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Selection of optimal mix design with simultaneous use of RSF and RCA with emphasis on the initial strength of RCA

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ABSTRACT: In this research, the properties of concrete made with recycled concrete aggregates (RCA) and reinforced with recycled steel fibers from waste tires (RSF) were investigated. In the production of RCA, 3 types of concrete wastes with initial strengths of 20, 40, and 80 MPa were used. The results of aggregates tests showed that increasing the initial strength of RCA increases the density and abrasion resistance and decreases the water absorption and amount of mortar attaching to the surface of these aggregates. In the making of specimens, 0, 50, and 100% of natural aggregates (NA) were replaced by RCA. In addition, the specimens were reinforced by using 0, 0.5, and 1% RSF. Various tests such as slump, UPV, water absorption, compressive strength, splitting tensile strength, and flexural strength were performed on 21 mix designs. The results of these tests indicated that the use of RCA had a negative effect on the workability, quality, and mechanical properties of concrete, which can be prevented by increasing the initial strength of RCA and also using RSF. Finally, by economic analysis and optimization of mixing designs, it was concluded that it is justified to use RSF and 50% RCA with an initial strength of 40 and 80 MPa, in terms of economy, resistance, workability, and quality.

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1- Introduction

More than 42,000 tons of construction and demolition (C&D) wastes have been produced in Tehran, Iran. This volume of construction wastes had adverse environmental consequences. One of the solutions to manage this type of wastes is to recycle and reuse it [1]. Recycling and reuse of C&D wastes as a substitute for natural aggregates (NA) helps to preserve the environment [2]. In previous researches, both decreasing and increasing effects on concrete strength due to the use of recycled concrete aggregates (RCA) have been reported [3]. Chan et al. [4] reported the negative effects of using RCA and Sahraei Moghadam et al. [5] reported the positive effects of using these aggregates. One of the reasons for the variable behavior of concretes containing RCA in previous studies could be related to the initial strength of RCA. Therefore, one of the variables discussed in this study is the initial strength of concrete wastes used in RCA production.

Annually, 1 billion tires are abandoned worldwide, while only 33% of them are recycled and the rest are incinerated or left in the nature. Leaving scrap tires in nature can lead to many environmental problems, while recycling them can prevent these problems [6]. Not only the powder of scrap tires can be used for the production of new tires or in the production of bitumen, but also the wire in them can be an excellent alternative to industrial steel fibers in the production of fiber-reinforced concrete [7]. On the other hand, the production of industrial steel fibers causes the production of CO_2 and the destruction of natural resources, while replacing them with recycled steel fibers (RSF) can help preserve natural resources and reduce environmental pollution [8]. In addition, concrete shows brittle performance under tensile and impact loads that the use of fibers eliminates these concrete defects [9-12]. Therefore, another variable discussed in this study is the percentage of RSF used in concrete.

This study investigates the effect of initial strength (20, 40, and 80 MPa) of concrete wastes and volume fraction (0, 0.5, and 1%) of recycled steel fibers from scrap tires (RSF) on the fresh and hardened properties of recycled concretes. For this purpose, various tests such as slump, water absorption, UPV, compressive strength, splitting tensile, and flexural strengths were performed. In addition, in order to determine the optimal mix design, multi-criteria optimization (MCO) and economic analysis were executed.

2- Methodology

2- 1- Parent concretes

Parent concretes with three strength grades of 20, 40, and 80 MPa were used to produce RCAs. First, a compressive strength test was performed on three standard cylindrical

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Table 1. Mix proportions.

Mix ID	OPC (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)				Water (kg/m^3)	RSF (% in Vol)
			NA	RCA				
				20 MPa	40 MPa	80 MPa		
R0-F0	488	652	1024	0	0	0	205	0
R0-F0.5	488	652	1024	0	0	0	205	0.5
R0–F1	488	652	1024	0	0	0	205	1
R50-C20-F0	488	652	512	480	0	0	205	0
R50-C20-F0.5	488	652	512	480	0	0	205	0.5
R50-C20-F1	488	652	512	480	0	0	205	1
R100-C20-F0	488	652	0	960	0	0	205	0
R100-C20-F0.5	488	652	0	960	0	0	205	0.5
R100-C20-F1	488	652	0	960	0	0	205	1
R50-C40-F0	488	652	512	0	485	0	205	0
R50-C40-F0.5	488	652	512	0	485	0	205	0.5
R50-C40-F1	488	652	512	0	485	0	205	1
R100-C40-F0	488	652	0	0	970	0	205	0
R100-C40-F0.5	488	652	0	0	970	0	205	0.5
R100-C40-F1	488	652	0	0	970	0	205	1
R50-C80-F0	488	652	512	0	0	497	205	0
R50-C80-F0.5	488	652	512	0	0	497	205	0.5
R50-C80-F1	488	652	512	0	0	497	205	1
R100-C80-F0	488	652	0	0	0	994	205	0
R100-C80-F0.5	488	652	0	0	0	994	205	0.5
R100-C80-F1	488	652	0	0	0	994	205	1

specimens made from each parent concretes, in accordance with ASTM C39 [13]. The results of the compressive strength test show good compliance between the compressive strength of the specimen and the considered strength grades for parent concretes. After ensuring the compressive strength of the considered mix designs, the parent concretes were made. After 90 days, parent concretes were demolished and recycled.

2- 2- Material

In this study, ordinary Portland cement (II) based on ASTM C150 [14] was used. Recycled steel fibers from scrap tires (RSF) of 0, 0.5, and 1% volume of concrete were used to reinforce the concrete specimens. These fibers had different shapes. In order to determine the physical properties of these fibers, accurate measurements were performed on 200 of them. These measurements indicated that a significant proportion of RSF was 30-50 mm long and 0.2-0.3 mm in diameter. Four different types of aggregates, including natural aggregate (NA) and three types of RCAs (recycled aggregate from concrete wastes) with initial strengths of 20, 40, and 80 MPa were used. These aggregates were prepared with the same grading.

2- 3- Mix proportion and specimen preparation

Table 1 presents mix proportions. Variables of mix proportions include the percentage of NA replacement with RCAs (0, 50, and 100%), the initial strength of RCAs (20, 40, and 80 MPa), and the volumetric percentage of RSF (0, 0.5, and 1%). Mix proportions are named so that the number opposite the letter R indicates the percentage of NA replacement with RCAs, the number opposite the letter C indicates the initial strength of RCAs, and the number opposite the letter F indicates the amount of RSF. The concrete development method was started by blending the dry cement and aggregates for 2 minutes in mixing machine. Then, the needed water was gradually added to the mixture. To prevent conglomeration, in the final stage, the RSF was gradually added to the concrete mixture. All specimens were stored for 24 hours at 25 °C temperature and 85% relative humidity, then cured in water tanks at 20 °C for 28 days. After 28 days, the tests were performed on the specimens.

2- 4- Tests procedure

In order to investigate the effect of RCA and RSF on concrete workability, the slump test was performed in accordance with ASTM C143 [15].

Based on ASTM C39 [13], the compressive strength test was performed on cubic specimens, with the loading rate being 0.3 MPa/s. The test used a digital compression testing machine with a capacity of 1000 kN. The test managed to determine the maximum compressive force tolerated by the specimen. For the calculation of compressive strength, Equation (1) was used.

$$\sigma_c = \frac{P}{A} \tag{1}$$

where, σ_c, P, and A are the compressive strength, the maximum compressive force tolerated by the specimen, and the cross-sectional area of the specimen (100 × 100 mm), respectively.

Based on ASTM C496 [16], the Splitting tensile strength test was conducted on cylindrical specimens having a diameter of 100 mm and a height of 200 mm at a loading rate of 0.05 MPa/s. Splitting tensile strength computations were based on Equation (2).

$$\sigma_t = \frac{2P}{\pi . L . D} \tag{2}$$

where, σ_t, P, D, and L are the splitting tensile strength, applied force, the cylindrical specimen diameter (100 mm) and the cylindrical specimen length (200 mm), respectively.

Based on ASTM C1609 [17], the TPB (three-point bending) test was conducted. A load cell with a 100 kN capacity was used to measure the applied force. For the computation of flexural strength of beams, Equation (3) was used.

$$\sigma_f = \frac{3FL}{2b.d^2} \tag{3}$$

where, σ_f, F, L, and b are the flexural strength, the applied force, the span length, the beam width and the beam height, respectively.

3- Results and Discussion

RCAs have low density and abrasion resistance and high water absorption, in comparison with NA.

Increasing the initial resistance of RCAs increased the abrasion resistance and decreased water absorption and the amount of mortar attached to their surface.

There was a linear and inverse relationship between the initial strength of RCAs and water absorption as well as the abrasion of these aggregates.

Replacement of NA with RCAs as well as the use of RSF reduced the workability of concrete while increasing the initial strength of RCAs had no effect.

RCAs and RSF increased porosity, decreased quality, and subsequently decreased UPV, while increasing the initial

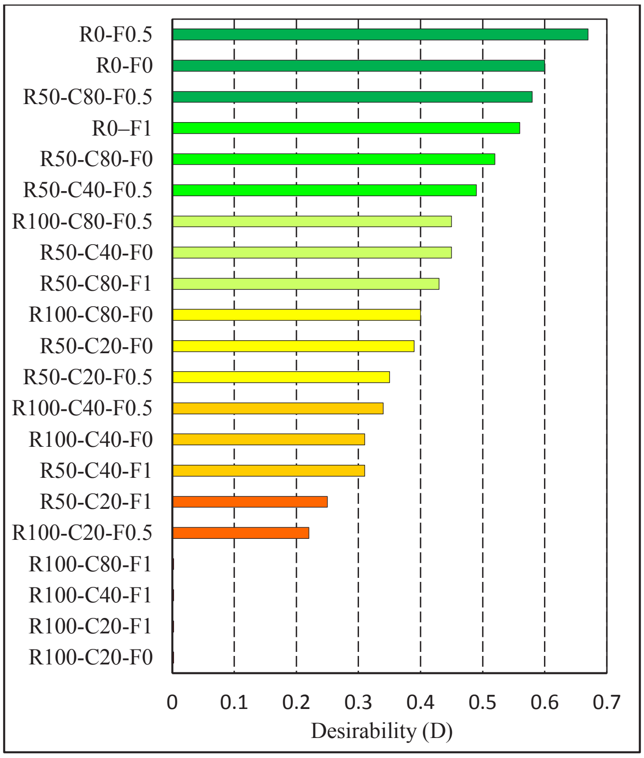

Fig. 1. Overall desirability of mix designs.

strength of RCAs improved the quality of recycled concrete.

RSF improved the mechanical properties of concrete, while its effect on improving tensile and flexural strengths was much more significant.

RCAs weekend the mechanical properties of concrete.

Increasing the initial strength of RCAs improved the mechanical properties of recycled concretes so that specimens containing RCA with an initial strength of 80 MPa had almost the same mechanical properties of specimens containing NA.

4- Conclusion

Regarding the results obtained from multi-criteria optimization (MCO), the replacement of 50% NA with high initial strength RCAs as well as using RSF is justified in terms of workability, quality, water absorption, mechanical properties, and economic aspects (see Figure 1).

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