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Effect of copper slag on the mechanical properties and fracture energy of fiber reinforced cementitious composite

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ABSTRACT: One of the most important weakness points of concrete is its drawback in tension and cracking. The use of fibers in concrete greatly reduces this disadvantage. Fiber-reinforced cementitious composite (FRCC) is a type of fiber-reinforced concrete (FRC) that does not contain coarse aggregate and only has fine aggregate. In fact, the high level of cement in FRCC is a problem for the environment. This problem can be solved by using different cement replacement materials as a part of cement. In this study, the effect of copper slag on the mechanical properties and fracture energy of fiber-reinforced cementitious composite (FRCC) containing polypropylene fiber is investigated. Silica fume and copper slag were replaced as a part of cement. For this purpose, a control mix without silica fume and copper slag, 4 mixes containing 5%, 7%, 10% and 15% silica fume, and 4 mixtures with 5%, 10%, 20% and 30% copper slag was casted. In specimens containing silica fume, the ones with 15% of it had the highest quantity of fracture energy, compressive, tensile, and flexural strengths. Among the samples having copper slag, the ones containing 10% and 20% of it had the highest values above. It is worth noting that some binary mixtures containing both copper slag and silica fume were prepared too. Comparing the results of all the mentioned mixtures, it is concluded that the best results belong to the binary mixture containing both 15 % copper slag and 15 % silica fume.

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1- Introduction

Concrete is one of the most important and useful construction materials and is a brittle material with low tensile strength. One of the most important types of concrete is the one containing Portland cement. Fiber-reinforced concrete can be fabricated by adding short fibers to the mixture in order to improve its tensile behavior. The above fibers act like bridges to prevent the expansion and opening of cracks [1]. Fiber-reinforced cementitious composite (FRCC) is a type of fiber-reinforced concrete that does not have coarse aggregate. In other words, the main compounds are water, cement, fibers and fine aggregates such as silica sand. One of the most important problems in the use of FRCC is its high grade of cement. Therefore, cement replacement materials can be used to lower the cement content. One of these replacement materials is silica fume. Mazloom et al. [2] showed that the use of appropriate values of silica fume leads to an increase in the strength and durability of concrete at different ages. According to previous studies, silica fume increases compressive strength, tensile, flexural and fracture energy of concrete and other cementitious materials [3, 4]. Another cement replacement material is copper slags, which is a waste material. Other researchers have used copper slag as a cement replacement material, and this material had different effects due to the type of mixture [5-7]. In fact, these researches show that copper slag can be used as an alternative for a part of cement.

The purpose of this study is the fabrication of FRCC with high mechanical and fracture energy properties. In this investigation, copper slag and polypropylene fibers, which were more available, were used instead of fly ash and polyvinylalcohol fibers. In fact, to reduce the amount of cement in this scheme, silica fume and copper slag were used. Finally, compressive strength, tensile strength, flexural strength and fracture energy of FRCC were used to select the best mix design.

2- Methodology

One of the mix designs of cementitious composites is introduced by Yu et al. [8]. Their investigated mix was used as a primary basis for this work. According to the existing facilities in Iran, the mix is changed and is presented in the following. The cement used in this study is Portland cement type 1-425. The utilized silica fume had an apparent weight of 250 kilograms per cubic meter, and its specifications were consistent with the ASTM C1240 standard [9]. Very fine silica sand of grained 130 to 250 µm was used here. Also, non-crystalline copper slag was used in this research. The fibers used in this study were polypropylene fibers with a length of 10 mm. The number of fibers used in this study was

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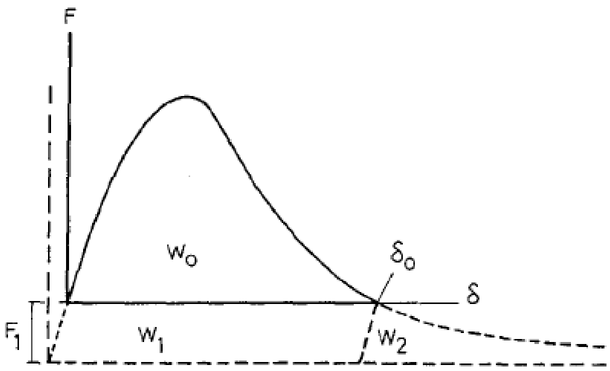

Fig. 1. Higher mode effects (MDOF effects) on HE demand

2 % of the total volume of the mix. In this study, the mixes having only silica fume included 5%, 7%, 10%, and 15% of this material. The ones having only copper slag contained 5%, 10%, 20%, and 30% copper slag. The initial binary mixtures contained the combinations of 10% and 15% silica fume with 10% and 20% copper slag. The final binary mixes included the optimum silica fumes level of 15% and copper slag percentages of 12.5%, 15% and 17.5%.

In order to determine the compressive strength, 150 mm cube samples were constructed. Also, the loading rate was 0.3 MPa per second. The tensile splitting test was used to determine the tensile strength of the samples. For the determination of rupture modulus of concrete, four-point flexural tests with the universal testing machine were used. These experiments were carried out on rectangular samples of 100×100×350 mm^3. One of the effective parameters in determining the properties of concrete is its fracture energy. In this study, the fracture energy of the samples is obtained based on the method determined in Figure 1 and Eq 1. [10]. In this equation, *A* is the fractured cross-sectional area. In this study, it is the cross-section of the beam.

$$G_F = \frac{W_0 + 2F_1\delta_0}{A} \quad (1)$$

3- Results and discussion

The specimens were tested under mentioned conditions. The results of compressive strength, tensile strength, flexural strength and fracture energy are as follows.

3.1. Compressive Strength

In the samples containing silica fume, the maximum compressive strength belonged to the one containing 15% silica fume, and its value was 52.43 MPa. On the other hand, in the samples containing copper slag, the sample with 20 %copper slag had the highest compressive strength of 49.42 MPa. The best binary mix contained 15 % silica fume and 15 % copper slag, and its compressive strength was 57.13 MPa.

3.2. Tensile Strength

In the samples containing silica fume, the one containing 15% silica fume had a maximum strength of 4.73 MPa. In the samples having copper slag, the ones containing 10% copper slag, with the value of 4.16 MPa, had the highest tensile strength. The binary samples containing 15% silica fume and 15% copper slag were the best mix, and its tensile strength was 4.98 MPa.

3.1. Flexural Strength

In the samples having silica fume, the one containing 15% silica fume had the maximum flexural tensile strength of 7.22 MPa. In the samples having copper slag, the ones containing 10% copper slag, with the value of 6.62 MPa, had the highest tensile strength. The binary samples containing 15% silica fume and 15% copper slag were the best mix, and its flexural tensile strength was 7.48 MPa.

3.2. Fracture Energy

In the specimens with silica fume, the one containing15% silica fume had the maximum fracture energy of 6.87 N/mm. In the samples having copper slag, the ones containing 10% copper slag, with the value of 6.3 N/mm, had the highest fracture energy. The binary samples containing 15% silica fume and 15% copper slag were the best mix, and its fracture energy was 7.01 N/mm.

4- Conclusions

In this research, the effects of silica fume and copper slag on the mechanical properties and fracture energy of FRCC are investigated. In the mixes containing only silica fume as a cement replacement material, the optimal percentage of it was 15%. In the case of using only copper slag, the optimal percentage of it was 20% for the compressive strength and 10% for the tensile strength, flexural strength and fracture energy. The final optimal mix design for compressive strength, tensile strength and fracture energy chosen through binary samples contained 15% silica fume and 15% copper slag.

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