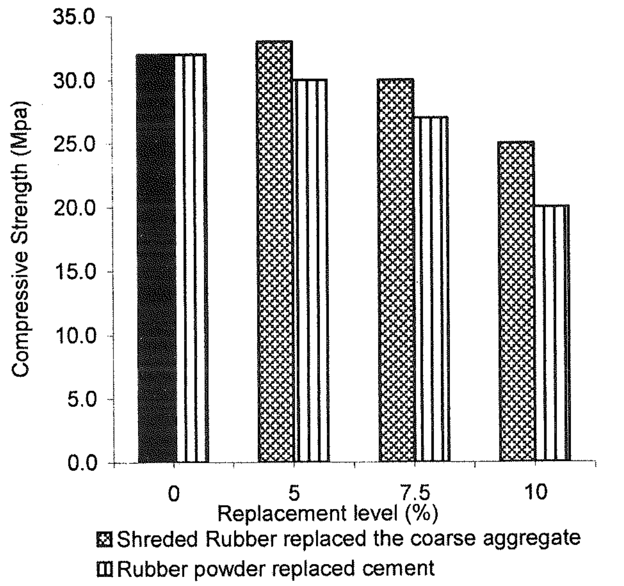
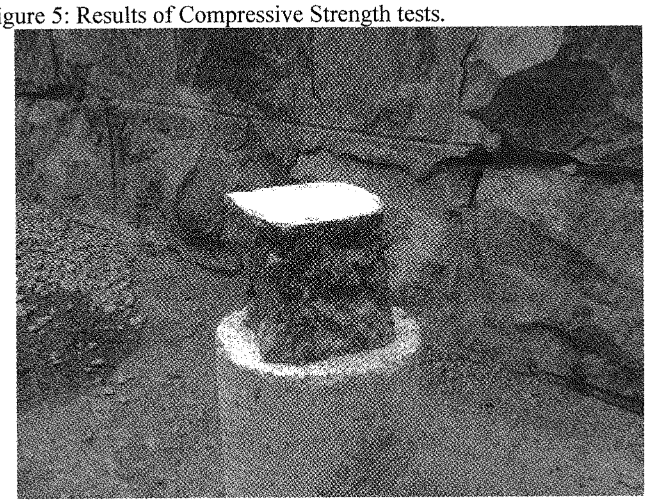


Figure 5: Results of Compressive Strength tests.



a) Control sample

b) Rubber concrete

Figure 6: Failure of cubic samples under compressive loading.

concrete mix design. On the other hand, the compressive strength of concrete depends on the physical and mechanical properties of these materials (which have considerable superiority over rubber). Therefore, reduction in the compressive strength of concrete is expected.

4- During molding and vibration, because the specific gravity of rubber materials is lower than aggregates, rubber particles tend to move toward the upper surface of the mould, resulting in a high concentration of rubber particles at the upper layers of the specimens. This problem is manifested more clearly in the first group. Non-uniform distribution of rubber particles at the upper layers tends to produce non-homogeneous samples and leads to a reduction in concrete strength at those parts, such that its failure occurs at lower stresses.

5- The lower strength of the second group compared to the first group was due to the reduction in the quantity of cement used as adhesive materials.

Since, rubber has a lower stiffness compared to aggregates; existing of rubber in concrete reduces the concrete matrix stiffness and lowers its load bearing capacity. It also seems that a slight increase in the compressive strength of the specimens containing 5 percent shredded rubber due to a small reduction in the coarse aggregate quantity of the mix design, which has, in turn, modified the aggregate grading of rubberized concrete. In other words, the weight ratio of coarse aggregate compared to other materials (cement and fine aggregate) has been improved.

From the findings of this research, it reveals that 5% replacement of rubber for aggregate or cement would not have a noticeable effect on concrete strength. This behavior (a slightly increasing or decreasing in strength) may be due to the experimental errors. Meanwhile, the failure mode of these samples in both groups is similar to control sample as shown in Figure 6.

B. Modulus of Elasticity

The results of Young modulus for all mix designs are shows in Figure 7. As it can be seen, replacing coarse aggregate by waste tire rubber would decrease modulus of elasticity. This trend is repeated in group 2.

Considering concrete as a base model of a composite compound consisting of two phases ,i.e. ,aggregate and cement, it is observed that the aggregates modulus of elasticity (as the aggregates properties would influence on Young modulus) and the volumetric ratio of these particles in concrete has an important role on the Young modulus of concrete. With increasing Young modulus of aggregate, the concrete Young modulus also increases.

Therefore, it is clear that the replacing of aggregate and cement with rubber particles, which have low Young modulus, decreases the concrete Young modulus. This result has been reported by other researchers that mentioned before [5 and 10].

C. Tensile Strength

The results of tensile strength are shown in Figure 8.

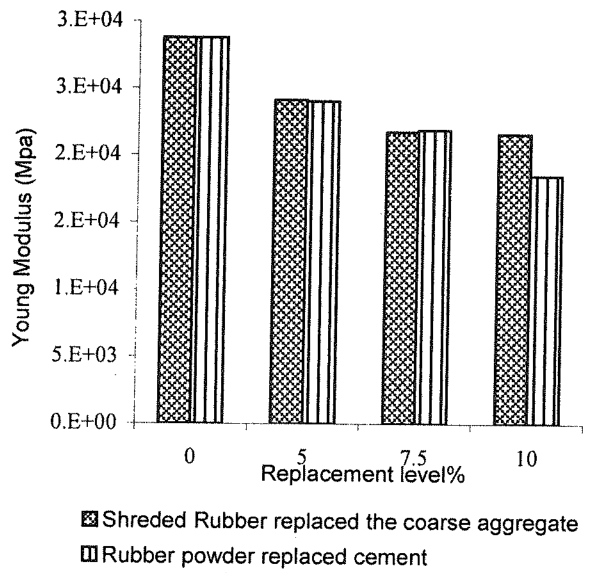


Figure 7: Results of Young modules tests.

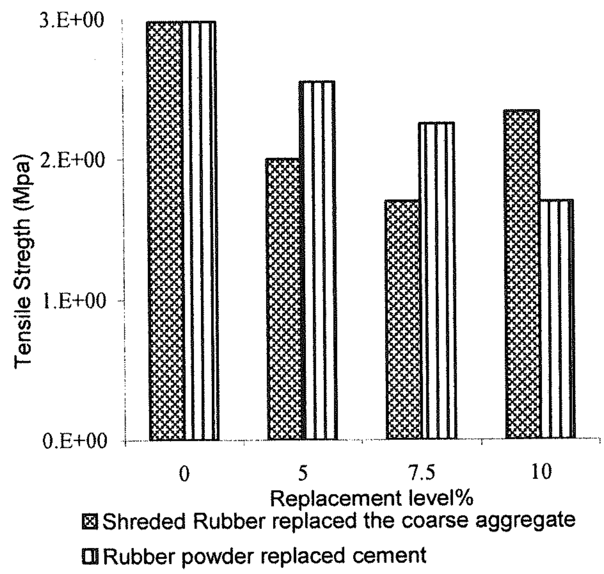


Figure 8: Results of tensile strength.

The tensile strength of the concrete was reduced with increasing rubber in both groups. The reduction of tensile strength in the first group was about twice when compared to the second group. The reduction in tensile strength with 7.5 percent replacement was 44 and 24 percent, respectively, in the first and second group as compared to the control sample.

Griffith theory describes the behavior of materials when exposed to tensile loading. According to this theory, materials contain microcracks and crevices, which act as stress rising points on tensile loading and may cause failure of this surface and released the energy stored in the materials. If the released energy is sufficient to propagate cracks, the conditions for immediate failure are provided, but if some barriers will exist, crack expansion is stopped and the load can be increased. In concrete, micro cracks grow and extend if stress is applied. When crack extension in the cement paste is confronted with barriers such as a large cavity, un-hydrated cement particles or a soft material that requires greater energy to disintegrate, its development is hindered.

Tire rubber as a soft material can act as a barrier against crack growth in concrete. Therefore, tensile strength in concrete containing rubber should be higher than the control concrete. However, the results showed the opposite of this hypothesis.

The reason for strength reduction in rubberized concrete can be hypothesized. First, because the weak bonding between rubber and cement paste, the interface between rubber and cement paste may act as a microcrack. It could increase stress in transition zone and accelerates concrete failure. Secondly, visual observation of failure surface shows that rubber tearing is not observed after concrete failure (this is more clearly apparent in the first

Figure 9a: Failure Mode of concrete after splitting tensile loading.

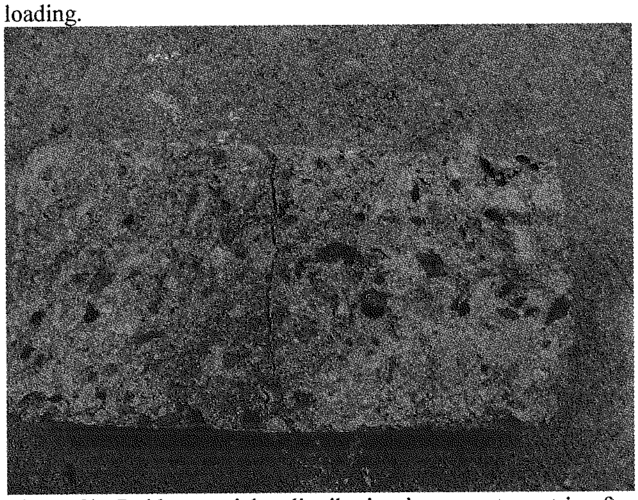


Figure 9b: Rubber particles distribution in concrete matrix after failure on tensile loading.

group). The reasons for this behavior may be as follows: if rubber has a positive effect in increasing concrete strength, the bonding force between rubber and cement paste shall be strong enough to transfer the load from rubber to cement paste. Otherwise, during crack expansion and when it encounters rubber particles, the inserted force causes a surface debonding between rubber and cement paste. Therefore, it can be said that rubber acts just as a cavity or a stress rising to accelerate concrete failure. This theory confirms and complies with visual observation of broken surface during
tests, such that, rubber may be detached from concrete matrix by one finger. Failure modes of rubberized concrete in tensile and distribution of rubber particles in matrix are shown in Figure 9.

D. Flexural Strength

The results of flexural strength tests are shown in Figure 10. Addition of rubber to concrete reduces flexural strength. The reduction in flexural strength occurred in

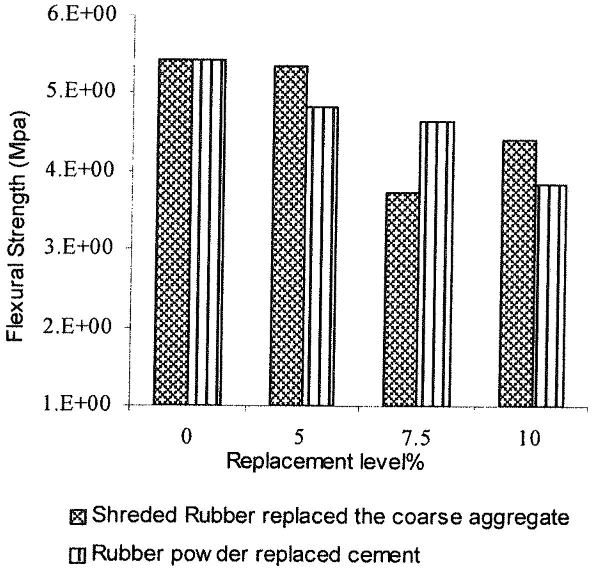


Figure 10. The Results of flexural strength for the first and second group strength.

both groups, but the rate of reduction is different from one group to another. The highest reduction occurred in the first group by applying 7.5 percent of shredded rubber to replace coarse aggregate. A reduction of 31 percent, with respect to the control sample, was observed in the first group. This value is only 15 percent for the second group.

According to a general principle governing flexure, on flexural loading, it produced a tensile stress on one side of the neutral axis and compressive stress on the other side.

When, the flexural stresses exist on concrete, due to lower tensile strength of concrete comparing to its compressive strength, before concrete reaches its ultimate strength in the compression region, failure will occur. As a result, the most important factor in reducing flexural strength, are the same as tensile strength, the lack of proper bonding between rubber particles and the cement paste. This conclusion was confirmed with the visual observation made after breaking the flexural tested samples. It was observed that shredded rubber could be easily removed from concrete. The loose bond in the first group (shredded rubber) was more obvious than the second group, i.e. ,powdered rubber.

4. CONCLUSION

Based on these laboratory investigations, the following conclusions can be drawn:

1- The compressive strength of concrete depends on two factors: grain size of the replacing rubber and percentage added. In general, compressive strength will be reduced with increasing the amount of rubber in concrete. Up to 5 percent, changes in compressive strength, is too low to influence concrete properties. The highest reduction in compressive strength is related to 7.5 and 10 percent replacement for both groups. Reduction in the compressive strength in the first group is about 10 to 23 percent and in the second group about 20 to 40 percent. The compressive strength in the first group is higher than the second group.

2- The tensile strength of concrete is reduced when rubber particles used instead of other materials in concrete. The most important reason for this hypothesizes is lack of proper bonding between rubber and the matrix, which plays the key factor in reducing tensile strength. With replacing 5-10 percent in the first group, the reduction is about 30 to 60 percent and in the second group it reaches to bout 15 to 30 percent.

3- Replacing rubber particles by cement and aggregates reduces the flexural strength of rubberized concrete. However, the rate of reduction was different. In the first group, reduction is about 2 to 12 percent and in the second group reaches to 12 to 30 percent. Similar reasons for the tensile strength are applied for the flexural strength.

4- Generally, rubberized Portland cement concrete could be made using shredded rubber or powder rubber in partial replacement by volume of coarse aggregate or cement. From the practical viewpoint, rubber content up to 7.5% of coarse aggregate and 5% of cement is desirable.

Based on official Iranian Industrial Ministry statistics, it was estimated that approximately 20 million tons of cement was produced in Iran in 2005. It is consumed in concrete mix design, slurry, and cement blocks. The amount 10 million tons of cement are consumed in such concrete. If 5 percent by weight of cement is replaced by rubber powder, over 700,000 tons of scrap tires will be needed. For constructional application, more physical and durability investigations of rubberized concrete are necessary.

5. ACKNOWLEDGMENT

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