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Properties of Concrete Containing Scrap (Recycled) Tire-Rubber

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Abstract: Solid waste management is one of the major environmental concerns all over the world and in Kuwait. Over 5 billion tons of non-hazardous solid waste materials are generated in Kuwait each year. Of these, more than 2 million scrap-tires (approximately 2 million tons) are generated each year. In addition to this, about 7 million scrap-tires have been stockpiled. Due to the increasingly serious environmental problems presented by waste tires, the feasibility of using elastic and flexible tire–rubber particles as aggregate in concrete is investigated in this study. Tire-rubber particles composed of tire chips, crumb rubber and a combination of tire chips and crumb rubber were used to replace mineral aggregates in concrete. These particles were used to replace 10, 15, 20 and 25% of the total mineral aggregate's volume in concrete. Concrete cubes with dimensions of 100×100×100 mm^3 and prisms with dimensions of 75×75×300 mm^3 have been prepared and tested for their compressive strength. It was observed that, increasing the tire-rubber content, reduces the compressive strength, the unit weight and density of the concrete compared to plain concrete. Moreover, modulus of elasticity decreases as waste crumb tires replacement increases. The study concludes with useful comments and suggestions.

Key words: Tire-rubber, compressive strength, unit weight, air content, recycling, solid

INTRODUCTION

More than 2 million scrap-tires are produced in Kuwait each year (RMA., 2019). In addition to this, more than 7 million tires are currently stockpiled in Rhayyah Northern of Kuwait (RMA., 2019). These stockpiles are dangerous not only due to potential environmental threat but also from fire hazards and provide breeding grounds for rats, mice, vermines and mosquitoes (Bhogayata and Arora, 2017; Schaefer *et al*., 2018; Jacob-Vaillancourt and Soreli, 2018; Eldin and Senouci, 1994; Fedroff *et al*., 1996; Siddique and Naik, 2004; Hernandez-Olivares *et al*., 2002; Li *et al*., 2004). Actually, in 2012 a fire broke out in the dumpsite. Hundreds of firefighters from six stations as well as soldiers and employees of the Kuwait Oil Company (KOC) tool parts in the efforts to extinguish the blaze. Over the years, disposal of tires has become one of the serious problems in environments. Landfilling is becoming unacceptable because of the rapid depletion of available sites for waste disposal. For example, France which produces over 10 million scrap-tires per year will have a dwindling supply of landfills starting from July, 2002, due to a new law that forbids any new landfill in the country. Used tires are required to be shredded before landfilling. The importance of recycling of waste tires coupled with the interest in overcoming the aforementioned concrete defects have motivated a significant body of research pertaining to rubberized concrete. Properties, testing and design of rubber as an engineering material were investigated in 1960 (Khalid *et al*., 2018; Yin *et al*., 2015; Segre and Joekes, 2000). Saxena *et al*. (2018) and Segre and Joekes (2000) used tire-rubber particles as concrete aggregates, elucidating rubberized concrete properties and proposed an analytical approach to predict the strength in rubberized concrete. Thorneycroft *et al*. (2018) studied rubberized Portland cement concrete and offered some practical uses of rubberized concrete, including reduction factors. Their paper contains limitations and concerns of using tire-rubber concrete as well. Li *et al*. (2004) used waste tires in the form of fibers and developed waste tire fiber modified concrete. The static and dynamic behavior of recycled tire-rubber-filled concrete was investigated by Hernandez-Olivares *et al*. (2002). Hama and Hilal (2017) and Siddique and Naik (2004) presented an overview of research published on the use of scrap tires in Portland cement concrete. Bhogayata and Arora (2018) investigated the properties of rubberized concretes containing silica fume through six designated rubber contents. These previous findings reveal that the properties of rubberized concrete are affected by type, size, content and the procedure of incorporating the rubber into the concrete.

A tire is a composite of complex elastomer formulations, fibers and steel/fiber cord. Tires are made of plies of reinforcing cords extending transversely from bead to bead on top of which is a belt located below the thread. Typical types of materials used to manufacture tires and Table 1 lists typical composition of manufactured tires by weight.

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Typical materials used in manufacturing tire*:

- Synthetic rubber
- Natural rubber
- Sulfur and sulfur compounds
- Phenolic resin
- Oil
  - Aromatic
  - Naphthenic
  - Paraffinic
- Fabric
  - Polyester
  - Nylon
- Petroleum waxes
- Pigments
  - Zinc oxide
  - Titanium dioxide
- Carbon black
- Fatty acids
- Inert materials
- Steel wires

*(RMA., 2019)

In this study, tire-rubber concrete properties are investigated using mechanical and non-destructive testing for different sizes of tire particles. The experimental observations and subsequent explanations of tire-rubber concrete behavior under compressive strain are presented. Ultrasonic analysis investigates sound absorption and the ultrasonic modulus of tire-rubber concrete.

Experimental program: Concrete cubes with dimensions of 100×100×100 mm^3 and prisms with dimensions of 75×75×300 mm^3 will be prepared and tested for their compressive strength. The design compressive cubes and prisms strength will be prepared according to ACI (ACI., 2014; 2016) mix design for plain concrete specimen, with an average compressive strength of 40 MPa. Type of concrete mixes to be used in this study are shown below:

Type 1: Control mix made with normal coarse and fine aggregates. Eighteen cubes and nine prisms will be used. (without any tire-rubber).

Type 2: Coarse aggregates replacement with coarse tire-rubber with percentages of 10, 15, 20 and 25%. Ninety cubes and forty-five prisms will be used. (Normal aggregates will be used in this mix type).

An average compressive strength for different cube and prism mixes will be taken after 7, 14 and 28 days. Each reading will be taken as the average of six test results. This brings the total number of test specimens to 108 cubes and 54 prisms in addition, there will be 7 slump tests.

Table 1: Typical composition of manufactured tires by weight

Composition (wt.%)	Automobile tire	Truck tire
Natural rubber	14	27
Synthetic rubber	27	14
Carbon black	28	28
Steel	14-15	14-15
Fabric, filler, accelerators and antiozonants	16-17	16-17

Table 2: Properties of the different concrete mixes

Property	10% rubber (kg)	15% rubber (kg)	20% rubber (kg)	25% rubber (kg)
Rubber weight	1.13	1.70	2.26	2.82
Cement	6.40	6.40	6.40	6.40
Water	3.07	3.07	3.07	3.07
Sand	10.18	9.60	9.05	8.50
Coarse aggregate$^{3/4}$	4.20	4.20	4.20	4.20
Coarse aggregate$^{1/2}$	6.60	6.60	6.60	6.60
Coarse aggregate$^{3/8}$	6.60	6.60	6.60	6.60
Without cement	0.48	0.48	0.48	0.48

MATERIALS AND METHODS

Waste rubber: Tire-rubbers has been employed in concrete mixes. The proportions of the various chemical constituents of the tire rubbers has been presented earlier.

Concrete mix: The concrete mix for the control specimens have been designed according to ACI (ACI., 2014). The mix proportions are shown in Table 2. Using these mix proportions, percentages of fine and coarse aggregates have been replaced with scrap tire-rubber particles with proportions as previously indicated. Constituent materials for concrete mixes included a type I Portland cement meeting ASTM C150 requirements, crushed stone gravel with a maximum size of 20 mm as a coarse aggregate, natural sand with a 4.75 mm maximum size as fine aggregate and tire-rubber particles. Tire particle specifications. These specifications were provided by tire manufacturers according to ANSI and ACI (American National Standard Institute; American Concrete Institute) tests. One type of scrap tire-rubber particles were used: that is coarse tire chips produced by mechanical shredding.

Tire particles were not pretreated before their incorporation into the concrete mixture. The properties of fine and coarse aggregates were determined according to ASTM standard test methods C127, C128, C129 and C136. The grading of tire–rubber materials was determined based on the ASTM C136 method. The grading curve of rubber materials was determined by using crushed stones in each sieve in order to provide adequate pressure on tire-rubber particles to pass the sieves. Data regarding the properties of the aggregates and the rubber particles are given in Table 2. The specific gravity of the cement was evaluated to be 3.15 g cm^{-3}.

RESULTS AND DISCUSSION

The effect of the percentage of tire-rubber on the compressive strength of concretes is shown in Fig. 1 and 2. The strength value seems to decrees with percentages of waste rubber. The compressive strength value seems to decrease with higher percentages of tire-rubber. This is attributed to the poorer cohesion between the rubber aggregates having smooth impermeable surfaces and the cement paste.

In addition, the figures illustrate the effect of the percentage of tire-rubber as aggregate replacement on the initial and final setting times of concrete mixes made with the considered types of concrete mixes. Both initial and final setting times exhibit an increasing almost-linear relation with the percentages of replacement with tire-rubber in concrete. The delay in the initial and final setting times is attributed to the ASR phenomenon. This is more pronounced in the setting times of concrete mixes made with coarse aggregates where values exceed 25 h above 50% replacement proportions.

Moreover, the ASR phenomenon which is characterized by an expansion of the mix, appears to cause a further decrease in the cohesion between rubber aggregates and the cement matrix which also delays initial and final times of setting.

In analysing and explaining Fig. 1 and 2 will show the following: Increasing the rubber-tire content, reduces the compressive strength. As an example, if we choose the 7 days curing for the different tire-rubber replacements, we can notice that the compressive strength has reduced by 34, 50, 61 and 70% for the 10, 15, 20 and 25% replacement, respectively. This could be explained/attrbuited by the follwing reseans: First, because rubber is much softer than the surrounding cement paste, upon loading, cracks are initiated quickly around the rubber particles due to this elastic mismatch, Which propagate to bring about failure of the rubber-cement matrix. Second, due to weak bonding between the rubber particles and the cement paste, soft rubber particles may be viewed as voids in the concrete mix. The assumed increase in the void content would certainly cause a reduction in strength. The third possible reason for the reduction in strength is that the strength of concrete depends greatly on the density, size and hardness of the particles.

To evaluate the properties of fresh concrete, slump and unit weight were measured according to ASTM C143, ASTM C138 and ACI (ASTM., 1988), respectively. A compressive strain-control test was conducted for hardened concrete specimens to obtain the stress-strain curves for all of the specimens. The test was performed by a universal testing machine and a sensitive data acquisition system. The machine yielded a loading value variation due to a constant rate of specimen deformation. This rate was chosen to be 0.005 mm sec^{-1}.

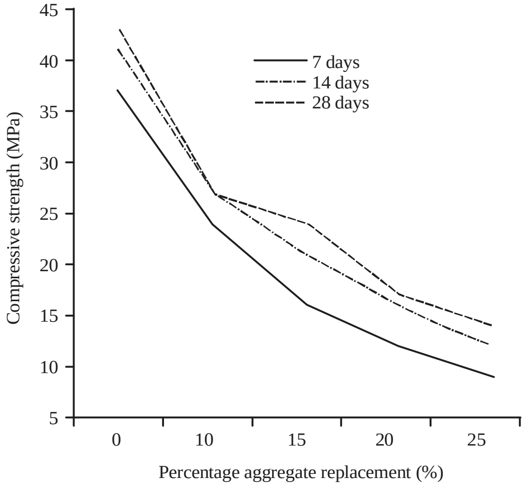

Fig. 1: Average compressive strength for all specimens

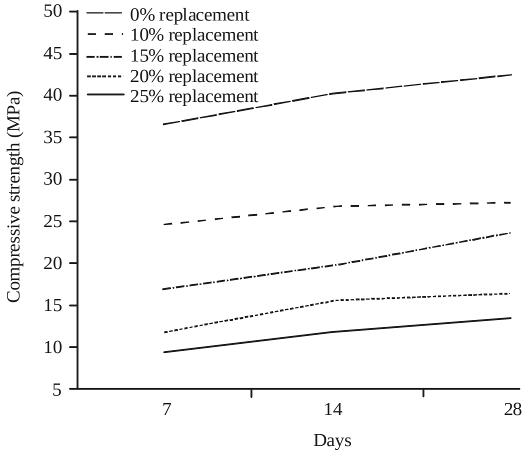

Fig. 2: Average compressive strength of all specimen according to days

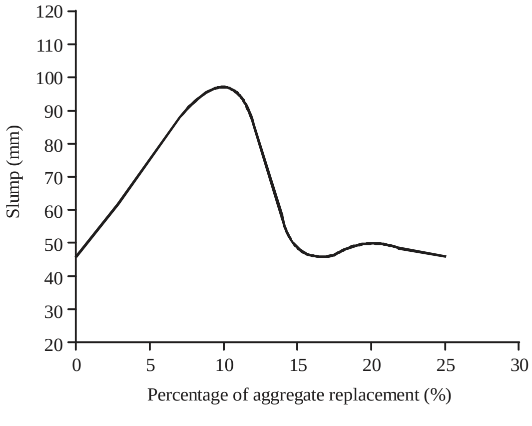

Fig. 3: Slum test for all the different mixes

Variations of slump and unit weight of fresh concrete with respect to tire aggregate concentration are presented in Fig. 3. The workability, defined as the ease with which

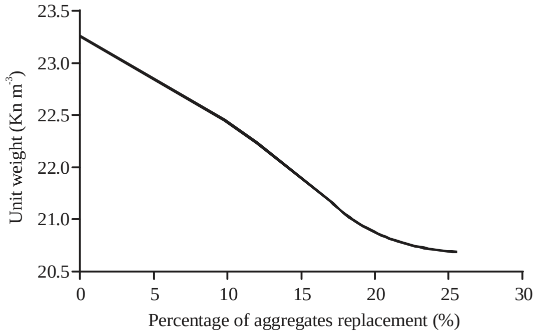

Fig. 4: Unit weight of different mixes

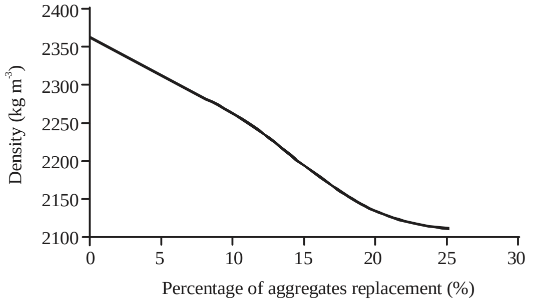

Fig. 5: Density of different mixes

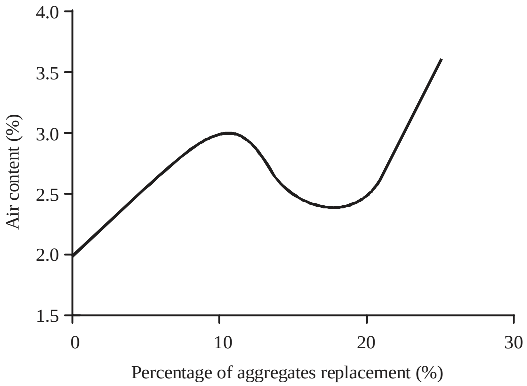

Fig. 6: Air content for all mixes

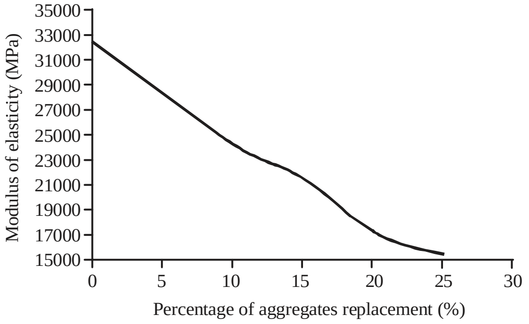

Fig. 7: Modules of elasticity of all mixes

concrete can be mixed, transported and placed, of fresh concrete is affected by the interactions of tire particles and mineral aggregates. As shown in Fig. 3, the slump for all mixes fluctuates slightly over the minimum value for tire-rubber aggregate concentrations, however, it reached a maximum value when the tire aggregate concentration was 10%. Tire aggregate concentrations exceeding 25% reduced the slump. The slump for 0 mixes decreases to a minimum value with tire aggregate concentrations of 15%. In general, the rubberized concrete specimens have acceptable workability in terms of ease of handling, placement and finishing. As shown in Table 2, the ordinary procedure for evaluating the slump of the investigated mixes does not support the actual state of the mix workability. These findings suggest that another method is required to properly measure the slump of rubberized concrete (Eldin and Senouci, 1994).

The unit weight of the concrete ranged from 2320-2074 kg m^{-3}, depending on rubber-tire content (Fig. 4). Increasing the rubber-tire content reduces the unit weight and density of the concrete, resulting in lighter concretes (Fig. 5). The unit weights of the 15, 20 and 25% mixes were reduced 8, 11 and 11.5%, respectively, compared to plain concrete. The unit weight reduction is a result of the lower unit weight of tire-rubber particles replacing the much heavier mineral aggregates. Thus, rubber-tire concrete could be used wherever lightweight concrete is required. For example, tire-rubber concrete containing low tire-rubber concentrations can be used in structures to reduce earthquake damage. Due to the high water absorption of tire particles, the ratio of the fresh concrete unit weight to the hardened unit weight in tire-rubber concrete is greater than that of plain concrete. Therefore, tire-rubber concrete is expected to be more porous than plain concrete. A smaller reduction in unit weight, compared to that of the 20 and 25% mixes was realized for 10% mixes with rubber concentrations lower than 15%. At higher concentrations, the result is reversed.

The air content for the different percentage of aggregate mixes are shown in Fig. 6, it is within the range of 2-3.52%. Increasing the rubber-tire content increases the air content within the concrete, resulting in lighter concretes. Moreover, modulus of elasticity decreases as waste crumb tires replacement increases (Fig. 7). The modulus of elasticity is a measure of the stiffness of a material and while the rubber percentage increases the stiffness of rubberized mixes decrease and the reason may be because of the hardness and stiffness of rubber particles less than sand.

Figure 8, presents the results of water absorption for the different mixes. It can be absorbed that the water absorption is increasing as the tire-rubber replacement increases. This could be attributed to the increase of voids within the mix in the case of the replacement of

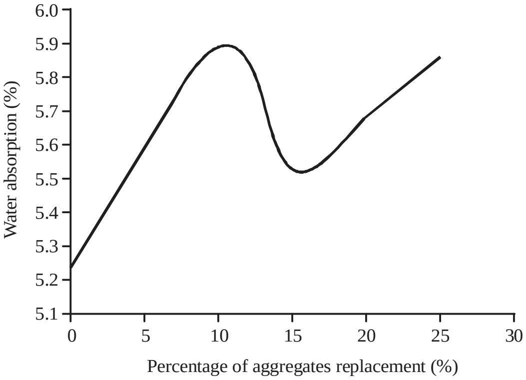

Fig. 8: Water absorption of all mixes

aggregates (coarse) with tire-rubber aggregates. Moreover, voids could increase do the weaker bonding between tire-rubber particles and cement and coarse aggregate. Therefore, when the mixes are going under curing, the water will fill the voids and as a result the water absorption will increase.

CONCLUSION

The increase in the awareness of waste management and environment-related issues has led to substantial progress in the utilization of waste/by-products like tire-rubber. This study has presented various aspects on tire-rubber and its usage in concrete which could be summarized and concluded as:

Fresh rubberized concrete mixtures with increasing rubber concentrations present lower unit weights compared to plain concrete. Workability of rubberized concrete with coarse rubber particles is reduced with increasing rubber concentration; however, rubberized concrete with fine rubber particles exhibits an acceptable workability with respect to plain concrete.

The substitution of mineral aggregates with tire-rubber particles in concrete results in large reductions in ultimate strength and the tangential modulus of elasticity. Due to the considerable decrease in ultimate strength, rubber concentrations exceeding 25% are not recommended. Pretreatment of tire particle surfaces should be considered for possible improvement of tire-rubber concrete mechanical properties. An investigation is needed to identify the influence of rubber's mechanical properties on the ultimate strength of rubberized concrete.

Tire-rubber offers a number of advantages for its use as aggregates replacement including its durability, impermeability, improved abrasion resistance, hardness, enhanced flow properties without the referral to super plasticizers and finally its pozzolanic properties that make it an excellent candidate for use as partial cement replacement and filler.

A comprehensive, co-ordinated and continuous program of awareness is necessary to educate the public with regards to recycling. Such a program is necessary to ensure uniformity and continuity of the flow of high-value recyclable materials. As the percent of waste crumb tire replacement increases, compressive strength decreases. As the percent of waste crumb tire replacement increases, density decreases. As increasing waste crumb tires replacement percentage from 0 -25% by ratio 5% for each mix, the slump test results showed no significant change, so, all mixes are close to each other in consistency.

The density and unit weight of mixes are decreasing as the replacement percentage increasing. As increasing waste crumb tires replacement percentage from 0 -25% by ratio 5% for each mix, air content is increasing also. Modulus of elasticity decreases as waste crumb tires replacement increases. In addition, by using recycled tire-rubber aggregates has numerous advantages and benefits such as: extending the life of landfills due to reduction of quantities of waste arriving at the landfills.

Governmental and private recycling industries (companies) would be encouraged and expanded which will consequently affect the national economy. Utilization of virgin materials would be minimized which would help in protecting and saving the environment and its natural resources. The other benefit of recycling is the considerable reduction of the price of products made of recycled materials. This study has exclusively focused on the mechanical and physical properties of tire-rubber concrete for rubber replacements of mineral aggregates. There is a need for future studies to investigate energy absorption of tire–rubber concrete under dynamic loading, and also the durability of tire-rubber concrete under adverse weathering conditions.

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