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Applying Solid Residues of Copper Slag in Kerman Sarcheshme of Iran as Sand Replacement for Self-Compacting Concrete

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Abstract
The reuse of mineral wastes is one of the most suitable solid wastes solutions. Throughout the world, the large of the granular aggregates used in constructions exploit natural mountain resources and rivers. Using mineral waste as a part of concrete, it can be helped to create a green environment and also contribute to sustainable development. Since the copper production process in the Sarcheshmeh copper condensation factory is the source of the production of slag as waste and useless materials. These wastes can be used to produce concrete. In this paper, that is based on a laboratory study, attempted to examine the physical and chemical properties of waste materials. The effect of these materials as sand replacement was studied on the properties of Self-condensation, strength, corrosion and absorption of water self-compacting concrete. Thus, sand was replaced with the percentages of 0, 20, 40, 80 and 100 with copper slag, and the effect of this replacement on properties of self-condensation, strength, corrosion, and water absorption of self-compacting concrete studied. The results indicate that the replacement of sand with copper slag has caused an increase in slump flow and by increasing the percentage of replacement an increase in the rate of obstruction was observed. The compressive strength with the replacement of sand, with 20, 40 and 60 percent of copper slag, increased by 11.3, 15.5 and 12.4% respectively. And replacing sand with copper slag will cause more concrete corrosion.

Keywords: Self-compacting concrete, Copper slag, Self-density properties, Resistive properties, Mineral waste.

Introduction

One of the important points in the implementation of concrete structures is the full compaction of concrete and its proper fitting in the formwork. Self-compacting concrete, SCC is a type of concrete that is able to flow and compact under its own weight; completely fill the formwork even in the presence of dense reinforcement in the case of elements such as shear wall and column, whilst maintaining homogeneity without need of any additional type of compaction. The full compaction of concrete and its proper fitting in the form works the one of the most important points in the correct implementation of concrete structures. The compaction of concrete with the usual method such as use of vibrators caused multiple problems such as segregation of the grains and facade sand. Thus, self-compacting concrete is a very convenient

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solution to deal with these problems, it was first introduced to achieve the structure of stable concrete in 1988 and the initial studies surrounding the performance of self-compacting concrete were conducted by Okamura and Ozawa (1997) and Okamura (1997) at the University of Tokyo. According to a theory, self-compacting concrete is a concrete that has the compaction, without the need for external energy and without suffering any major segregation and bleeding. Today, due to the reducing the human force because of SCC's own congestion, the improvement in durability due to reduction in permeability and more freedom of action in the design of sections has led to the use of self-compacting concrete in many manufacturing activities. Also, SCC have many benefit but SCC is still not the first choice concrete for many application because of it is more sensitive to small variation in mix proportion and material properties (Rigueira et al., 2009). On the other hand, a large expansion in industries was observed over the past decade. With the development of industries, the production of its products increases. The use of industrial waste, soil or secondary materials was proposed to produce cement and self-compacting concrete because it helps reduce the consumption of natural resources (Vahidi et al, 2017 a; Padash et al, 2015). Copper slag is one of the waste products produced by chemical industries that will create some environmental problems in the surrounding areas if not properly discarded. Copper slag is also one of the materials known as a waste and useless material, which can be a promising future in manufacturing and manufacturing industry as a partial replacement of cement or sand (Vahidi et al, 2017 b). Many researchers currently have the possibility of using copper slag as a replacement of cement, but less research is reported in the field of using slag as a replacement of the reported sand.

The potential of using copper slag as a replacement of sand in self-compacting concrete production can be promising by various achievements of environmental biology as well as economic to produce self-compacting concrete. The achievements of this study can be used for concrete manufacturing and mining complexes. All of the contracting company, government and private consultants and employers who use their concrete in small-scale projects in the civilian development project, enjoy the achievements of this study to increase their work quality.

Many researchers have examined the possibility of using copper slag as aggregates in concrete and its effects on strength properties and the long-term properties of mortar and concrete. Despite the advantages of the use of copper slag as aggregates, some negative effects such as time delay settle reported (Ayano and Sakata,2000), especially when copper slag was used only as a fine aggregate. The following are a number of investigations carried out on the use of copper slag as a replacement of cement or aggregates. Ayano and Sakata (2000) reported that the effect of copper slag on the summit time varies with the size of the copper particles (i.e. the smaller particles of copper slag are deposited more late).Although the effect of the copper slag on the summit time was decreased with the increase of washing time.

Shoya et al. (1997) reported that the speed of de-aeration with the application of copper slag as a fine aggregate suited to water ratio to cement, volume of copper slag and air volume was increased. They concentrated on replacing less than 40% of the amount of cement using copper slag to control the rate of de-aeration, less than 5 liters per cubic meters.

Hwang and Laiw (1989) reported that the amount of de-aeration of the mortar made with copper slag was lower than that of natural sand. Although heavy special weight, glassy and polished particle size with irregular shape of copper slag aggregate is effective in de-aerating properties, they reported that a sample drop that includes copper slag fine aggregates was equal to or even less than that of a slag-free sample. Several papers indicated that the tensile and compressive strength of a concrete sample made with copper slag as aggregates, usually of normal concrete or even in many cases, was more than the control mix. It is noteworthy that the use of copper slag as fine aggregate can greatly increase the resistance of abrasion of the mortar. Hwang and Laiw (1989) investigated the compressive strength of mortar and concrete, which includes fine aggregate of copper slag, with different ratios of water to cement. They concluded that mortar containing a high amount of copper slag sand at w/c= 0.48 had a lower premature strength.

Mobasher et al. (1996) investigated the use of copper slag as a cement additive in concrete mixtures during their research phase. They reported that the use of copper slag up to 51% of cement substitutes caused a significant increase in the strength of normal concrete.

Al -Jabri et al. (2009) used copper slag as a sand replacement for provide the high-performance concrete. They found that the efficiency and strength up to 50 percent replacement of sand with copper slag increased and Water absorption was decreased up to 40%.

Fadaee et al. (2014) studied the properties of concrete made using slag of Sarcheshmeh copper mine complex as replacement cement materials. They found that the replacement of copper slag instead of a part of the cement reduced the compressive strength of concrete for a higher percentage of 35% in different ages.

Khanzadi and Behnood (2009) studied the mechanical properties of high-strength concrete combined with copper slag as a substitute for coarse aggregate. They found that the compressive strength of 28 days was 10 to 15 percent, and the splitting tensile strength 10 to 18 percent increased with the replacement of copper slag compared to the control sample.

Afshoon and Sharifi (2014) used copper slag as an alternative to cement in self-compacting concrete. They found that replacing cement with copper slag could increase the efficiency and flow of concrete slump. Therefore concrete with a lower water/cement ratio and higher strength can be produced.

Sharma and Khan (2017) investigated the effect of copper slag as a sand replacement on self-compacting concrete. They found that the highest increase in compressive and tensile strength was obtained with 20 and 60% replacement, respectively.

Other studies on the hydration of mixed cement blends with copper slag (Mobasher et al., 1996), clay stabilized with copper slag (Gupta et al., 2012) and the effects of copper slag as a substitute for fine aggregate on the behavior and final strength of the tall and narrow strengthened columns (Alnuaimi, 2012) indicated that copper slag is a good alternative to aggregate materials and cement.

Materials and Methods

One of the effective factors in the application of self-compacting concrete is the proper selection of its constituent parts. Obviously, if the selection of materials is not performed correctly, then the main characteristics of the self-compacting concrete will never be achieved. Therefore, familiarity with physical and chemical properties of consumable materials is required. Any change in the consumable material at the time of manufacturing the laboratory samples will result in errors and a more precise and complete judgment of the results will be more difficult (Taghiof et al, 2013). In order to avoid this, in this research, firstly, consumer materials were prepared as needed and stored in an appropriate place to use materials of the same physical and chemical characteristics. In this section, the specifications of the materials used in the preparation of self-contained concrete, containing slag, and then the mixing design are given for each one.

Cement

In this research, cement type two cement factory of Kerman with a specific weight of 3.15gr/cm^3 and a specific surface of 2850 cm^2/gr has been used. Table 1 also shows the chemical composition of this type of cement, which was compared with the specifications of the ASTM C150 standard, and the results indicated that the cement was of high quality.

Silica Fume

In this study, the production of silica fume of Azna Ferro-Alloy Factory with a specific weight of 2.32gr/cm^3 and a specific surface of 2850 cm^2/gr was used. Table 1 shows the chemical composition of silica fume.

Fly Ashe

In this research, F-type fly ash production of the company Namikaran with a specific weight of 2.3gr/cm^3 and a specific surface of 2800 cm^2/gr has been used. Table 1 also shows the chemical composition of the used fly ash.

Copper Slag

The copper slag in this experiment was produced at Sarcheshmeh copper complex. Copper slag, as black glass beads, whose particle size is like sand, usually found in the Rafsanjan copper manufactory. The specific weight of the used slag was3.7 gr/cm^3 and its density was 2.1 kg/m^3.The chemical composition of the slag used in table 1, and its graining curve was given in Figure1.

Table 1. Chemical properties of copper slag, fly ash, silica fume and ordinary Portland cement

Component (%)	Copper Slag	Fly Ash	Silica Fume	Ordinary Portland Cement
LOI	-	-	-	1.3
SiO2	34	61.34	93.86	21.74
Al2O3	2	25.11	1.32	5
Fe2O3	48.78	4.42	0.87	4
CaO	4.89	4.94	0.49	63.04
MgO	1.23	1.09	0.97	2
SO3	1.83	0.08	0.1	2.9
K2O	0.87	1.01	0.2	1
Na2O	0.63	0.59	0.3	2.3
TiO2	0.44	1.5	-	0.3
CuO	0.55	0.015	-	-

Fine and Coarse Aggregate

The used fine and coarse aggregate for the construction of broken concrete designs made from mines around Kerman city. All of the materials needed for the project were prepared and deposed at the same time in order to prevent the change of soil during the work, and the tests related with determine coarse and fine aggregate curve was performed according to ASTM D422 standard and is consistent with the upper and lower limits of the permissible regulations known by the ASTM C33 standard. Fine aggregate softness modulus 2.8 and Fine and Coarse aggregate density were measured 2.6 and 2.50 respectively. The moisture content in the fine and coarse aggregate was measured 1 and 2 percent respectively. In Figure 1, the coarse and fine aggregate curve with copper slag was presented.

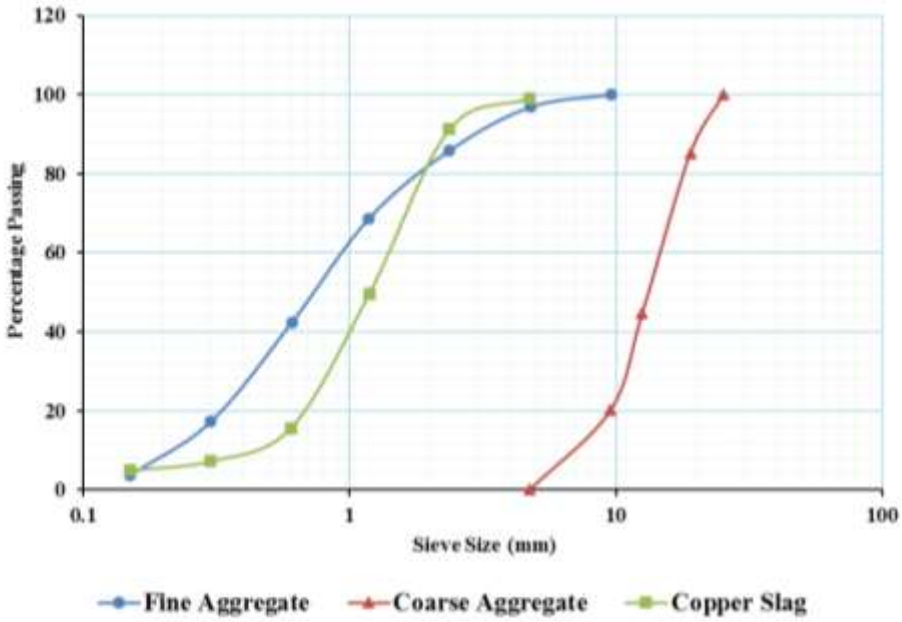

Figure 1. Particle size distribution of fine aggregate, coarse aggregate and copper slag

Superplasticizer

The Super plasticizer was a type of PCE with a specific weight of 1.13 and a solid 40.2% of the product of the company (BASF).

Self-compacting Concrete Mixing design and Description of Experiments

Considering that the ACI Committee-237 has defined the flow and filling the template with self-compacting concrete, it has recommended that, in accordance with existing recommendations and standards, the design of mixing any concrete of its own composition should be carefully and scrupulosity, several mixing designs was investigated first. In order to confirm the compatibility of the mixing designs, the slump tests, T50, V funnel and L box tests were performed and the results were compared with the permitted values of the EFNARC Recommendation. Finally, a mixing design was selected as a blend design and then replaced by a replacement sand with different percentages of copper slag was produced by mixing designs

(Table 3). At each step, with constant holding of all components, a percentage of sand was replaced by slag and self-compacting properties were controlled by a change in the Super plasticizer. In order to confirm the self-compacting of the mixing designs, the slump tests, T50, V funnel and L box tests were performed (Figure 2) and the results were compared with the permitted EFNARC Recommendations, and the results are presented in Table 4.

Table 3. Mix proportion of self-compacting concrete

Mix Description	Cement (Kg/m³)	Water (Kg/m³)	Fine Aggregate (Kg/m³)	Cupper Slag (Kg/m³)	Coarse Aggregate (Kg/m³)	Fly Ash (Kg/m³)	Silica Fume (Kg/m³)	Superplasticizer (Kg/m³)
SCC-0CS	342	251	980	٠	680	160	60	6.5
SCC-20CS	342	251	784	196	680	160	60	6.5
SCC-40CS	342	251	588	392	680	160	60	5.5
SCC-60CS	342	251	392	588	680	160	60	5.5
SCC-80CS	342	251	196	784	680	160	60	4.5
SCC-100CS	342	251	0	980	680	160	60	4.5

Figure 2. Self-compacting concrete tests

Table 4. Fresh properties of SCC compared with EFNARC

Mix Description	Slump Flow (mm)	V-Funnel (s)	T50 (s)	L-Box (H_2/H_1)
SCC-0CS	650	11.1	5	0.83
SCC-20CS	670	10.2	4.6	0.84
SCC-40CS	680	9.9	4.2	0.91
SCC-60CS	680	9.6	4.1	0.89
SCC-80CS	700	8.74	3.7	0.94
SCC-100CS	710	8.3	3.8	0.94
EFNARC	650-800	6-12	2-5	0.8-1

To evaluate the compressive strength for all mixing designs, 9 samples of 10 cubes (for each age, 3 samples) were prepared and after treatment (the treatment conditions of the samples were in accordance with ASTM C31/C31 M-96 and for All samples were considered the same) at the age of 7, 14 and 28 tested (Figure 3). Based on the standard specifications of ASTM C78-94, 6 flexural samples (for each age of 2 samples) were made and placed under flexural test after treatment at age 7, 14 and 28. To evaluate the splitting tensile strength, three standard cylindrical samples (30 × 15) were used and were tested at ages 7, 14 and 28 after treatment (Figure 3).

Figure 3. The compressive and splitting tensile strength of samples

Water penetration depth determination test was carried out according to EN 12390-8. To do this, for each mixing design, three 10 × 10 cubes were made immediately after the surface molding of the sample, exposed to water pressure, with a rough wire brush and at 28 days for 72 hours under pressure 500kPa. Then the sample was removed from the machine and after drying perpendicularly to the surface exposed to water pressure, Doubling and the depth of water penetration was measured.

In order to investigate the corrosion of concrete, from each mixing design, three specimens were prepared and after 28 days of treatment, the samples were removed from the water and after drying, their weight was measured, then one sample in a solution of 5% sulfuric acid and one sample in a solution of iron sulfate 5 Percent and one sample in pure water was placed and after 30 days, in accordance with ASTM-C267-01, to weigh them, we rinsed them 3 times with water and dried with scoop. Subsequently, the samples were placed on their lateral surfaces for 30 minutes until the surfaces of the nails were completely dried and then measured.

Results of Fresh Concrete

In this section, the effect of copper slag on the properties of self-compacting concrete was studied. In Figure 4, the results of self-compacting concrete slump flow, containing different percentages of copper slag are presented. On the basis of this, although with the presence of copper slag, the amount of water was reduced significantly, there was an increase in the slump flow diameter of self-compacting concrete containing copper slag grains. For example, the slump flow in SCC-0CS was measured at 650 mm, which was increased by replacing 100% sand with copper slag grains of 710 mm. This indicates an increase in flow ability by increasing the sand replacement with copper slag grains. The smoothed surface of copper slag compared with sand, can be attributed to this phenomenon.

As shown in Figure 4, sand replacement with copper slag has increased the amount of slump flow, so that by increasing the sand replacement with slag from 0 to 20, 40, 60, 80 and 100 percent, the increase slump was about 3.1, 4.6, 4.6, 7.7 and 9.2.

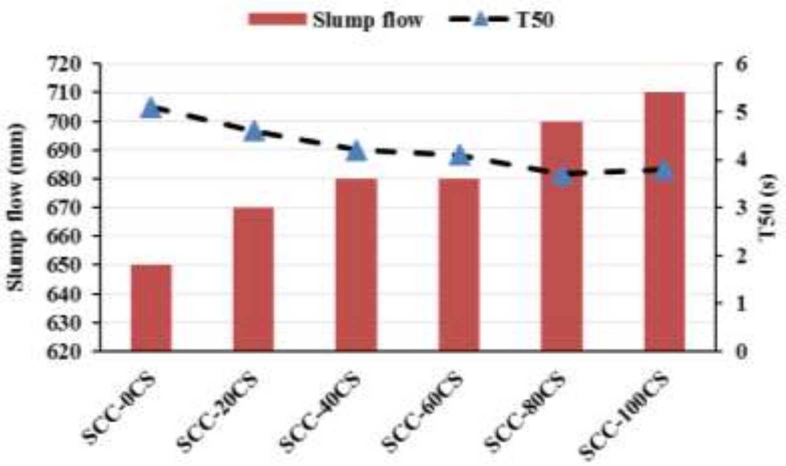

Figure 4. Variation of Slump flow and T50 for different percentages of copper slag replacement

In the T50 test, generally the time of T50 less than two seconds can cause detachment and a time greater than five seconds can increase the chances of obstruction. Research has shown that a mixture of copper slag rather than sand has sufficient viscosity to increase resistivity to detachment.

Figure 4 shows the effect of different slag replacement rates on time T50. As you can see, T50 decreases with increasing percentage of replacement.

The effect of copper slag on the time passed through the V funnel was shown in Figure 5. The passage time of the V funnel in the range of 8.3 seconds varies for 100% sand replacement with slag and 11.1 seconds for the control sample. As you can see, the increase in copper slag has reduced the passage time of the V funnel, which can be due to its weight gain.

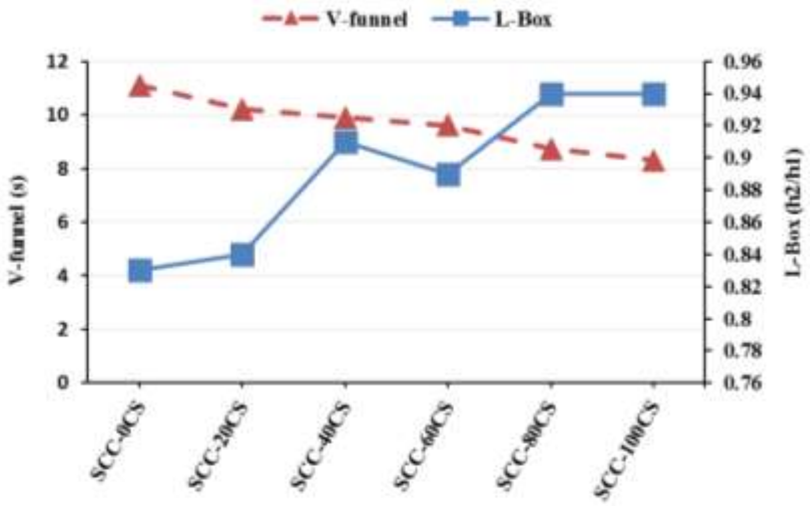

Figure 5. Variation of V funnel and L-Box tests for different percentages of copper slag replacement

The results of the L box for all groups are shown in Figure 5. As it is seen, with an increase in the replacement percentage, we increase the rate of obstruction. It seems that the entirely circular texture of copper slag has increased the porosity of self-compacting light-weight concrete. Of course, there was an exception in the replacement percentage of 60 which seems to be a laboratory error.

Properties of Hardened Concrete

Compressive Strength

The compressive strength of self-compacting concrete samples containing various percentages of copper slag at the age of 7, 14 and 28 days was shown in Figure 6. These strengths are obtained from the average of 3 samples tested at each age. As it can be seen, the compressive strength of the control sample at 28 days was 29.1 MPa, by replacing the sand with20, 40 and 60 percent with copper slag , 32.4, 33.6 and 32.7 MPa, respectively, increasing compressive strength. With increasing the replacement percentage to 80 and 100 percent result was reducing the compressive strength.

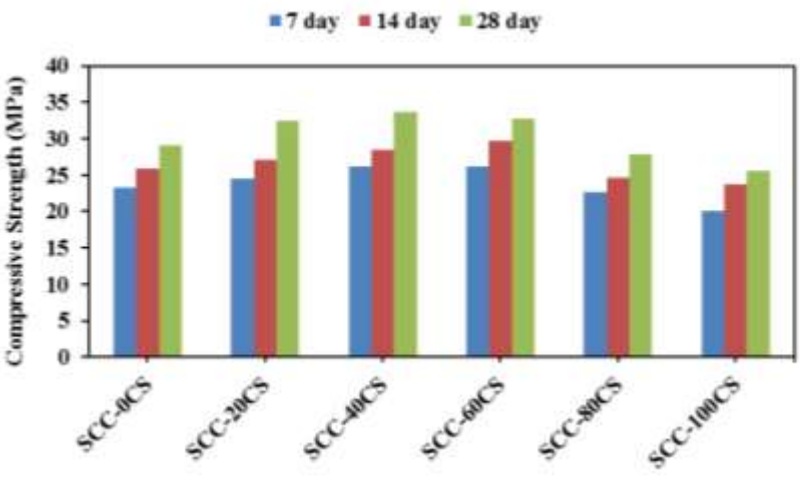

Figure 6. Variation of 7, 14 and 28 day compressive strength for various percentages of copper slag replacement

The highest compressive strength at the age of 28 days for the SCC-40CS sample, in which 40% of the sand was replaced with copper slag, was obtained. In all percentages, compressive strength increases with age of concrete. The rate of increase in strength with increasing age in all designs was almost constant.

Tensile Strength

The tensile strength of self-compacting concrete samples containing various percentages of copper slag at the age of 7, 14 and 28 days was shown in Figure 7. As you can see, the tensile strength of the control sample at the age of 28 was 3.31 MPa, which was increased by replacing the sand with 20 and 40% copper slag to 3.39 and 3.45 MPa, respectively, by increasing the replacement percentage to 60, 80 and 100% We will see a reduction in compressive strength. It can be said that the highest tensile strength was obtained at the age of 28 days of the SCC-40CS sample, in which 40% of the sand was replaced with copper slag. With increasing concrete age, tensile strength increases in all percentages. The rate of increase in strength with increasing age in all designs was almost constant.

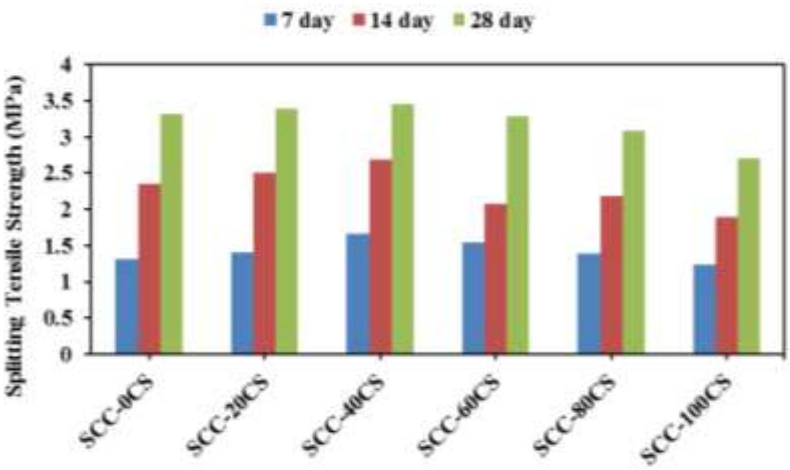

Figure 7. Variation of 7, 14 and 28 day splitting tensile strength for various percentages of copper slag replacement

Flexural Strength

The flexural strength of self-compacting concrete samples containing various percentages of copper slag at the age of 7, 14 and 28 days was shown in Figure 8. As it can be seen, the flexural strength of the control sample at the age of 28 days was 4.3 MPa, which was increased by replacing the sand with 20, 40, 60 and 80% copper slag to 4.9, 6.4, 6.7 and 5.5 MPa, respectively, with increasing percentage Replacement will be 100% with decreasing flexural strength. So, it can be said that the highest flexural strength at the age of 28 days was the SCC-60CS sample in which 60% of the sand was replaced with copper slag. In all percentages, with increasing concrete age, flexural strength increases. The rate of increase in strength with increasing age in all designs was almost constant.

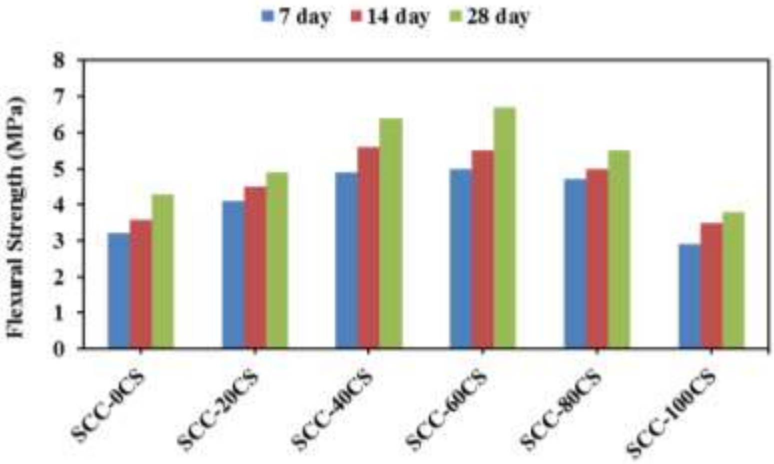

Figure 8. Variation of 7, 14 and 28 day flexural strength for various percentages of copper slag replacement

Results of Corrosion Test and Permeability

In Figure 9, the percentages of weight and compressive strength variations of the samples are shown in acidic and sulfate corrosive media. As we can see, replacing sand with copper slag leads to weight loss and loss of strength more than the control sample. The highest percentage of weight loss and acid strength were 5.8 and 10.1 respectively and in Sulfate environment 5.1 and 9.5 percent for replacement percentages of 40 and 80 was registered. So it can be said that it was better not to use copper slag as a sand replacement in acid corrosive and sulfate-based environments.

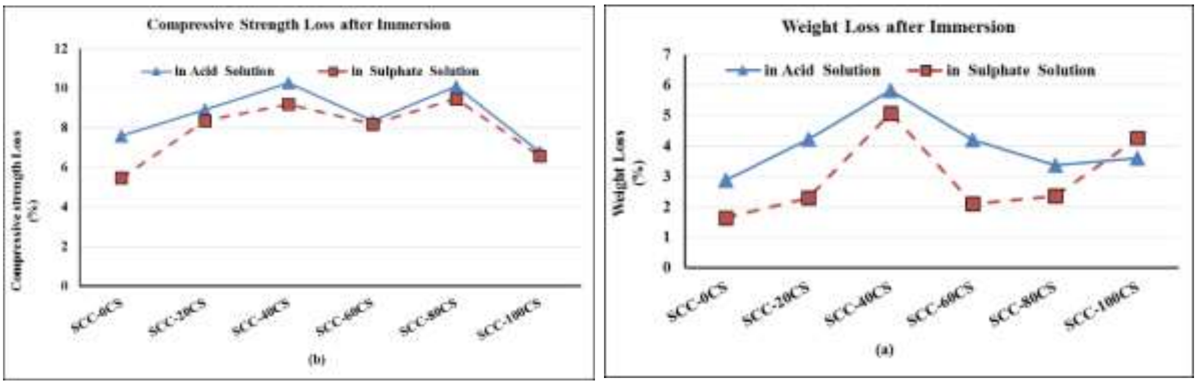

Figure 9. Wight and compressive strength loss of specimens in acidic and sulfate corrosive environment after 30 days

The depth of water penetration was shown in Figure 10. As can be seen, by increasing the percentage of sand replacement with copper slag up to 40%, the depth of penetration of water decreased and then increased. The highest penetration depth was recorded at 100% replacement. So it can be said that the durability of copper slag containing concrete was increased by 40% as a substitute for sand and then reduced.

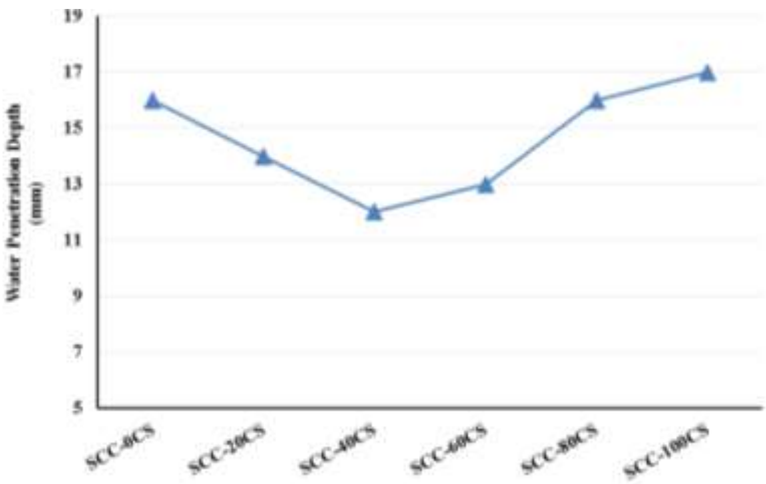

Figure 10. The depth of water penetration

Conclusion

As it was stated, in this article, it was tried to replace the solid-copper slag in their concrete, to manage and dispose of a considerable amount of organic waste. It also attempts to improve the properties of concrete produced on the basis of the specific nature and characteristics of slag. Following are some of the results obtained from experiments on their self-compacting concrete samples produced with copper slag are provided.

- Replacement of sand with copper slag has increased the amount of slump flow, so that as slag increased by replacing sand from 0 to 20, 40, 60, 80 and 100 percent; the increase of slipping was about 3.1, 4.6, 4.6, 7.7 and 9.2 was achieved.
- Research has shown that blends containing copper slag have enough viscosity of sand to increase separation resistance. And by increasing the percentage of replacement of copper with the slag, the time T50 decreases.
- The passage time of the V funnel in the range of 8.3 seconds for 100% replacement of sand with slag and 11.1 seconds for the control sample varies. As you can see, the increase in copper slag has reduced the passage time of the V funnel, which can be due to its weight gain.
- By increasing the replacement percentage, we increase the rate of obstruction. It seems that the entirely circular texture of copper slag has increased the porosity of self-compacting light-weight concrete. Of course, there was an exception in the replacement percentage of 60 which seems to be a laboratory error.
- The compressive strength of 28 days by replacing sand with 20, 40 and 60% copper slag respectively increased to 11.3%, 15.5% and 12.4%. By increasing the percentage of sand replacement with 80 and 100 percent slag, we witness a loss of 4.1% and 12% of compressive strength. The highest and lowest compressive strengths were observed for 40% and 100% replacement of sand with slag.
- The tensile strength of the control sample at the age of 28 days was 3.31 MPa, which was increased by replacing the sand with 20 and 40% copper slag to 3.39 and 3.45 MPa, respectively. By increasing the replacement percentage to 60, 80 and 100 percent, we will see a decrease in tensile strength. Thus, it can be said that the highest tensile strength was obtained at the age of 28 days of the SCC-40CS sample, in which 40% of the sand was replaced with copper slag.

- The 28-day flexural strength by replacing sand with 20, 40, 60 and 80 percent of copper slag increased to 14, 48.9, 55.8 and 27.9 percent, respectively. By increasing the percentage of sand replacement with 100% slag, the control had a drop of 11.6% of the flexural strength. The highest and lowest flexural strength was observed for 60% and 100% replacement of sand with slag.
- The use of copper slag instead of sand will increase corrosion and decrease the strength of concrete in acidic and sulfate environments. Therefore, it was recommended to avoid replacing sand with copper slag as much as possible in acidic and sulfate environments
- The results of the water penetration experiment showed that 40% of the replacement of sand with copper slag would decrease the permeability of self-compacting concrete containing slag.

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