Mechanical Properties of Concrete with Waste Tire Rubbers as Coarse Aggregates

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ABSTRACT: The promotion of automobile industry has accompanied with increase in prevalent waste material such as waste tire. The undegradable nature of the rubber and the consequent disposal problem has lead to a serious environmental issue in the recent decades. To overcome this problem, many innovative solutions have been proposed. Using this waste material in concrete can solve these problems. In this study, the effect of replacing coarse aggregate with tire chips on mechanical and physical properties of concrete, such as compressive strength, tensile strength, flexural strength, modulus of elasticity, is examined. At first, tire is cut into chip particles and then partially replaced the coarse aggregates, and some specimens was cast and tested for this purpose. The experimental results show that the replacement of coarse aggregates by rubber particles for up to 5% by weight have no important effect in prevalent properties of concrete, but more replacement of these materials, changes the concrete properties significantly.

1 INTRODUCTION

Waste tire rubbers are materials that do not decompose and disintegrate in the nature; so they are considered as environmental pollutants. With the growth of automobile industry, and the subsequent increase in tire production rate in recent decades, tire waste has created abundant difficulties. Many innovative solutions have been proposed to solve this problem. Rubber particles are applied as a last circulating material in petroleum industry, also in asphaltic pavement and recently in Portland cement concrete. The latter case is under consideration in this study.

Since waste rubber properties and its weight percent influences the physical properties and durability of concrete, their applications should be limited to the results obtained in the same physical and application terms.

In recent decade, associated problems with waste tire have been considered more than before and this caused to do some investigation on properties of concrete having waste rubbers (Eldin et al [1993], Amos et al [2000], Fattuhi, et al [1996], Khatib et al [1999], Naik et al [1991] , Siddique et al [2004], Topcu [1995]) as ingredients of the mix. These studies are based on the effect of: size, replacement percentage, and surface treatment of rubber.

Frequently, in these studies, two broad categories of waste rubber have been considered such as Chip and Crumb rubber:

1) Shredded or Chip rubber which replaced the gravel. To produce this rubber, it is needed to shred the tire in two stages. By the end of stage one, the rubber has length of 300-430 mm long and width of 100-230 mm wide. In the second stage it's dimension changes to 100-150 mm by cutting. If shredding is further continued, particles of about with 13-76 mm in dimensions are produced and are called "Shredded particles."

2) Crumb rubber that replaces for sand, is manufactured by special mills in which big rubbers change into smaller torn particles. In this procedure, different rubber particles in size may be produced depending on the kind of mills used and the temperature generated. In a simple method, particles are made with a high irregularity in the range of 0.425-4.75 mm. In more complex procedures i.e. Micro – milling process, the particles made are in the range of 0.075-0.475 mm.

Eldin et al [1993] conducted experiment with using waste tire as chip and crumb rubbers as alternative to aggregate to investigate compressive and tensile strength of concrete. Their results indicated that there is an 85 % decrement in compressive strength and 15% in tensile strength when coarse aggregate fully replaced by equal volume of chip rubber; but with replacing fine aggregates with crumb by equal volume, there would be decrement up to 65% in compressive strength and 50% in tensile strength. Both products are flexible and could absorb more energy under tensile and compressive loading.

Khatib et al [1999] studied the influence of adding two kinds of rubber, Crumb (very fine to be replaced for sand) and Chip (at the size of 10-50mm to be replaced for gravel). They made three groups of concrete mixtures. In group A, crumb rubber to replace fines, in group B, chip rubber to replace coarse aggregate and in group C both types of rubber were used in equal volumes. In all the three groups eight designated rubber contents in the range of 5 – 100 % were used.

They found that the compressive strength of concrete would decrease with increasing rubber content. For example replacing 100% gravels by chip rubber would decrease the compressive strength of concrete up to 90%, meanwhile, they showed that the rubberized concrete made with chip has less strength than concrete made with crumb rubber.

Serge et al [2000] in their study added rubber particles into cement paste (rubber particles had a size with maximum 50 µm). In order to decrease hydrophobic in rubber surface NaOH was chosen. At first, the surface of rubber particles modified by saturated NaOH for 20 minutes. They concluded that the rubber particles treated by NaOH shows better cohesion with cement paste. Their results indicated that there was an improvement in flexural strength by this procedure, but a 33% decrement occurred in compressive strength.

By comparing and contrasting these studies, it is clear that these differences in their results are due to the quality of gravel materials and cement as well as various procedures used for attaining to concrete mixture designs. Meanwhile, in all of these studies, replacing gravel materials has been done by volume percentage. In this research programme, to review the influence of using waste rubber the percent replacement by weight is considered for replacing the standard Iranian coarse aggregate and various mix designs and mechanical tests were performed.

2 MATERIALS AND EXPERIMENTS

2.1 *Materials and Mix design*

Material used to make concrete specimens were fine aggregate, coarse aggregate, cement, super plasticizer, tire chips and water. The properties of fine and coarse aggregates were determined. The coarse aggregate was selected from crush stone, which was maximum 25 mm in size. The gravel used had 2.37 (gr/cm^3) specific gravity in saturated surface state and 2.04 % water absorption. The fine aggregate had the same specific gravity and 2.46% water absorption. The grades distribution curves for coarse and fine aggregate together with the Iranian standard’s limits are given in Figures 1 and 2. To make chip rubber, at first, automobile tire was shredded by an apparatus to 50 – 100 mm in dimension. Then its wires were isolated, and after that converted into small dimensions (10-20 mm) by cutters to achieve the same size as the coarse aggregate. The grading of the rubber chips is depicted by continuous solid line in Figure 1. In these figures also there has been shown standard ranges (Iran National Standard-No.302) in dotted lines.

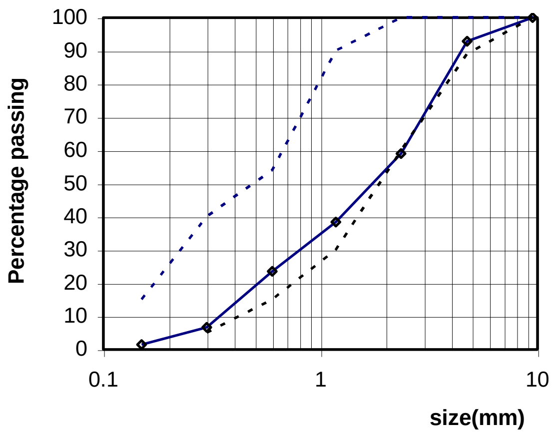

Figure 1. The grading curve of the fine aggregate used together with the Iranian standards limiting curves.

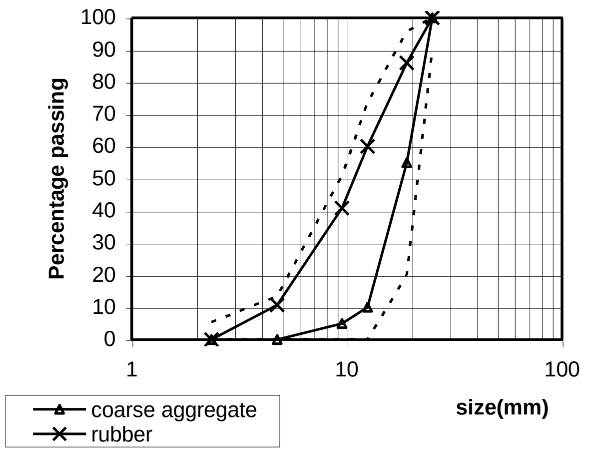

Figure 2. Coarse aggregate and rubber grading together with the Iranian standards limiting curves (dotted lines).

In these experiments, type II cement and drinking water, were used. To obtain desirable slump, super plasticizer was used with 0.4% by weight of cement. In concrete mixture design water/cement ratio was chosen 0.5, and the amount of sand, cement and gravel in one m^3 of concrete were 858, 380, and 927 kg respectively.

In these experiments, the coarse aggregates, is replaced by shredded rubber by 5, 7.5 and 10 percent by weight and all the other parameters are kept constant. The mixes code named as RA x, which is for replacement of aggregate by x percent. For example RA5: Replacing 5 percent by weight rubber particles for aggregates.

The Control Mix in this work is named CM. Mix design specifications are given in Table 1.
In all samples, cement and fine aggregate use 380 and 858 kg/m^3 respectively.

Table 1. Mix design details of the prepared mixes

Specimens Code Name	Shredded Rubber (kg/m3)	Coarse Aggregates (kg/m3)
CM	0.0	927
RA5	46.4	884
RA7.5	69.5	861
RA10	93	839

24 hours after casting the concrete into moulds, specimens were demolded and were kept in a concrete curing chamber for 28 days. At least three specimens were tested at each age .

The compressive strengths were determined using 150×150 mm cubic specimens, and were tested according to the standard BS 1881: part 116: 1993. Also the tensile strength and modulus of elasticity specimens were determined according to BS 1881: part 117: 1983 and BS 1881: part 121: 1983.

Flexural strength test was also carried out according to BS 188: part 118: 1983 by making prismatic specimens of 100 × 100× 500 mm dimensions.

3 RESULT AND DISCUSSION

3.1 *Compressive Strength*

The compressive strength results are presented in Figure 3.based on testing three specimens and taking the mean value. As it can be seen, by increasing rubber contents, the compressive strength will decrease .

By replacing rubber content up to 5% of coarse aggregate, about 5% increase in compressive strength was obtained. But with increasing rubber to 7.5 and 10%, a reduction of 10 and 23% in compressive strength will be resulted comparison to control specimen.

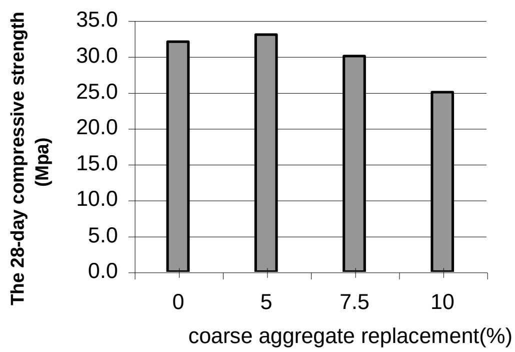

Figure 3. The results of 28-day compressive strength

The most important causes of reducing compressive strength could be hypothesized as follows :

Because rubber has more elasticity than hardened cement paste surrounding it, fracture would begin from their interface and propagate through concrete. This would accelerate rubber-cement matrix fracture.

Because of unsuitable adhesion between rubber and cement paste, soft particles of rubber would be considered as void in concrete, in which, increasing rubber would increase those voids, then decreasing in compressive strength would result.

Since compressive strength relates to factors such as density, size interlocking and rigidity of the aggregates, therefore replacing aggregate by rubber would decrease the compressive strength as expected.

The increase in strength with 5 % replacement of coarse aggregate by rubber compared to control mix can not be readily explained as the compressive test results of the three specimens tested, were within ± 1 percent of the mean values. The results obtained for this group of specimens are different when compared to the other existing research works (Eldin and Senouci, Amos and Roberts, Fattuhi, and Clark, Khatib and Bayomy, Hernandez et.al.). The first hypothesis that could be suggested for this is that rubber initially acts as filler of voids in the concrete matrix. This hypothesis can not be true as the rubber sizes used were in the range of coarse aggregate sizes and not ground powder .

Other hypothesis is the increase compatibility and cohesion of used rubbers with other materials in the concrete; but this hypothesis also can not be right as in the crushed specimens, the rubber particles could be easily removed from rupture surfaces of concrete matrix by bare hands.

Possible reasons for this increase in strength could be due to the improvement of coarse aggregate grading when low percentage of aggregates are replaced by shredded rubber or may be due to the changes it makes to the mix ratios and causes improvement in strength. However more experimental investigation is needed for this.

3.2 *Tensile Strength*

The tensile strength results are given in Figure 4. As it can be seen, increasing rubber in concrete would decrease tensile strength. The most reduction is observed up to 7.5 % replacement. This behavior in tensile strength development can be explained with the Grifith theory.

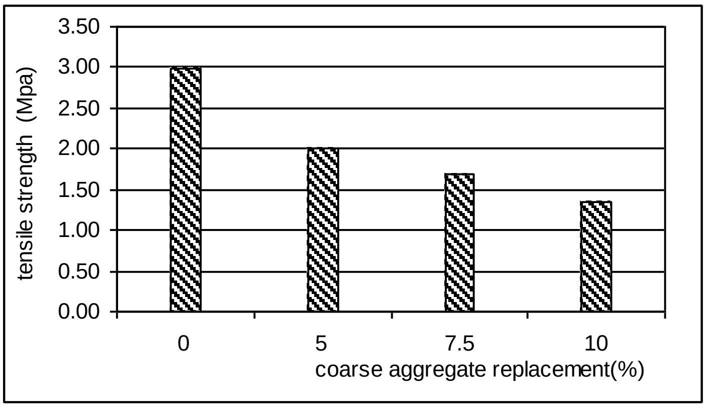

Figure 4. Results of tensile strength tests.

Based on this theory, materials have tiny cracks that develop as stress riser on loading tensile force points, and this would disjoint previous surfaces and make new surfaces. Therefore, saved energy in the mass would be released. If this released energy is enough to extend the cracks, mass would be failed immediately. However a resistance by other soft chemical compound (or softer aggregates like rubber), this expansion would be stopped, and force could be increased until rapture. However with increasing stress in concrete, micro crack grows. When crack expansion in the cement paste is confronted with barriers such as a large cavity, an un-hydrated cement particle and / or a soft material that requires greater energy to disintegrate, it stops advancing.

Rubber acts as a soft material and could behave as a resistance against crack propagation. Therefore, rubberized concrete should have higher tensile strength than control concrete; however, the results show the opposite. This behaviour may hypothesize as follows: First, because of lack of cohesion between rubber and cement paste, their interface would experience a micro cracks, due to loose bonding between the two materials; the interface region accelerates concrete breakdown.

Second, studying cracked concrete shows that there is no rubber tearing after crack. If rubber is to have positive role to increase concrete strength, the bonding force between rubber and cement paste shall be sufficiently great, otherwise during crack expansion and when it comes into contact with rubber particle, the exerted stress causes a surface segregation between rubber and cement paste. Therefore, it can be said that rubber acts just as a cavity and a concentration point leading to quick concrete breakdown. This theory confirms and explains that rubber surfaces may be easily detached from concrete matrix and this was experienced when studying the ruptures surfaces.

Another matter related to concrete is that, when tensile strength is exerted on boundaries, the main rupture location is the interface of cement paste and aggregate. On the other hand, observations of ruptured surfaces confirm lack of cohesion between rubber and cement paste as well. Thus, in rubberized concrete, with using shredded rubber, which is in size of coarse aggregate, tensile strength becomes lesser than control concrete.

Therefore, it was thought that the adhesion between the matrix rubber and the aggregates was very poor. The more aggregates added, the more weak boundary layers would be produced at the interface between the matrix rubber and the aggregates. Thus, it resulted in a decrease of tensile strength.

3.3 *Flexural Strength*

The results of flexural strength tests are shown in Figure 5. As it can be seen from the figure, replacing coarse aggregate by up to 5 % shredded rubber into concrete will not decrease flexural strength but replacing more will decrease the strength at different rates.

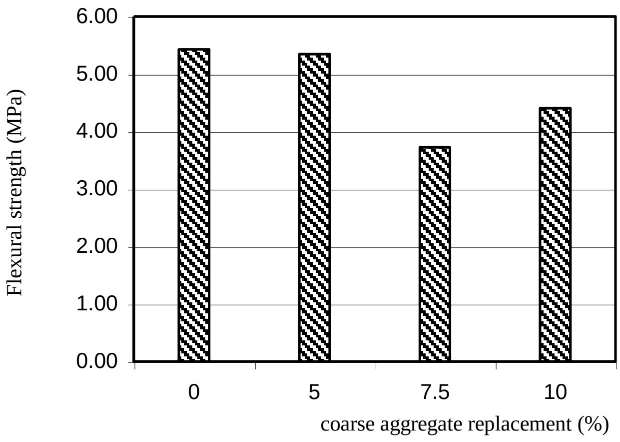

Figure 5. The Results of flexural strength tests

According to the general principle governing flexure, flexural stresses exerted on concrete produce tensile stress on one side of neutral axis and compressive stress on the other, so that with combination of the coupled tensile and compressive forces, they can neutralize the flexural moment.

The tensile strength is much less when compared with compressive strength in concrete; so in flexural loading, concrete will be failed in lower stresses and before concrete bears its final strength in compressive area. Therefore the most important factor in reduction of flexural strength, (just like tensile strength), is weak bonding between to rubber and cement paste.

3.4 *Module of Elasticity*

The results of Young modules for various mix designs are shows in Figure 6. As it can be seen, replacing coarse aggregate by waste tire rubber would decrease modulus of elasticity.

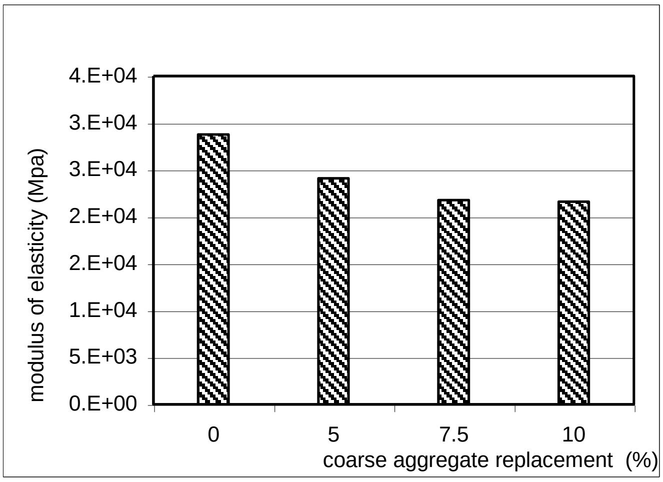

Figure 6. Results of Young modules tests

Considering concrete as a base model of a composite compound consisting of two phases i.e. aggregate and cement, it is observed that the impact on aggregates is due to modulus of elasticity (As the aggregates properties would influence on Young modulus) and to the volumetric ratio of these particles in concrete. Therefore, the greater modulus of elasticity for aggregates the greater modulus of elasticity in concrete. For aggregates with higher Young modules than cement paste, the higher volume of aggregates in the concrete the higher the modulus of elasticity.

Rubberized concrete modulus of elasticity is defined by the formula given by Li and associates [9]; they applied formula to calculate young’s modulus for normal concrete. To achieve this formula, they assumed concrete as a substance composed of cement paste and aggregates, and then the formula was corrected for rubberized concrete

(1) $$E_a = \frac{f_1 E_1 + f_2 E_2}{f_1 + f_2}$$

Where E_a is modulus of elasticity of aggregate which, some part of it replaced by rubber
E1 and E2 are aggregate and rubber modulus of elasticity, respectively;
f_1 and f_2 are volume percent of aggregate and rubber, respectively ($f_1+f_2+f_3=1$, where f_3 is cement volume percentage).

Concrete and rubber modulus of elasticity approximately are [9]:
Aggregate module of elasticity: 30000-120000 Mpa
Cement paste module of elasticity: 10000-30,000
Rubber module of elasticity: 5-1200 Mpa.

Hence, increasing the rubber replacement for coarse aggregates in concrete reduces the equivalent modulus of elasticity and consequently modulus of elasticity of concrete which is directly related to the volume of rubber added.

4 **CONCLUSION**

In this study, numbers of laboratory mixes based on common standards were made and tested. The analysis of the experimental results showed the followings:

Replacing 5 % of coarse aggregate by shredded rubber slightly increases the compressive strength of the concrete but replacing more than 5 %, reduces the concrete strength. The optimum or critical percentages of replacement can be determined by experimental testing for different type of materials and grading used.

Replacing shredded rubber reduces the tensile strength of the concrete. The most important reason for this is the lack of cohesion and bonding between rubber and concrete matrix. When 5-10 % coarse aggregate is replaced by shredded rubber, tensile strength reduces about 2-12 %.

The flexural strength of Rubberized Concrete is reduced about 30 to 60 % when 5-10% coarse aggregate is replaced by shredded rubber.
Modulus of elasticity is reduced, when replacing 5-10 % coarse aggregates by shredded rubber; there is a strength reduction by 17 to 25 %.

Additionally, there are many different potential applications for non structural concrete in civil engineering works like the back fillings, concrete curbs for roads and etc. Rubberized concrete with higher percentages of rubbers can satisfactory be used in these types of applications. Other properties of rubberized concrete such as: Strength freezing-thawing cycles, shrinkage, heat transfer coefficient and energy absorption should be determined for special applications of concrete as required.

ACKNOWLEDGMENTS

This study was partially supported by the Building and Housing Research Center and Azad Uni. They provided support for publication of this paper and for continued research on rubberized concrete.

REFERENCES

Eldin, N.N, Senouci, A.B., 1993 "Rubber_ tyre particles as concrete aggregates". ASCE Journal of Materials in Civil Engineering, p.p. 478-496.

Amos, A.D., Roberts, M., 2000 "Use of ground rubber tyres in Portland cement concrete", Proceedings of the International Conference of Concrete, University of Dundee, Scotland, pp. 379-390.

Fattuhi, N.I., Clark, N.A., 1996 "Cement-based materials containing tyre rubber". Journal of construction and Building Materials, p.p. 229-236.

Hernandez-Olivares, F., Barluenga, G., Bollati, Witoszed, B.,. 2002 "Static and dynamic behavior of recycled tyre tubbe-filled concrete", Cement and Concreter Research, p.p. 1587-159.

Khatib, Z.K., Bayomy, F.M. 1999 "Rubberized portland cement concrete", ASCE Journal of Materials in Civil Engineering, p.p. 206-213.

Naik, T.R, Singh, S.S, 1991 "Utilization of discarded tyres as construction materials for transportation facilities". Report No.CBU-1991-02, UWM center for By-products Utilization. University Of Wisconsin-Milwaukee, Milwaukee, 16 pp.

Rostami, H., Lepore, J.,Silverstraim, T., Zundi, I.,. 2000 "Use of recycled rubber tyres in concrete", Proceedings of the International Conference on Concrete, University of Dundee, Scotland, UK, pp. 391-399.

Segre, N., Joekes, I.,. 2000 "Use of tyre rubber particles as addition to cement paste". Cement and Concrete Research, p.p.1421-1425.

Siddique,R., Naik, T.R., 2004 "Properties of concrete containing scrap-tyre rubber_ an overview", 24(563-569).

Topcu, 1995 I.B.,. "The properties of rubberized concrete". Cement and Concrete Research, p.p. 304-310.