Use of Recycled Tire in Concrete for Partial Aggregate Replacement

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***Abstract*—The paper investigates possible use of recycled tire in concrete for partial fine aggregate replacement to provide possible solution for tire waste management as well as aggregate resource conservation. Commercially produced tire crumbs of size ranging between 0.80 to 4.0 mm were used for partial replacement of fine aggregates in concrete. Three fractions of 20%, 40% and 60% replacement were considered in addition to a control mix. A lean mix proportion of 1:2:4 with water-cement ratio of 0.50 was used in this study. In the fresh state, workability improved with increase in replacement percentage of tire crumbs. In hardened concrete, the compressive strength, tensile strength and flexural strength decreased with increase in fraction of tire crumbs. The apparent density was only slight changed while voids and water absorption decreased because of increase in workability. The relative values of strength exhibit a linear relationship with replacement ratio.**

***Index Terms*—concrete, recycled tire, aggregate replacement, compressive strength**

I. Introduction

Concrete is a composite material made up of coarse aggregate held together in cement – fine aggregate matrix. The coarse aggregates used in manufacturing concrete are either naturally occurring or crushed rock and the fine aggregate is sand. As concrete is the most commonly used construction material, the natural resources are being utilized at a rapid rate. On the other hand, waste tires pose a serious environmental problem all over the world. As part of waste management, several techniques have been proposed for recycling waste tire. One of the potential ways of utilizing tire waste is to utilize it in construction sector for aggregate replacement. The recycled tires can be utilized in concrete either as partial or full replacement of either coarse or fine aggregates at a time or both at once. Herna ́ndez-Olivares *et al.* [1] used crushed tire rubber between 0.85 and 2.15 cm long with an average of 1.25 cm to replace 5% of aggregate by volume in a 1:1.94:3.07 (cement: sand: coarse aggregate) mix. It did not imply significant variation of strength. Garrick [2] used specially prepared tire rubber chips and fibers to modify concrete mix (1:1.88:3.5). He concluded that rubberized concrete exhibit higher toughness than plain concrete mix, higher ductility and resistance to cracking but lower compressive and tensile strength. Ling and Nor [3] used two mix proportions (1:2:3.67 and 1:1.89:3.78) and replacement of fine aggregate at 10%, 20% and 30% and concluded that as the rubber content increase, the compressive strength and the dry density decrease compared with the plain cement concrete. Eshmaiel *et al.* [4] considered replacement of coarse and fine aggregates using 5%, 7.5% and 10% replacement by volume in separate mixes with the same w/c- ratio of 0.50. They concluded that strength properties decrease with increase in replacement of rubber in any form (coarse aggregate, fine aggregate or cement). Azmi *et al.* [5] used different w/c- ratios and approved finding of Eshmaiel *et al.* [4]. Panda *et al.* [6] explored the possibility of incorporating scrap tire rubber chips as coarse aggregate in concrete mixture using replacement by volume of coarse aggregate from 3% to 12%. Increase in percentage replacement of rubber decreased the slump value, workability, compressive strength, split tensile strength and flexural strength of the specimen. El-Gammal *et al.* [7] studied the use of waste tire rubber as fine and coarse aggregate. They tested three types of mixtures, full replacement of coarse aggregate, full replacement of fine aggregate and 50% replacement of fine aggregate with powder tire rubber. They observed reduction in compressive strength for all samples that more in coarse aggregate replacement compared to fine aggregate replacement. Abaza and Shtayeh [8] explored the potential to produce a non-structural concrete using waste crumb tires. 25%, 50%, 75% and 100% of fine aggregate replacement. They observed that compressive strength, density and modulus of elasticity dropped as percentage of replaced rubber increased.

This paper investigates possible use of commercially available recycled tires crumbs for aggregate replacement in concrete to be used for non-structural purposes. The research considers partial replacement of fine aggregates with recycled tire rubber and investigates its effect on the strength and physical properties of resulting concrete. Workability is measured in the fresh state and compressive strength, tensile strength, flexural strength, apparent density, percentage voids and water absorption are evaluated in hardened state.

II. Materials

The concrete was prepared using locally manufactured ordinary Portland cement (ASTM: Type-I). The coarse

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and fine aggregates used were conforming with Omani Standards [9]. The recycled tire crumbs used for fine aggregate replacement were in the size range of 0.80 to 4 mm. The gradation curve of the rubber crumbs and fine aggregates used in this study are shown in Fig. 1. It is clear that most of the crumbs (≈ 60 %) are within the size range 1.18 - 2.36 mm. Specific gravities of coarse aggregate, fine aggregate and tire rubber were estimated to be 2.69, 2.85 and 1.05 respectively.

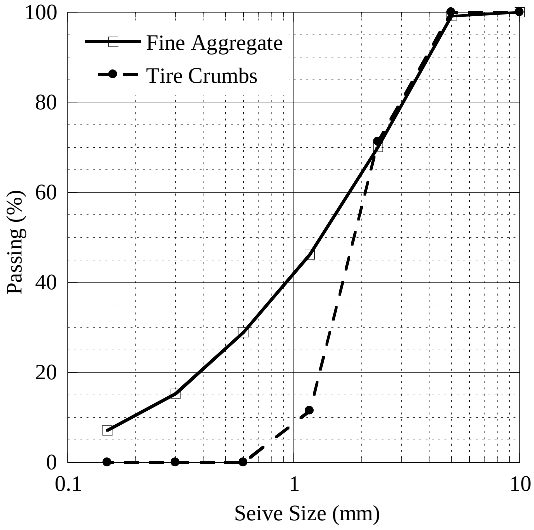

Figure 1. Gradation for fine aggregates and tire crumb

TABLE I. BATCH QUANTITIES FOR MIXES

Constituents	Mix			
	Control Mix (CM)	RF-20	RF-40	RF-60
Cement (Kg)	31.4	//	//	//
Sand (Kg)	62.7	50.2	37.6	25.1
Aggregate (Kg)	125.4	//	//	//
Tire Rubber (Kg)	-	4.4	8.8	13.2
Water (Kg)	15.7	//	//	//
Plasticizer (ml)	-	300	300	300

'//' – same as Control Mix; RF- Replacement Fraction Mix (%)

III. SAMPLING AND TESTS

A. Mix Proportion

Mix proportion of 1:2:4 (cement: fine aggregate: coarse aggregate) with a water cement ratio of 0.50 was used in the study. The control mix (CM), without rubber tire replacement, was produced for reference values of all the properties investigated. Three replacement percentages of 20 %, 40% and 60% were considered labeled RF-20, RF-40 and RF-60 respectively. Since the water content is small (≈ 7%) and the tire rubber is uniformly graded, 300 ml of super plasticizer was used to improve workability and ease sample preparation for the mixes with tire rubber. Table I shows the mix proportions and the weights used for cement, sand, aggregate, tire rubber and water in a single batch. Concrete mixing and specimen preparation was done as per ASTM C-192 [10], details on the specimens shall be discussed in the next section. No segregation was observed in any of the mixes. The specimens were removed from moulds 24 hours after casting and cured for 28 days before testing.

Volumetric replacement of fine aggregate with recycled tire rubber was considered. The mass of tire rubber (Table I) was calculated using respective specific gravities. Eq (1) and (2) were used to calculate amounts of aggregate and recycled tire for a given replacement fraction " α".

$$m_{\alpha,tire} = m_{agg} \times \alpha \times {SG_{tire}}/{SG_{agg}} \quad (1)$$

$$m_{\alpha,agg} = (1-\alpha) \times m_{agg} \quad (2)$$

where: α = fractional replacement of aggregate considered (20%, 40% or 60%); $m_{\alpha,tire}$ is mass of tire rubber to be used with 'α' replacement; m_{agg} = total mass of aggregate in the control mix; $m_{\alpha,agg}$ = mass of aggregate in the mix with 'α' replacement; SG_{tire} = specific gravity of tire rubber; SG_{agg} = specific gravity of aggregate.

B. Specimens and Tests

Table II lists the mechanical and physical properties of hardened concrete that were investigated. Three specimens were tested for each mix and the property is reported as the average of the three values.

TABLE II. TESTS ON HARDENED CONCRETE

Property Tests	Sample and Size (mm)	Test Standard
Cube Compressive Strength	Cubes (150 x 150 x 150)	BS EN 12390 [11]
Cylinder Compressive Strength	Cylinder (150 Φ x 300)	ASTM C39 [12]
Flexural Strength	Prism (100 x 100 x 500)	ASTM C79 [13]
Tensile Strength	Cylinder (150 Φ x 300)	ASTM C496 [14]
Density, Voids and Water Absorption	Cubes (100 x 100 x 100)	ASTM C642 [15]

Φ – Diameter.

IV. RESULTS AND DISCUSSION

In the fresh state, the slump value of 30 mm was recorded for the control mix while value of 90 mm was observed with RF-20 mix. The RF-40 and RF-60 both resulted in collapsed slump with values of 170 mm and 190 mm respectively. Though the control mix lacked the plasticizer, the comparative result of mixes with replacement indicates that slump increased as tire rubber content increased with the same amount of plasticizer.

Table III summarizes the findings of this research. The cube compressive strength for the control mix is 35.2 MPa, while it decreased from 35.5 MPa and 17.8 MPa as replacement increased from 20% to 60 %. The cube compressive strength at 20% fine aggregate replacement indicated a slight improvement in strength compared with control mix, which may be because of better compaction as a result of increase in workability. The cylinder compressive strength is 26.4 MPa, while it decreased from 17.8 MPa and 6.4 MPa as replacement increased from 20% to 60 %. The tensile strength (split cylinder strength) is 3.4 MPa, while values of 2.2 MPa, 1.9 MPa and 1.50 MPa were observed with replacement of 20%, 40% and 60 % respectively. The flexural strength showed similar trend with a value of 7.6 MPa for the control mix and 7 MPa, 4.6 MPa and 3.6 MPa for replacement of 20%, 40% and 60 % respectively. The higher lose in cylinder strength and tensile strength can be attributed to a weaker bond between rubber and cement-sand matrix. Table III also lists apparent density, air voids and water absorption for the mixes considered. The decrease in density was small compared with the control mix, maximum drop observed was 9.2 % for RF-60. The air voids and water absorption decreased with inclusion of tire rubber. This reduction should be due to higher workability of the mixes with tire rubber that gave better compaction. The lowest values of voids and water absorption were 9.8 % and 4.4 % receptively, observed in RF-20 mix. As the replacement ratio increased these values increase because the uniformly graded rubber leads to more voids even with increased workability.

TABLE III. SUMMARY OF TEST RESULTS

Hardened Concrete Property	Mix			
	CM	RF-20	RF-40	RF-60
Cube Comp. St. (MPa)	35.2	35.5	26.9	17.7
Cyl. Comp. St.(MPa)	26.4	17.8	9	6.4
Tensile St. (MPa)	3.4	2.2	1.9	1.5
Flexural St. (MPa)	7.6	7	4.6	3.6
App. Density (g/cm3)	2.62	2.47	2.44	2.38
Voids (%)	15.8	9.8	14.1	16
Water absorption (%)	7.15	4.4	6.2	8

CM – Control Mix; RF – Replacement Fra
ATIVE values ction Mix (%)

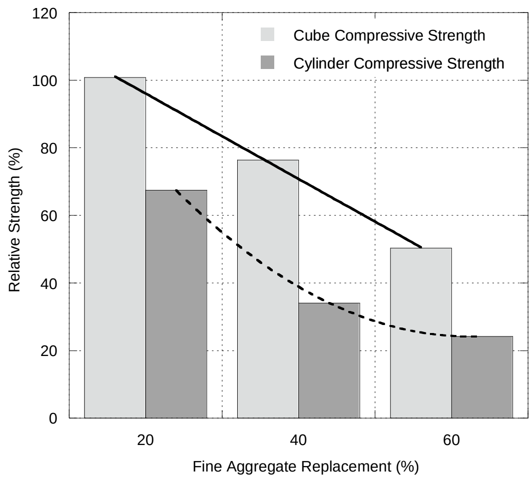

Figure 2. Relative compressive strength

Fig. 2 shows the relof the cube compressive strength and cylinder compressive strength for the replacement mixes, with regression model used to fit the available data. The reduction in cube strength with increase in tire content can be represented as a linear model with R-value of 0.9998 with a rate of strength loss at 25% beyond 20% replacement. For cylinder strength, a quadratic model gives an R-value of 1.000. Fig. 3 shows the relative tensile and flexural strength of the replacement mixes. The tensile strength can modeled using linear regression (R=0.9966) while the flexural strength is well represented using a quadratic regression (R=1.000).

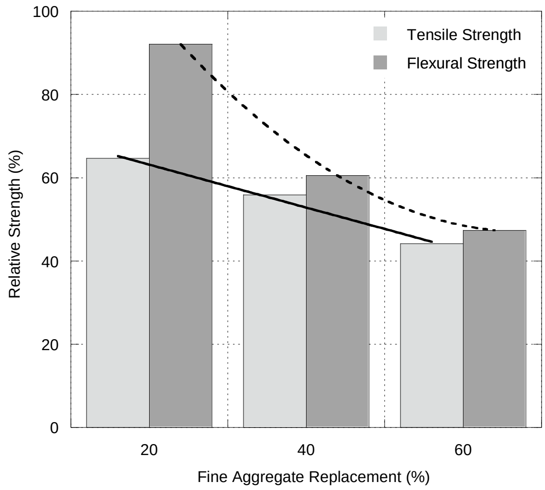

Figure 3. Relative tensile and flexural strength

Fig. 4 shows the relative voids and water absorption for the replacement mixes which can be modeled using linear regression with R=0.9759 and R=1.000 respectively. Fig. 5 shows relative apparent density that can represented using linear regression with R=0.9820. This indicates that the replacement of fine aggregates with tire rubber has a linear effect on the cube compressive strength, Tensile strength, Air voids, water absorption and density. However, a quadratic model is essential to represent the relationship for cylinder compressive strength and flexural strength. This nonlinear behavior is due to poison's effect in case of cylinder strength and while in case of flexural strength it is due to the weaker interlocking and bond due to rubber crumbs.

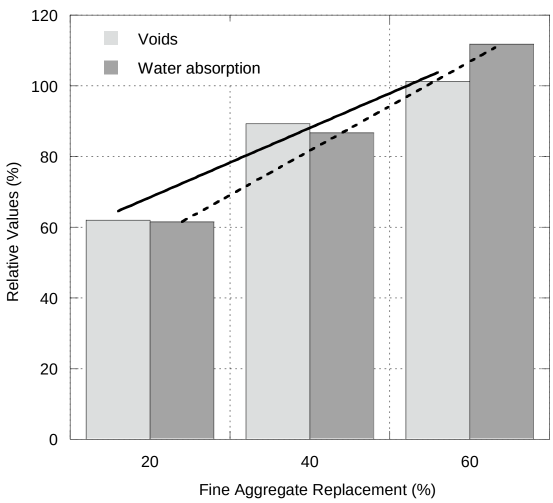

Figure 4. Relative air voids and water absorption

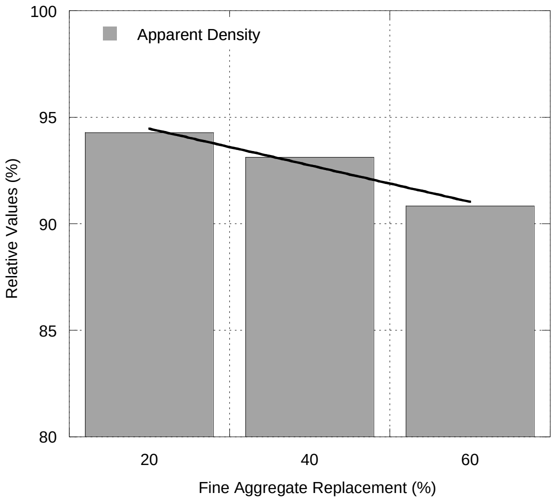

Figure 5. Relative apparent density

V. Conclusion

The experimental study investigated the use of recycled tires for partial replacement of fine aggregates in non-structural concrete using fraction of 20%, 40% and 60%. Based on the results, following conclusions may be drawn:

- Workability of the mix increases with increase in tire rubber content.
- Compressive strength, tensile strength and flexural strength all decrease as the percentage of tire rubber increased.
- The apparent density is only slightly decreased; the maximum reduction is almost 10% with the 60% replacement.
- Increase in workability lead to reduction in voids and water absorption due to better compaction, but with large replacement fraction of uniformly graded tire rubber the benefit is nullified.
- The relative values of all the strength and physical characteristics investigated can be represented using simple regression models.

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