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Experimental Lnvestigation on Mechanical Characteristics and Environmental Effects on Rubber Concrete

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Abstract: The feasibility of the use of scrap tire rubber in concrete was investigated. The tests conducted in two groups: replacing of coarse aggregates with crumb rubber and cement particles with rubber powder. To distinguish the properties of new concrete, the following mechanical and durability tests were designed: compressive, tensile and flexural strength, permeability and water absorption. Rubber addition could affect the concrete properties depend on the type and percentage of the rubber added. Although the rubber addition modifies the mechanical characteristics of concrete in a way, but higher rubber content could not be useful. Concrete durability showed more dependency to the type of rubber instead of percentage of rubber. Moreover, to optimize the mechanical and durability of rubberized concrete, the useful percentage of rubber has been recommended.

Keywords: concrete, tire rubber, physical characteristics, concrete durability.

1. Introduction

Continued worldwide growth of the automotive industry, which are non-exhaustible when present in nature, has tremendously boosted tire production. This growth has generated illegal stockpiles and uncontrolled tire dumps. More than 270 million scrap-tires are produced in United States each year.[1] In addition to this, more than 300 million tires are currently stockpiled throughout the United States. These stockpiles are dangerous not only due to potential environmental threat, but also from fire hazards and provide breeding grounds for mosquitoes, rats and mice.[2]

Currently, there is no precise statistic about the number of scrap tires in Iran, but estimates show that about 200,000 tones rubber tires was produced in 2006.[3] If the approximate useful life for a tire be two-year, it could be estimated that about 100,000 tones of scrap tire will be produced annually.

One of the proposed methods for application of these materials is their consumption in the production of concrete. Iranian industrial ministry report[4] shows that approximately 20 million tones of cement was produced in Iran, in 2006. It is consumed in concrete mix design, slurry and cement blocks. It could be estimated that ten million tones of cement is consumed in non structural or semi-structural concrete. If only 5 percent by weight of cement is replaced by rubber powder, over 500,000 tones of scrap tires will be needed. Moreover, if discarded tire rubber is used to manufacture concrete, all accumulated scrap tires will be consumed.

Examination of previous research carried out by Eldin and Senouci revealed[5] that when tire chip or crumb rubber is contained in concrete, the compressive and tensile strength are drastically reduced such that replacement of coarse aggregates by shredded rubber led to a decrease equal to about 85 percent in compressive strength, and 15 percent in Brazilian tensile strength (splitting). If fine crumb rubber replaces the fine aggregates, the reduction would be equal to 65 percent in compressive strength and 50 percent in tensile strength. Both of these combinations had soft (ductile) failure and had great energy absorption capacity under tensile and compressive loadings. Khatib and Bayoma[6] investigated the impact of adding two types of tire rubber in the concrete. In this research, the water to cement ratio and compressive strength of the control sample were adopted as 0.48 and 35 MPa, respectively. Replacing 100 percent of aggregates with tire rubber resulted in about 90 percent reduction in compressive strength. Additionally, compressive strength reduction in concrete containing coarse rubber chips is greater when compared to concrete containing fine crumb rubber.[6] Although adding tire rubber to concrete causes a reduction in compressive strength, a positive impact is evident in the failure mode. With the substitution of 60 percent of tire rubber, the concrete assumed characteristics of plastic materials.

The findings by Topcu[7] also revealed that adding coarse rubber chips to concrete reduced its compressive and tensile strength more than in the case of adding crumb rubber, but the findings stated in the references[8,9] indicated the opposite. Of course most of researches show replacing rubber by coarse or fine aggregates causes to create ductile concrete with low strength.

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No tangible data was obtained regarding durability tests. Only reference [10] has pointed that permeability and durability of rubberized concrete is generally increased as rubber chips are replaced for coarse aggregates.

In the following research the effect of replacing of rubber particles instead of coarse aggregate and cement was investigated. The most emphasis was solving the problems associated with the stockpiles of rubber in Iran. So, different mechanical and durability tests were designed. Moreover; previous research [1-2 & 5-13] has explored the results of substituting tire rubber for fine and coarse aggregates based on "volumetric percentage." This paper outlines the expansion and development of research designed to investigate the feasibility of using scrap tire to make concrete in Iran. These studies make no reference to exploring the results when these substitutions are based on weight percentage. Also, replacing the rubber powder with cement, could be another research significance compare to other research. Nearly, all previous researches added rubber in concrete or replaced rubber with aggregates while in this research both replacing rubber with cement and replacing rubber with aggregates have been investigated. The results of this research showed that the designed rubberized concrete had strength enough to use as structural or other application. After achieving acceptable mechanical properties, durability of rubberized concrete was investigated. So, it is possible to judge and recommend about the application of rubberized concrete. In this way the environmental problems associated with the stockpile of rubber tire in Iran could be solved.

2. Experimental investigation

Various laboratory samples were designed, prepared and tested after curing in standard conditions in order to review the impact and resulting characteristics of replacing concrete materials (coarse aggregates, fine aggregates, and cement) with waste tire rubber.

2.1 Materials

Coarse aggregates used to make samples were of angular type with a maximum size of 1 in (25 mm). Fine aggregates were also selected from the crushed and washed type. Charts related to coarse and fine aggregate grading, indicating size distribution of grains, are shown in Figs. 1 and 2. Standard boundary (Iranian National Standard No.302) is also shown in these figures through the dotted lines.

For coarse aggregates, the specific gravity in surface saturated state and water absorption are respectively measured as 0.000159 lb/ft^3 (2.55 g/cm^3) and 2.04 percent, on the basis of ASTM C 128-88. For fine aggregates (sand), the above values were measured as 0.000148 lb/ft^3 (2.37 g/cm^3) and 2.46 percent, respectively, on the basis ASTM C 127-88.

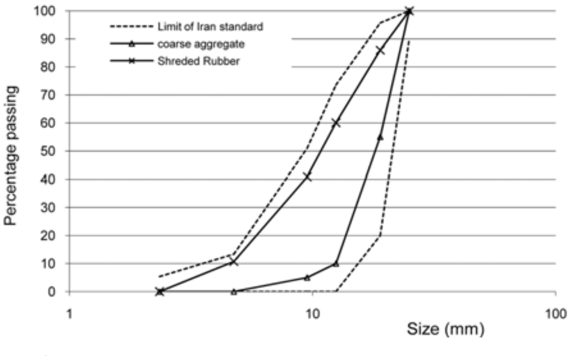


Fig. 1 Coarse aggregate and rubber grading with boundary limits of standard 309 Iran.

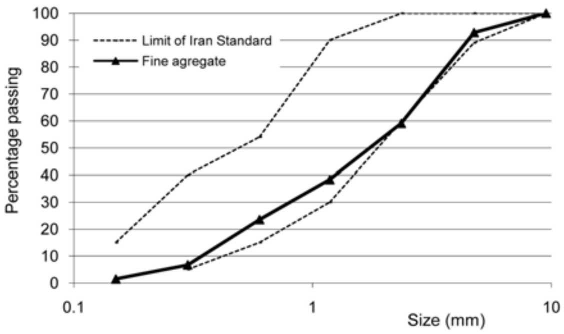


Fig. 2 Fine aggregate grading showing boundary limits of standard 302 Iran.

It is noted that type II Portland cement and tap water were used. Since applying of tire rubber in the mix would reduce workability of concrete, obtaining desirable slump required use of melcrete super-plastizer. Tire rubber used in the experiments is applied in the following two shapes:

Shredded rubber for replacement for coarse aggregates in normal concrete. To prepare such rubber, big pieces of tire rubber were chopped in the laboratory by scissors into smaller chips of the specified size such that grading is similar to that of coarse aggregates.

Powdered rubber with size of 0.016~0.020 in (400 to 500 micrometer) for replacement with cement in concrete. To prepare rubber powder, crumb rubber was processed to powder in special grinders.

Determine of physical properties and chemical composition of the rubber was too difficult because the rubber which used in this research, obtained from scrap tire rubber in market and it included many types of tires. So depending on the application, the composition of rubber compounds could be varying. So it is not possible to find exact amount of ingredient but it included approximately: rubbers (30~50) wt%, carbon black (20~30) wt% , zinc (1~3) wt% , stearic acid(1~3) wt%, sulphur(1~2.5)%, extending oil (8~13)%, and accelerators(1~2.5) wt%.

Also, the tensile strength was 16~20 MPa and elongation was 400~500%.

2.2 Specimens

After needed materials were prepared as per specifications and concrete mix design according to the British method, laboratory specimens were made in two groups. To obtain the reliable result, three samples were made and tested for each type of test. In both groups the water/cement ratio was taken as 0.5 and super-plasticizer was used 0.4 percent by weight of cement.

First group: In this group, coarse aggregates were replaced by shredded rubber in three weight percentages = 5, 7.5 and 10. The samples were named as RA x, which is an abbreviation for aggregate replacement by x percent.

Second group: In this group, cement was replaced by rubber powder in three weight percentages = 5, 7.5 and 10. The samples were named RC x, representing x percent replacement of rubber powder for cement.

In both groups two different types of treatment were examined on 7.5% weight rubber tire replacement. In the batch designated as R7.5T (in both groups), the rubber particles were treated with carbon tetrachloride (CCl_4) for 10 minutes and after that rubber particles were used in concrete mixture. The second treatment composed of two stages: firstly the rubber particles were treated with CCl_4 as mentioned above, and then they were treated with NaOH 40% for 10 minutes. Finally, the rubber particles were rinsed with tap water to remove the excessive NaOH solution.

The control sample (normal concrete) in this research is named CS. The specification of laboratory specimens and their mix design are given in Table 1.

After pouring concrete into molds, they were covered by either wet cloth or plastic for 24 hours; after that, concrete samples were removed from the molds and were kept in a completely humid environment for 28 days.

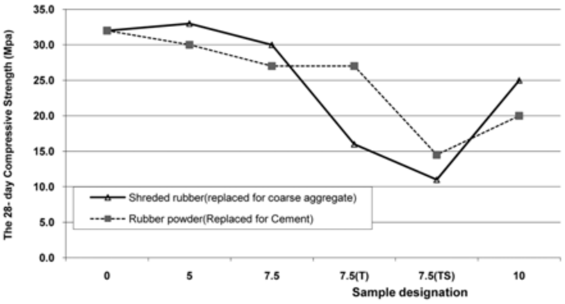
Compressive strength of samples were determined by making two cubic 5.9 × 5.9 × 5.9 in (150 × 150 × 150 mm) samples, which were kept in humid conditions after removal from molds and were tested according to the standard BS 1881: part 116: 1993. Also tensile strength tests were made according the standard BS 1881: part 117: 1983. The flexural strength test was also carried out according to BS 188: part 118: 1983 by making prismatic samples with 3.94 × 3.94 × 19.69 in (100 × 100 × 500 mm) dimensions.

Permeability tests were carried out according to the German standard DIN 1048 (based on pressurized water applied to one side of concrete for a fixed time of 96 hours). To determine diffusion depth within the samples after water absorption, the samples were crushed and water diffusion depth was measured. To determine water absorption into hardened concrete, a 28-day hardened concrete sample was immersed in water for 30 minutes at atmospheric pressure. The water absorption of concrete samples during 30 minutes was determined from the mass difference of the sample between dry and wet states then divided by its mass in its dry condition.

3. Results and discussion

3.1 Compressive strength test

The result of 28-day compressive strength tests and the sample after breaking are presented in Fig. 3. In the first group, as it is seen, with 5 percent rubber replacement, the compressive strength increases approximately 5 percent with respect to “Control Specimen” (which is made of normal concrete without any rubber); applying rubber particles up to 7.5 and 10 percent would reduce the strength in a way of 10 to 23 percent compared to normal concrete, respectively. Treating of rubber reduces the compressive strength of concrete compared to similar concrete with use of untreated (7.5T and 7.5TS batches compared to 7.5 batch in both groups) in the range of 40~60%. The strength of rubberized concrete in the second group is lower than that of first group. In this group addition of rubber powder decreases the compressive strength. This reduction is linear with rubber content. Modification of rubber powder could not improve concrete strength. Modifying



(a) The results of 28-day compressive strength for both groups

(b) Failure pattern of samples after compressive strength test

Fig. 3 The result of 28-day compressive strength tests and the sample after breaking.

Table 1 Specification of the prepared samples.

Sample designation		Weight of the materials used Kg per 1 m^3 of concrete				Description
		Cement	Rubber		Coarse aggregate	
			Powder	Shredded		
First group	CS	380.0	0.0	0.0	927.0)	Control
	5	380.0	0.0	46.4	884.0	Replacing 5 percent by weight rubber particles for coarse aggregates
	7.5	380.0	0.0	69.5	861.0	Replacing 7.5percent by weight rubber particles for coarse aggregates
	7.5T	380.0	0.0	69.5	861.0	Treating rubber particles with carbon tetrachloride on 7.5% replacement
	7.5TS	380.0	0.0	69.5	861.0	Treating rubber tire with carbon tetrachloride and NaOH on 7.5% replacement
	10	380.0	0.0	93.0	839.0	Replacing 10 percent by weight coarse aggregate with rubber powder
Second group	CS	380.0	0.0	0.0	927.0	Control
	5	361.0	19.0	0.0	927.0	Replacing 5 percent by weight rubber particles for cement
	7.5	351.5	28.5	0.0	927.0	Replacing 7.5percent by weight rubber particles for cement
	7.5T	351.5	28.5	0.0	927.0	Treating rubber particles with carbon tetrachloride on 7.5% replacement
	7.5TS	351.5	28.5	0.0	927.0	Treating rubber tire with carbon tetrachloride and NaOH on 7.5% replacement
	10	342.0	38.0	0.0	927.0	Replacing 10 percent by weight cement with rubber powder

with NaOH had a detrimental effect.

Rubber particles may affect the concrete strength in some ways: produce sites acting as nucleation for crack initiation, lower concrete load bearing capacity or its homogeneity.

The first step of concrete failure is crack initiation which follows by crack propagation leads to concrete failure. The voids and pre-exist track are examples of favorable nucleation sites. Rubber particles are softer than aggregate. So, during loading they act as voids and cracks would rapidly develop around rubber particles. Also, due to lack of strong bonding between rubber particles and the cement paste as compared to cement paste and aggregates, because rubber with non hygroscopic properties could not create good bonding with cement solution, the interfaces of rubber particles and cement may act as pre-existing crack and accelerates the crack nucleation.

In the rubberized concrete matrix, a part of the cement or aggregates is replaced by rubber particles and in this way their volumes will reduce accordingly. On the other hand, compressive strength of concrete depends on physical and mechanical properties of these materials (which have considerable superiority over rubber). Reduction in compressive strength of concrete is therefore predictable. Moreover, molding and vibration applied during making concrete samples, rubber particles move toward the upper surface of the mold, resulting in a high concentration of rubber particles at the top layer of the specimens. This is because of the lower specific weight (or specific gravity) of rubber materials compared to the other components of concrete. This problem is more evident in the first group. Non-uniform distribution of rubber particles at the top surface tends to produce non-homogeneous samples and leads to a reduction in concrete strength.

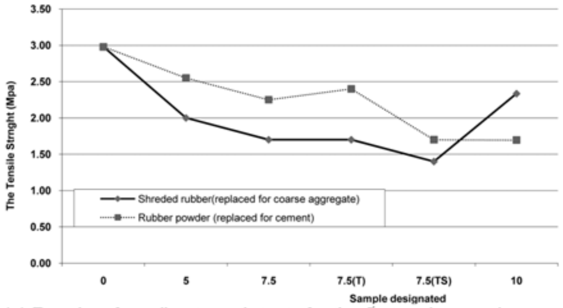
Lower strength of the second group relative to the first group is due to reduction in the quantity of cement used as adhesive materials.

It also seems that the slight increase in compressive strength noted in the sample containing 5 percent shredded rubber is due to a small reduction in coarse aggregate quantity of the mix design, which has in turn modified and corrected aggregate grading of the concrete. In other words, aggregate ratio by weight relative to other materials is improved

Rubber particles treated with NaOH and CCl_4 produced concrete with different characteristic. Treating rubber with CCl_4 produced concrete with normal strength. Carbon tetrachloride is a strong solution and treating rubber tire with it would solve all dirt, oils and impurities from the rubber surface. The treated rubber could create better and stronger bonds with cement and in this way it should improve the concrete strength; but treating rubber tire with carbon tetrachloride may solve some rubber particles corners and reduces its irregularities which are very important and act as anchorages and improve concrete strength. So, the concrete strength will decrease. Treating rubber particles with NaOH will increase air-entrained in concrete. Rubber particles compose of organic components (such as isoprene, styrene, butadiene, etc.). Reaction of a base with organic materials will produce bubbles which may remain in concrete and increase its deficiencies and reduce concrete strength.

3.2 Tensile strength

The results of tensile strength testing and the failure pattern of samples are given in Fig. 4. Tensile strength of concrete was reduced with the addition of rubber in both groups however the mechanism of tensile failure for rubber concrete is similar to normal concrete. The reduction of tensile strength in the first group was two times that of 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. Treating rubber tire with carbon tetrachloride improves the tensile strength a little in the second group. Treating rubber particles with NaOH has detrimental effect on tensile strength and decrease tensile strength with about 10 and 24% in the first and second group, respectively.



(a) Results of tensile strength tests for the first and second group

(b) Failure pattern of samples after tensile strength test

Fig. 4 The results of tensile strength testing and the failure pattern of samples.

The Griffiths theory[14] describes the relationship between applied nominal tensile stress and crack length at fracture, i.e. when it becomes energetically favorable for a crack to grow. Griffith was concerned with the energies of fracture, and considered the energy changes associated with incremental crack extension.

When a brittle material exposed to a tensile stress, it undergos incremental crack extension. During this process the only contributors to energy changes are the energy of the new fracture surface (two surfaces per crack tip) and the change in potential energy in the body. The surface energy term represents energy absorbed in crack growth, while the some stored strain energy is released as the crack extends (due to unloading of regions adjacent to the new surface energy). If the released energy is sufficient to cause the development of cracks, the conditions are predictors for immediate failure. If barriers were located in the crack development path, crack expansion is halted so that exerted pressure is increased. This process appears in concrete also as micro cracks grow and expand if stress is applied. Crack expansion in the cement paste will stop advancing when it is confronted with barriers such as a large cavity, an un-hydrated cement particle or a soft material that requires greater energy to disintegrate.

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 sample. However, the results are in contradiction with this hypothesis. The reason for this behavior may be due to the following phenomena:

First, the transfer region between rubber and cement may act as a microcrack due to loose bonding between the two materials; the weak transfer region accelerates concrete breakdown.

On the other hand, a review of the broken concrete shows that rubber shredding is not observed after concrete breakdown (this is more clearly apparent in the second group). The reasons for this behavior may be as follows: If rubber is to play a productive role in increasing concrete strength, the bonding force between rubber and cement paste must be sufficiently great. Otherwise during crack expansion and when it comes into contact with rubber particles, the exerted stress will cause a surface segregation between rubber and cement paste. It is understood that rubber acts as a cavity and a concentration point leading to quick concrete breakdown. This theory confirms and complies with observations of broken surfaces, detailing that rubber surfaces may be easily detached from the concrete matrix.

An additional variable that may affect the concrete behavior is the location of the main region of segregation when tensile strength is exerted on boundaries of large grains and cement paste which in turn weaken the generated transfer region.

By remembering that carbon tetrachloride treating will reduce irregularities at rubber surface and NaOH treating will create pores in concrete, and in this way tensile strength will reduce. It seems that producing pores has more detrimental effect on concrete tensile strength.

3.3 Flexural strength

The results of flexural strength tests are shown in Fig. 5. The addition of rubber to concrete reduces flexural strength. Reduction in flexural strength occurred in both groups and only the rate was different. The highest reduction occurred in the first group with 7.5 percent by weight replacement. A reduction of 31 percent with respect to the control sample was observed in the first group. This value decreased to 15 percent for the second group.

According to a general principle governing flexure, flexural stresses exerted on concrete produce tensile stress on one side of the neutral axis and compressive stress on the other. Based on this principle, with the combination of the coupled tensile and compressive forces the compressive moment can be neutralized.

Due to low (negligible) tensile strength of concrete as compared to its compressive strength, in lower stresses and before concrete reaches its ultimate strength in the compression region, failure will occur. As a result the most important factor in reducing flexural strength, as well as the compressive strength, is lack of good bonding between rubber particles and cement paste. This conclusion was reached because after breaking the concrete samples while conducting the flexural strength test, it was observed that shredded rubber could be easily removed from concrete. Loose bond in the first group, which used shredded rubber, was more obvious and higher than the second group, which used powdered rubber.

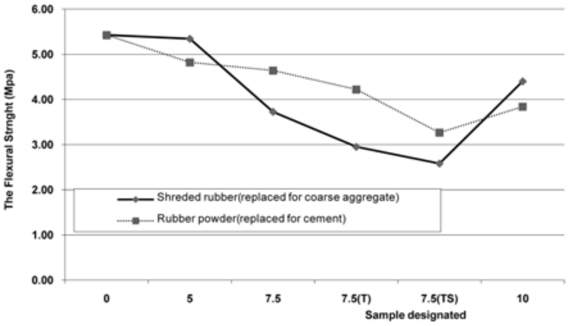


Fig. 5 The results of flexural strength for the first and second group.

None of the treatment improves the flexural strength. Similar to tensile strength, treatment with NaOH decreases the flexural strength more.

3.4 Permeability and water absorption

Permeability is the most crucial internal factor in concrete durability. A reduction in permeability of concrete would improve its other characteristics including durability against environmental conditions such as freezing and thawing cycles, reduction in corrosion of and steel bars in concrete exposed to aggressive minerals and or acids. High, medium and low permeability ranges specified in the standard DIN 1048 are given in Table 2. The results of permeability test and setup of this experiment are given in Fig. 6.

Evaluation and comparison of permeability test in a sample test revealed that: addition of rubber will increase water permeability in the first and second group. Rate of water permeability was increased up to 100 percent in comparison with the control sample in the first group. Water permeability was in the range of average in the first group and in the range of low to average according to the Standard DIN 1048 for the second group. Treating with carbon tetrachloride improves the water absorption and permeability in both groups, but NaOH treating has not positive effect.

The results of water absorption test were given in Fig. 7. The samples from the first group that were tested for water absorption were cracked while they located in oven to dry. Since shredded rubber was used in the first group have larger surface area than powdered rubber, the evidence of disbanding is more visible.

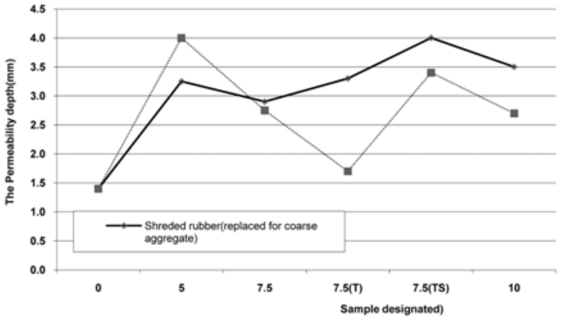
Even with this error, it seems that water absorption in the first group with respect to the control sample has been increased. Water absorption by the research samples was lower than that by the control sample, in the second group. It seems that reduction in porosity of concrete due to filling the voids with powdered rubber has reduced water absorption.

Comparison of the results for water absorption and the depth of water penetration show that in contrast to initial decrease of water absorption, depth of water penetration increased in the second group.

It appears that water permeability in concrete containing powdered rubber is non-uniform in such a way that even though water absorption is lower than that of the control sample, its water permeability increased. The reason for this behavior may be due to

Table 2 Permeability ranges according to standard DIN 1048

Permeability range according to standard DIN 1048	Low	Medium	High
Permeability depth in 4 days (mm)	Less than 30	30~60	Greater than 60



(a) Permeability of the first and second groups

(b) Permeability test setup

Fig. 6 The results of permeability test and setup of this experiment.

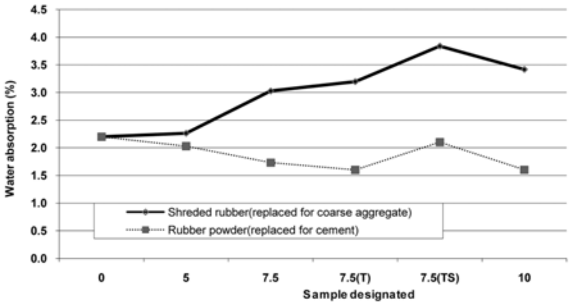


Fig. 7 The result of water absorption for the first and second group.

existence of capillaries for water flowing in the concrete containing rubber. This may be due to lack of good bonding between rubber particles and cement paste where interface surface between cement paste and rubber grains act as a channel for pressurized water to flow in the concrete containing rubber. Consequently, with the same water absorption and even lower, water permeability of the concrete containing rubber was increased with respect to the control sample.

Among other interesting points is the behavior of concrete containing rubber particles: in low percentages, the first group (containing coarse rubber particles) shows lower permeability and in high percentages, the second group shows smaller permeability. In general, easy permeability is done through shrinkage-induced microcracks, which provide capillaries for water passage around aggregates, especially coarse aggregates. This issue along with the loose bond between rubber particles and cement paste in concrete containing rubber explains the high permeability of rubberized-concrete.

In low percentages and in some given percentages, distribution of powdered rubber is greater than that of crumb rubber. Therefore, finding an interconnected and possibly straight passage among intersections between rubber powder and cement paste in the second group relative to the intersections of shredded rubber of the second group is expectedly higher. In higher percentages, there is a higher probability of finding interconnected passages among intersections between shredded rubber and cement paste. It seems that treating with carbon tetrachloride removes all dirt and oils of rubber surface and let better adhesion of rubber particles with cement paste by decreasing gaps between their interfacial surfaces. So, water absorption and permeability of rubberized concrete will decrease. In the other hand, treating rubber particles with NaOH will produce pores in concrete. These pores helps the flow of water through concrete, and in this way it increases water absorption and permeability of rubberized concrete.

Increased permeability of the second group may also be due to reduction in cement content in the second group of concrete, induced by replacement of rubber powder for cement in this group. A reduction in cement content leads to increase in water per cement ratio or an increase in the permeability of concrete.

4. Conclusions

Based on laboratory investigations, the following findings are accessible:

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. Changes in compressive strength, for up to 5%, are too low to influence concrete properties. The highest reduction in compressive strength is related to 7.5 and 10 percent replacement for both groups. The compressive strength in the first group is higher than the second group, up to about 7.5%.

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

4) Addition of rubber to concrete increased its water permeability by 100 to 200 percent as compared to the control sample. Permeability was higher in the second group. The highest value of permeability is related to 10 percent rubber replacement in the first group as compared to the control sample. But, the result of water absorption, which is parameters of water permeability, is lower. This contradiction is related to the different process of water diffusion in the tests. In the water absorption water diffuses through concrete by capillary pressure; but, in the permeability tests external pressure in conjunction with the capillary increase water diffusion rate.

5) Treating rubber tire particles with carbon tetrachloride and NaOH has different effect on concrete properties. Carbon tetrachloride treating rubber particles improved the water permeability

and water absorption of rubberized concrete, but it has a little positive effect on mechanical behavior of concrete. Treating rubber particlee with NaOH is not recommended, because it has not improved the concrete characteristics.

6) According to the result of this experimental research, replacing up to 7.5% coarse aggregate with shredded rubber or replacing up to 5% cement with rubber powder does not have important effect on concrete characteristics.

This study is done in accordance with the prevalent Standards. The research findings are therefore based on the laboratory studies and may differ with change in conditions such as materials characteristics changes in mix proportions of the ingredients, curing procedure, and also use of additives.

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