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Effect of Crumb Rubber on Fresh and Mechanical Behaviour of OPC-based Concrete

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ABSTRACT

Crumb rubber offers attractive benefits as well as sustainable recycling of used tires into a valuable resource when utilized in concrete. This study examined the fresh and hardened properties of rubberized concrete using angular and fiber crumb rubber. Crumb rubber was replaced by 0%, 2%, 4%, 6%, and 8% with coarse aggregate and locally produced fly ash (FA) was blended with cement at a constant ratio of 15:85 (FA:OPC). Based on the test results the workability decreased as the amount of rubber increased in the mix. The test results exhibited that the angular and fiber crumb rubber particles slightly decreased the compressive strength of concrete as compared to the control mix. The compressive strength was decreased by 33% and 37.67% in ACRC and FCRC, respectively, compared to the control mix. However, the flexural and tensile strengths of concrete were increased by approximately 8% and 43% for the maximum 8% dosage of fiber rubber.

KEYWORDS: Angular crumb rubber concrete (ACRC), fiber crumb rubber concrete (FCRC), workability, mechanical properties

1 INTRODUCTION

As the number of automobiles on the road has increased significantly across the world over time, one of the biggest issues with environmental and waste management is the build-up of vast volumes of scrap tires [1]. It was found that the addition of rubber fibers ultimately led to a reduction in workability [2]. The primary factors contributing to the reduction in compressive strength of crumb rubber concrete (CRC) were identified as the disparity in elastic modulus between crumb rubber and the cement matrix, as well as the inadequate bonding between these two materials [3]. It was observed that an increase in CR content intensified the increase in splitting tensile strength. Notably, when compared to other forms of CR particles, the use of fiber rubber aggregate in concrete resulted in a relative increase in strength [4]. The study's results indicated that in mixtures incorporating 10% to 20% CR, there was a notable increase in flexural strength, ranging from 7% to 21% [4]. Rubber particles significantly reduced flexural strength in concrete, with a 7.9% reduction in strength after 25% replacement with rubber aggregate [5]. The study found that using a small size of CR in concrete increased the flexural strength by 25% [2].

Although various studies have been published on the effect of crumb rubber in concrete, very few studies focused on the effect of rubber shape (angular or fiber) on the fresh and hardened properties of concrete. Therefore, this study aims to evaluate the performance of ACRC and FCRC. An optimized rubberized concrete mix was developed for structural applications and residential structures, aiming to enhance sustainability, create peaceful living spaces, and prioritize noise reduction [1].

2 EXPERIMENTAL PROGRAM

2.1 Materials and Mix proportions

The fly ash was obtained from the source of the coal power plant, situated in Karachi, Pakistan. The fly ash was classified according to the ASTM C-311/C-114 [6]. The chemical properties of OPC and Fly ash are shown in Table 1.

Table 1. Chemical Properties of Fly ash and Cement

Chemical Properties	SiO_2 (%)	Al_2O_3 (%)	CaO (%)	Fe_2O_3 (%)	SO_3 (%)	LOI (%)	P_2O_5 (%)	LOI (%)
Fly ash	49.55	28.02	8.24	4.39	0.49	2.87	1.37	2.87
Cement	21.31	5.89	62.2	2.67	2.6	1.59	1.59	1.59

The bulk density of sand was determined according to ASTM C29 [6]. The fineness modulus of sand was determined according to ASTM C-33 [7]. The bulk density of coarse aggregate was determined according to ASTM C127 [8]. The specific gravity of coarse aggregate is 2.72 and fine aggregate is 2.56. Waste crumb rubber and tire waste tubes were recycled into angular crumb rubber and fiber rubber, partially substituted with coarse aggregates. The size of ACR ranged from 2-5mm (width) and 20mm (length) while the size of the ACR was from 12 mm to 20 mm, and casted specimens are shown in Figures 1 and 2.

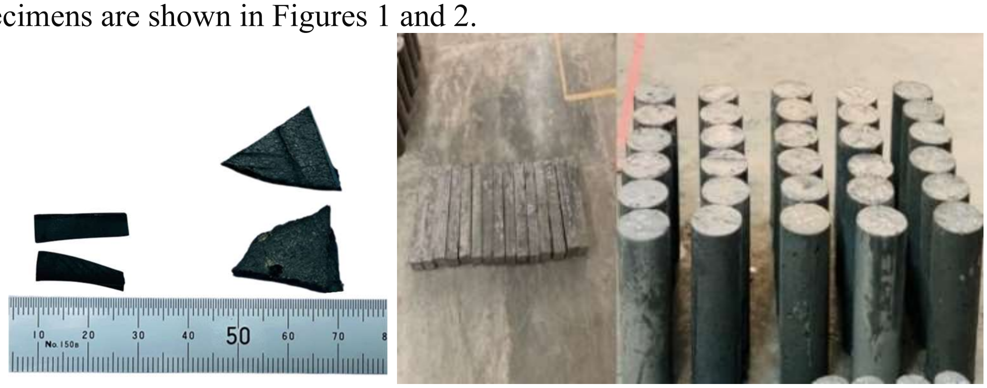

Figure 1(a) Size of Crumb rubber; (b) Casted Specimens for ACRC and FCRC

To achieve the workability, sodium naphthalene sulfonate formaldehyde was added. The details of the mix proportions in kg/m^3 of ACRC and FCRC according to the ACI 211.1 [9], as mentioned in Table 3.

Table 2. Details of Mix proportions

Mix ID	Cement	Fly Ash	Water	Fine aggregates	Coarse aggregates	ACRC/FCRC	SNF
-	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	ml
Normal Concrete	469.2	87.56	221.84	683.43	903.02	0	1%
ACRC (2-8%)	469.2	87.56	221.84	683.43	884.49 866.45 848.41 830.37	18.53 36.26 54.39 72.52	1%
FCRC(2-8%	469.2	87.56	221.84	683.43	884.49 866.45 848.41 830.37	18.53 36.26 54.39 72.52	1%

The workability of the mixes was determined using the slump cone apparatus as per ASTM C143 [10]. To investigate the effect on mechanical properties of concrete (ACRC and FCRC), compressive, tensile, and flexural strength tests were performed. The compressive strength was performed on molds, having a size of 150 mm×300 mm, at 7, 28, and 56 days after curing according to ASTM C39 [11]. The splitting tensile test was performed at 28 days, having a size of 150 mm×300 mm, according to ASTM C496 [12]. The flexural strength test was performed by third point loading on the beam samples having a size of 500 mm×100 mm×100 mm, performed at 28 days according to ASTM C78 [13].

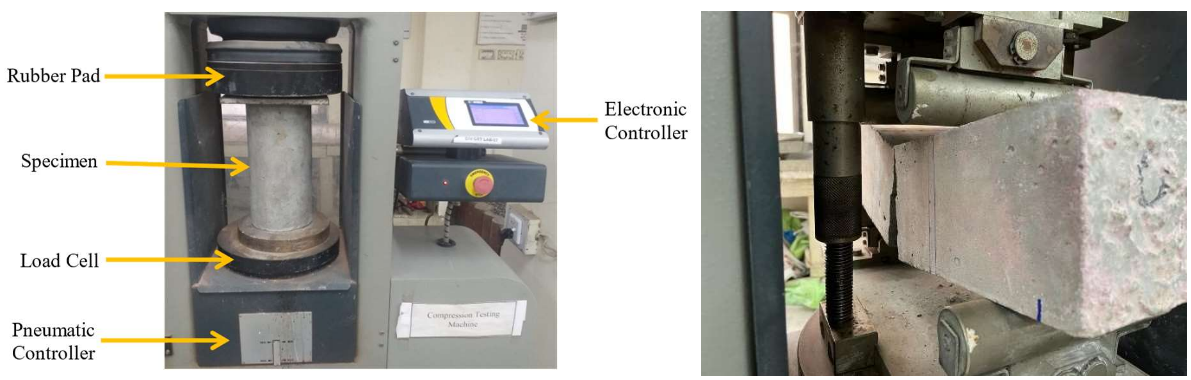

Figure 2 Experimental setup for (a) compressive strength test and (b) flexural test

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Workability

The workability of ACRC and FCRC was determined, and the results are shown in Fig 3. There was a significant effect on the workability of rubberized concrete by replacing the rubber content, compared to the control mix. Workability decreased as CR content increased in the mix. Rubber fibers in concrete did not affect workability, as angular crumb rubber substitution decreased workability. The rough surface and coefficient of friction of crumb rubber particles increased flow resistance, which caused a reduction in workability in rubberized mixes [5], [4].

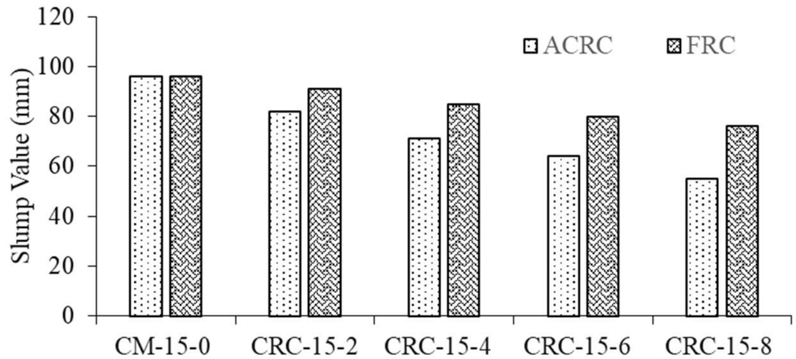

Figure 3. Slump value

3.2 Compressive Strength

The compressive strength test was performed at 7, 28, and 56 days at the control mix and different percentages of replacement of CR with coarse aggregate, as shown in Fig. 4. The compressive strength decreased as the substitution of CR increased compared to the control mix. It was found that ACR had greater compressive strength than FCR, but the addition of CR decreased strength due to less bonding and non-uniform load distribution, resulting in fractures. Rubber particles moved along mold surfaces during casting, reducing concrete strength and causing failure [14].

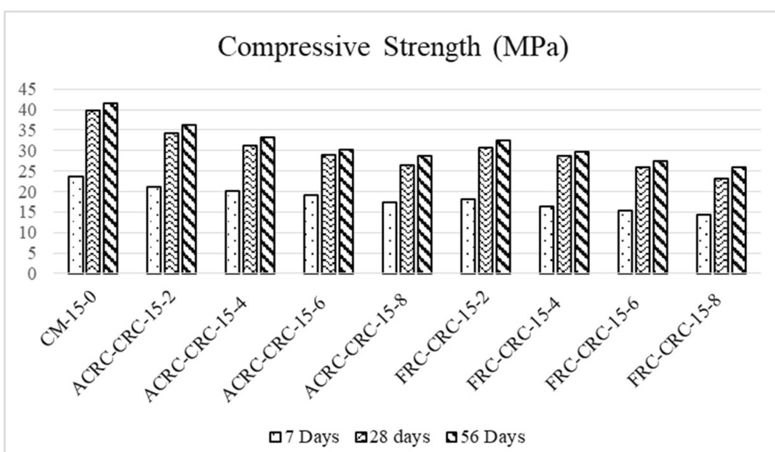

Figure 4. Compressive strength at 7, 28, and 56 days

3.3 Splitting Tensile and Flexural strength

The tensile and flexural test was performed on the specimens with or without CR at 28 days; the observed values are shown in Fig 5. The study found that tensile strength increased with 8% fiber rubber replacement with coarse aggregate compared to the control mix and ACRC [4]. The flexural strength also showed the same trend. The tensile strength of rubber-containing concrete was found to be lower due to poor connection, micro-cracks, and weak interface zones. It was found that fibre rubber concrete specimens had higher flexural strength than the control mix and ACRC, with the maximum value at 8% fiber rubber replacement [5]. The strength improvement was attributed to the use of 20 mm long fibers, which provided superior pulling resistance and high elasticity. The modified concrete's flexural strength improved with increased rubber fiber content, indicating a more crucial bridge between fractures [15], [16].

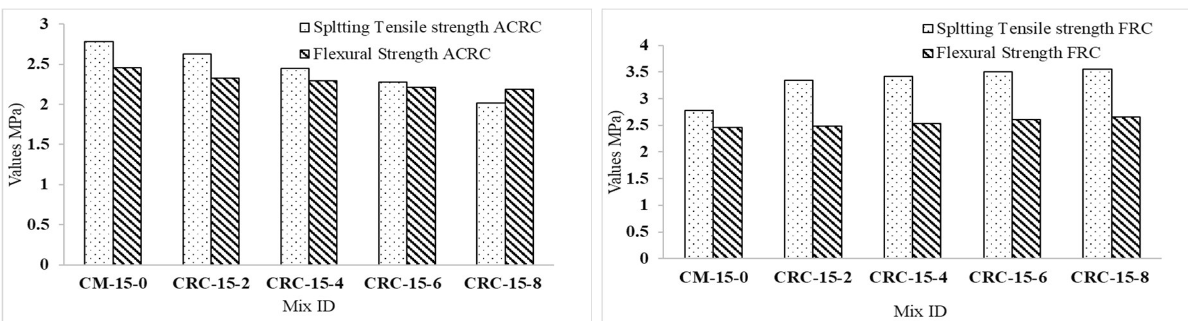

Figure 5. a) Splitting tensile strength and Flexural Strength of ACRC and b) Splitting Tensile and Flexural Strength of FRC

4 CONCLUSIONS

Crumb rubber was used as a coarse aggregate replacement, and the fresh, mechanical, and rubberized concrete were analyzed. To enhance these properties, fly ash was added in partial cement replacement. The following conclusions are taken from the experimental research data;

1. Workability decreased as the amount of angular crumb rubber increased, yet there was a slight difference in fiber rubber compared to the control mix. It has been seen that angular rubber shows good strength in compressive strength compared to fiber rubber.
2. Compressive strength decreased by 33% and 37.67% in ACR and FRC, respectively, compared to the control mix.
3. Flexural and tensile strength of concrete increased up to 8% replacement as FCR, relative to control mix and ACRC. It increased at 8% and 43% in both flexure and tensile strength respectively.

The future recommendation includes the use of crumb rubber particles with different coatings i.e., cement, NaOH, and KMnO4.

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