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INVESTIGATION ON USING COPPER SLAG AS PART OF CEMENTITIOUS MATERIALS IN SELF COMPACTING CONCRETE

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ABSTRACT

Self compacting concrete (SCC) is a relatively new phenomenon in materials' science. It is nearly two-decade-old. This type of concrete, with its special features, provides new possibilities that can be used to overcome problems resulted from the lack of proper density in concrete such as reduction of longevity and durability.

In recent years in Iran, rise of concrete production costs, especially the cost of cement, has always been a concern of concrete producers and consumers. Using slag and industrial waste to replace part of cement in SCC can reduce its cost and also helps reducing environmental pollution. In this study, it is attempted to use the slag of Sarcheshmeh mineral copper complex as part of cement for producing SCC and also, investigating the chemical and physical properties of slag material and mechanical properties of SCC, including its compressive strength. Therefore, the physical and chemical analyses were performed on the slag and cement. Then by making 10 cm sample cubes with different percentages of waste namely: 20%, 25%, 30%, 35% and 40% of slag, the SCC pasty phase tests such as J-Ring and V-Funnel were performed on fresh SCC and finally, to achieve the optimum mix design (the most appropriate percentage of slag material share of total cementitious materials), compressive strength tests were done on cubic samples and their mechanical properties were studied. The optimum replacement of cement-like substance material was chosen based on the criteria of resistance compressive strength of 7, 14, 28 and 42 days ages of concrete. The results showed that compressive strength of concrete at 28 days age with a substantial percentage of the slag material was not significantly different from the SCC samples without slag. By studying other SCC characteristics such as durability, this material can be introduced as a suitable alternative for part of cementitious materials in SCC.

Keywords: Self compacting concrete; cement; copper slag; compressive strength;

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mechanical properties.

1. INTRODUCTION

Self compacting concrete has been used in many construction activities because it is readily available. However, over the past decade has been widespread in the industry. With industry development, product wastes increase. The use of industrial waste, soil or secondary materials to produce cement and concrete is recommended because it helps to reduce the consumption of natural resources. Copper slag products produced by the chemical industries if not properly disposed, can cause environmental problems in the surrounding areas. Copper slag is a substance which is also known as a solid waste that could be promising in the construction industry as a partial or total replacement of cement. Many researchers are now found the possibility of using copper slag as a partial replacement of cement. The main goal of this paper is to study the mechanical properties of self compacting concrete containing slag copper as the replacement part of the cement.

2. PREVIOUS WORKS

In this paper, the slag of Sarcheshmeh copper complex as replacement of some percentage of cement is considered. Copper slag is a waste material which can be regarded as a pozzolanic material. In the field of using industrial slag in concrete, a lot of work has been done. In this section, an overview of previous research studies regarding the use of waste materials in concrete is discussed:

Vaidya and Allouche evaluated the strain sensing of carbon fiber reinforced geopolymer concrete [1]. Brindha and Nagan evaluated the durability of the concrete mixed with copper slag [2]. The use of copper slag in cement were investigated by Nazer, Pavez and Rojas [3]. Onuaguluchi and Eren tested the durability characteristics of concrete mixtures containing copper tailings as an additive [4]. Naturals aggregates were been replaced by slag products by Zeghichi [5]. Al-Jabri et al. used copper slag as sand replacement for high performance concrete [6]. Al-Jabri, Taha and Al-Saidy examined the effect of copper slag as fine aggregate on the characteristics of cement mortar and concrete with experimental work [7]. Pazhani studied the mechanical properties of concrete made of copper slag [8]. Naganathan et al. researched about the development of bricks using thermal power plant bottom ash and fly ash [9]. Onuaguluchi and Eren did experiments on copper tailings as a potential additive in concrete [10]. Khanzadi and Behnood studied the mechanical properties of high strength concrete incorporating copper slag as coarse aggregate [11]. Studies on fly ash concrete were performed by Dakshima Murthy et al. [12]. Marku and Vaso did optimization studies on copper slag content in cement mixed with waste [13]. Farzadnia, Abang and Demirboga examined incorporation of mineral admixtures in sustainable high performance concrete [14]. Gupta et al. did an experimental study on clay stabilized with copper slag [15]. Alnuaimi did an experimental work on the effects of copper slag as fine aggregate replacement on the ultimate strength and behavior of reinforced concrete slender columns [16]. Wright and Frohnsdorff researched about the durability of building materials [17]. Sabet et al. did some research on the mechanical and durability properties of self consolidating high performance concrete incorporating fly ash [18]. The effect of different mineral additions on rheology and compressive strength of self compacting concrete was studied by Nécira et al. [19]. Experimental investigation was performed on high performance reinforced concrete column with silica fume and fly ash by Muthupriya et al. [20].

Although there are many studies that have been reported by investigators on the use of copper slag in cement concrete, not much research has been carried out in Iran and other countries concerning the incorporation of mechanical properties effect of copper slag in SCC. Therefore, to generate specific experimental data on properties of native copper slag as sand and cement replacement in SCC, the present study has been performed.

In this paper, first the sampling of Sarcheshmeh copper slag deposits in Kerman province of Iran was done and then sieve test for drawing their gradation curve was made. In the next step, the chemical analysis of copper slag was undertaken by XRD tests. In the following, after classification of slags, series of SCC mix designs with different percentages of slag as a substitute for sand and cement were prepared. To evaluate the performance of SCC pasty phase, standard tests including: V-Funnel, U-Box and J-Ring were performed and then hardened phase tests at ages 7, 14, 28 and 42 days were done and the mechanical properties of SCC were determined.

At the end, it is shown that use of some percentage of copper slag, in addition to improving the mechanical properties of SCC to an acceptable level, provides the possibility of using the recycled materials obtained from copper extraction process in the active mines in SCC and this reduces the environmental and air pollution in the region.

3. MATERIALS

3.1 Cement

Portland cement is a product that comes from grinding the clinker which is made of hydraulic calcium silicates and some calcium sulfate which is commonly used as additive.

The particle density of Portland cement is about 3.15 tons per cubic meters and is made from four materials namely: three calcium silicate, two calcium silicate, three calcium aluminate and four calcium aluminate ferrite.

Table 1 shows the four main components of cement with the symbols represent their character. Short abbreviations for these components that have been proposed by cement chemists are:

$H_2O = H$; $Fe_2O_3 = F$; $Al_2O_3 = A$; $SiO_2 = S$; $CaO = C$

Table 1: The main components of Portland cement

Component name	Constituent oxides	Abbreviations
3 calcium silicate	$3CaO.SiO_2$	C_3S
2 calcium silicate	$2CaO.SiO_2$	C_2S
3 calcium aluminate	$3CaO.Al_2O_3$	C_3A
4 calcium aluminate ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Strength, durability and other properties of concrete is mainly resulted from hydration of C_3S and C_2S.

Calculation of the amount of cement components resulted from its constituent original oxides is done by "Bog" and is known as "Bog equations" (Equations 1 to 4).

These equations show the main cement compounds. Values in parentheses show the percentages of the cement forming oxides with respect to the total weight of the cement.

$$C_3S = CaO\ (4.07) - SiO_2\ (7.60) - Al_2O_3\ (6.72) - Fe_2O_3\ (1.43) - SO_3\ (2.85) \quad (1)$$

$$C_2S = SiO_2\ (2.87) - 3CaO.\ SiO_2\ (0.754) \quad (2)$$

$$C_3A = Al_2O_3\ (2.65) - Fe_2O_3\ (1.69) \quad (3)$$

$$C_4AF = Fe_2O_3\ (3.04) \quad (4)$$

3.1.1 Standard technical specifications of cement

The standard specification for Portland cement is staded in ASTM[1] C 150 Portland cement Type 2 (PC - type II). This cement, due to certain limitations that are applied to its components, shows moderate resistance against sulfate attack. The heat generation of this cement is between cements type 1 and type 4 (which is cement with low heat generation). Thus, in some cases, this cement is known as a moderate heat generation cement. This cement is for general use and also for special use where moderate hydration heat is desired. Here, in performing all tests, cement type 2 was used.

In Tables 2 & 3 Physical and chemical characteristics of cement type 2 are shown, respectively.

Table 2: Physical properties of cement type 2

Physical properties required	Comp. strength (kg/cm^2) Days 28	7	3	2	Autoclave Exp %	Setting Time (min) Final	Initial	Blaine (cm^2/g)	R.S # 170 %
National standards	Min 315	Min 175	Min 100	-	Max 0.8	Max 360	Min 45	Min 2800	-
Momtazan cement factory characteristic	450 ± 20	330 ± 20	230 ± 15	-	0.16 ± 0.07	170 ± 15	125 ± 10	3100 ± 100	0.6 ± 0.3

Table 3: Chemical properties of cement type 2

Physical properties required	(I.R) %	(L.O.I) %	(SO3) %	(C3A) %	(Fe2O3) %	(Al2O3) %	(SiO2) %	(MgO) %
National standards	Max 0.75	Max 3.0	Max 3.0	Max 8.0	Max 6.0	Max 6.0	Min 20.0	Max 5.0
Momtazan cement factory characteristic	0.5 ±0.2	1 ± 0.2	2.45 ± 0.2	6.0 ± 0.5	3.8 ± 0.1	4.6 ±0.2	21.2 ± 0.4	1.4 ± 0.1

[1] American Society for Testing and Materials

3.2 Copper slag

Copper slag production history returns to the begining of extracting metals from ores by biological processes. It is obtained during the refining of crude copper smelting. Copper slag generated during production of one ton of copper is about 2.2 to 3 tons. The amount of copper slag produced in America is about 4 million tons/year, and in Japan is about 2 million tons/year. Slag management methods include recycling, metal recovery and depo-out.

Various types of slag as a by-product of incineration and metallurgical process are produced which often contain significant amounts of metals. In fact, slags are considered as a secondary source of metals. Slag is also used as the main material for making cement and floor ceramics. Slags have comparable properties or even better than their own original material. Waste produced in the process of copper smelting includes furnace reverb and converter slag. Generally, the converter slag is used to charge the furnace reverb but the reverb slag is piled in some places. Although, based upon some reports, Sarcheshmeh smelter reverb slag mainly has 4-5% alumina, 4-6% calcium oxide, 35-37% Fe, 30-34% silica and average of 0.7% copper but, in this work, the shares of main slag components are found in the labratories as explained in next section.

Copper slag is formed from oxidation of iron sulfide, using materials for melting and impurities in the concentrate and crushing part of the furnaces superalloys lining during smelting operations.

3.2.1 Physical and chemical properties of copper slag

Copper slag is cooled with black color and has glassy appearance. The specific gravity of the slag due to its iron content is changes between 2.8 – 3.8. The unit weight of copper slag is higher than the weight of ordinary rock fragments. Its absorption capacity is typically very low (0.13 percent). The Granulated copper slag is more porous and therefore, has a lower specific gravity and higher absorption capacity than the air-cooled slag [22]. The physical and chemical properties of copper slag are found by the authors in Sharcheshmen copper complex technical laboratory and also in the lab of Faculty of Engineering of Shahid Bahonar University of Kerman which are indicated in Tables 4 and 5.

Table 4: Physical properties of copper slag

Measuring unit	gr/cm^3	%	%
Sample Name	D	LOI	H_2O
Copper Slag	4.45	5.73	0.10

Table 5: Chemical properties of copper slag

Measuring unit	%	%	%	%	%	%	%	%
Sample Name	Al_2O_3	CaO	Cu	Fe_2O_3	K_2O	SiO_2	TiO_2	SO_3
Copper Slag	3.71	5.80	0.54	46.37	1.15	28.83	0.34	3.26

The granulated slags are formed in regular shapes and angular particles which mainly have the size between and 4.75 mm and 0.075 mm (sieve No. 200). Granulated and air cooled slag have desirable mechanical properties such as good stability and resistance against abrasion. The slags formed during the sulfide copper – nickel concentrate melting process mainly containes iron oxide, silica, K_2O, Sr_2O_3, Al_2O_3, CaO, MgO and copper and nickel metals, and also other impurities.

3.2.2 Usage of copper slag in concrete

The American Concrete Institute used the Brazil Bahia copper slag as construction material. They reported that the properties of these materials were equal or better than the traditional types. Thus, the copper slag has the potential of replacing in mixtures used in concrete or mortar. Using smelter copper slag as particles in the concrete was done by Akihiko and Takashi in 1996 [23]. The mortar strength were tested with cement / slag / water having 1/2/0.55 ratio. The grinding slag showed higher strength. The effect of several types of slag in mortar and concrete on the alkalinity reaction, reinforcing steel corrosion, wear, shrinkage, ice, and flux were investigated. Using copper slag increased concrete mixture strength [22].

3.3 Aggregate

Aggregates are granular material such as sand, gravel, crushed stone, crushed hydraulic concrete cement or cooled iron maidens slag which are used with hydraulic cement to produce concrete or mortar. Aggregate particles constitute 60 to 75 percent (almost $\frac{3}{4}$) of the absolute volume of concrete. The shape of the grains may be rounded, irregular, angular or broken, flake or needle. Depending on the size of the particle size, aggregates are divided into two groups of coarse and fine.

3.3.1 Fine aggregate (Sand)

All kinds of common sands in concrete production are also used in this type of concrete (self compacting concrete). Both types of sand, broken or rounded, including silica and limestone can be used. Particles smaller than 125 microns which are used as "powder", increse the fluidity properties of self compacting concrete and to produce uniform concrete, the moisture of used materials must be carefully controlled. The minimum amount of fine aggregates (sand and powdered binder materials) to prevent aggregation detachment, should not be less than a certain amount.

The sand used in the self compacting concrete mix design samples were from Kerman Mansouri mine.

3.3.2 Coarse aggregate (Gravel)

In self compacting concrete all types of coarse aggregates are used, but the most common sizes are 16 to 20 mm. However, aggregates approximately to 40 mm can also be used in self compacting concrete. The use of crushed aggregate increases the strength of self compacting concrete (due to increased interlock between particles), while the rounded aggregate (due to reduction of internal friction) improves ites fluidity. The aggregates used in this study as the sand were obtained from the Kerman Rostami mine. These materials were depot in the laboratory and after passing the sieve no. 3/4 according to ASTM C136 standard, coarse aggregates with a maximum size of 19 mm were used for self compacting concrete mix design. To apply the same environmental conditions for test specimens, in all experiments a controlled aggregation was used. This will ensure the omission of errors.

3.3.3 Combined aggregate gradation for concrete

In order to ensure a sufficient density of aggregates with minimum empty spaces, the combination of fine and coarse aggregate is used. This causes using less cement paste (water and cementitious materials) in concrete and also improves dimensional stability and durability.

3.3.4 Physical properties of aggregates

3.3.4.1 Coarse aggregate (Gravel)

Physical characteristics of coarse and fine aggregate were as follows:

Water absorption rate = 1.1 %
Natural moisture content = 1 to 2%
True specific gravity (weight room) = 2650 kg / m^3
Unit volume weight = 1520 kg / m^3

3.3.4.2 Sand

The physical properties of the sand used were as follows:

Water absorption rate = 1%
Natural moisture level = 2 to 3 percent
True specific gravity (weight room) = 2780 kg / m^3
Unit volume weight = 1670 kg / m^3
Sand value (S.E.) = 78

3.4 Mix water

Acceptance criteria for mix water are stated in ASTM C 94 and AASHTO T 26 standards. Impurity that makes the water unsuitable for using not only affects on appearance, setting time, compressive strength, corrosion resistance, but also may cause efflorescence, foul up, corrosion of rebars, volume instability, and reduction of concrete durability. Meantime, it should be noted that salt water as mixing water must not be used in reinforced concrete with a steel reinforcement.

Chemical analysis of water used in the concrete mix design is shown in Table 6.

Table 6: Chemical analysis of water for mix design

Mesuring Unit		ppm	ppm	ppm	
Sample Name	TDS	SO_4^{-2}	Cl	T.H.	pH
Water	287	74.5	63.80	167	8.0

3.5 Microsilica

Microsilica powder is a by-product of the Ferro silica manufacturing process in electric arc furnace. Microsilica powder has pozzolanic properties and is used in concrete for construction of offshore structures and all concrete structures exposed to chemical attack, particularly chlorides and sulfates. Increasing the durability of concrete, reducing the shrinkage of fresh concrete and preventing the corrosion of reinforcement in reinforced concrete are the main benefits of adding Microsilica powder. Microsilica in self compacting concrete causes high fluidity of concrete, increases the concrete durability and has an important role in adhesive and filling of high-performance concrete. Microsilica has approximately 90% of Microsilica dioxide. Table 7 shows the physical characteristics of Microsilica used in the mix design.

Table 7: Physical properties of microsilica

Melting point °C	Bulk density kg/m³	Specific weight gr/m³	Structure	Particle shape	Particle size (nanometr)	Specific surface m³/gr`
1230	300-500	1.9	Amorphous	Spherical	229	20-25

3.6 Superplasticizer

To make the self compacting concrete samples in this research, a special superplasticizer based on polycarboxylate for self compacting concrete was used in the mix design.

This superplasticizer is a dark brown liquid containing chemical base polymer dispersions carboxylate salt, having about 40% solid materials and specific gravity of about 1.03 kg/litre.

3.7 Rock powder

Very fine crushed particles (smaller than 125 microns) consists of limestone, dolomite and granite are used as powder. Using dolomite powders due to reactions of alkali and carbonates can cause concrete durability problems. In this study, Qom stone powder which is a type of limestone was used to make the samples.

4. TESTS PROGRAM

4.1 Mix design and sample details

In this study, six mix designs were investigated. Amounts of gravel, sand and cementitious materials (cement + waste) in all specimens were fixed and considered as 850, 1000 and 450 kg per cubic meter. Each of the mixtures were made with water to cement ratio of 0.35. The cement and slag materials for mix designs were as cement type 2 with the replacement percentages of, 20%, 25%, 30%, 35% and 40%.

To evaluate the mechanical properties of self compacting concrete, including compressive strength, six cube series with the dimensions of 10 × 10 × 10 cm was made as follows:

Self compacting concrete with no copper slag with the symbol of SCC

Copper slag self compacting concrete with 20 percent share of cementitious materials with the symbol of SCC +20% CS

Copper slag self compacting concrete with 25 percent share of cementitious materials with the symbol of SCC +25% CS

Copper slag self compacting concrete with 30 percent share of cementitious materials with the symbol of SCC +30% CS

Copper slag self compacting concrete with 35 percent share of cementitious materials with the symbol of SCC +35% CS

Copper slag self compacting concrete with 40 percent share of cementitious materials with the symbol of SCC +40% CS

The compressive strength test was performed on the samples at the ages of 7, 14, 28, and 42 days (ASTM C39).

Table 8: Self compacting concrete mix design

Water (kg)	SP (kg)	Stone Powder (kg)	Microsilica (kg)	Gravel 1 (kg)	Gravel 2 (kg)	Sand (kg)	Slag (kg)	Ceme nt (kg)	Material / Mix Design
168	20	120	50	450	400	850	0	450	SCC
168	20	120	50	450	400	850	90	360	SCC+20%CS
168	20	120	50	450	400	850	112.5	337.5	SCC+25%CS
168	20	120	50	450	400	850	135	315	SCC+30%CS
168	20	120	50	450	400	850	157.5	292.5	SCC+35%CS
168	20	120	50	450	400	850	180	270	SCC+40%CS

4.2.1 Self compacting concrete pasty phase tests

Self compacting concrete has distinctive capabilities comparing to any other concretes. The effective parameters of each of these capabilities are independent of each other so, many devices are needed to measure the characteristics of self compacting concrete and to investigate its behavior and effects of one or more factors. The purpose of manufacturing these experimental devices is modelling the severe situations of concreting in different environments and based upon the results of these tests we can measure the stability and workability of the self compacting concrete. Also, the stability of different concretes can be compared at the end of experiments.

4.2.1.1 J-Ring test

For this test it is required to moisten the base plate and the internal portion of slump cone. Also, the center of J- ring must coincide the center of the ring base plate. Then the slump cone must be put on the center. After pouring 6 liters concrete paste into the slump cone and smoothing the surface of concrete on top of it with a trowel, we must draw up the cone vertically with a constant speed which is not fast and not slow and let the concrete to flow freely. The concrete height difference of inside and outside the J- ring in four points is measured and averaged. The final diameter of the circle formed by the concrete paste in two perpendicular directions must be measured and averaged. If there is any syrup around the spread concrete, it must be recorded, (Figure 1).

Figure 1. J -Ring test

4.2.1.2 V-Funnel test

After placing the V-shaped funnel and its base on the ground, we moisten the internal surface of funnel. Then we close its valve and put a 12-liter bucket under the funnel. So, about 12 liters concrete paste which is normally sampled is poured into the funnel, (Figure 2). During the test, no compacting or tapping the body of the device should be done. After 10 seconds, the valve is opened and we allow the concrete to flow under its own weight out. The concrete withdrawal time is noted and then the funnel is filled by concrete again and we leave the concrete for 5 minutes. Then the valve is opened and the concrete withdrawal time is measured.

Figure 2. V Funnel test

4.2.2 Results of self compacting concrete pasty phase tests

In Table 9 the results obtained from special tests for self compacting concrete pasty phase are indicated.

Table 9: Results of self compacting concrete pasty phase tests

Mix design	V-funnel (s)	J-ring (mm)
SCC	11	10
SCC + 20%CS1	10	10
SCC + 25%CS1	9	12
SCC + 30%CS1	10	15
SCC + 35%CS1	12	9
SCC + 40%CS1	8	11

4.2.3 Results of self compacting concrete hardened phase test

After making mixtures and pouring them into the molds, curing the specimens were conducted. After 48 hours, the concrete samples were removed from the molds and stored at standard conditions. The compressive strength test results at ages between 7 to 42 days for self compacting concrete with different percentages of slag are shown in Table 10. These results are based on the average of the sample compressive strength. The compressive strength measured for standard concrete samples at different percentages of slag, in the ages of 7, 14, 28 and 42 days are given in Figures 3 and 4.

Table 10: Average compressive strength obtained in the tests

Weight (gr)	Mix Design	Age (Day)			
		7	14	28	42
2290	SCC	467.7	516.7	599.5	609.5
2335	SCC + 20%CS1	312.3	356.7	511.7	521.7
2175	SCC + 25%CS1	235.5	301.6	289	327
2195	SCC + 30%CS1	200.3	237.4	288.6	330.4
2285	SCC + 35%CS1	154.3	221.6	209.4	276.6
2280	SCC + 40%CS1	107.7	141.7	157	207.7

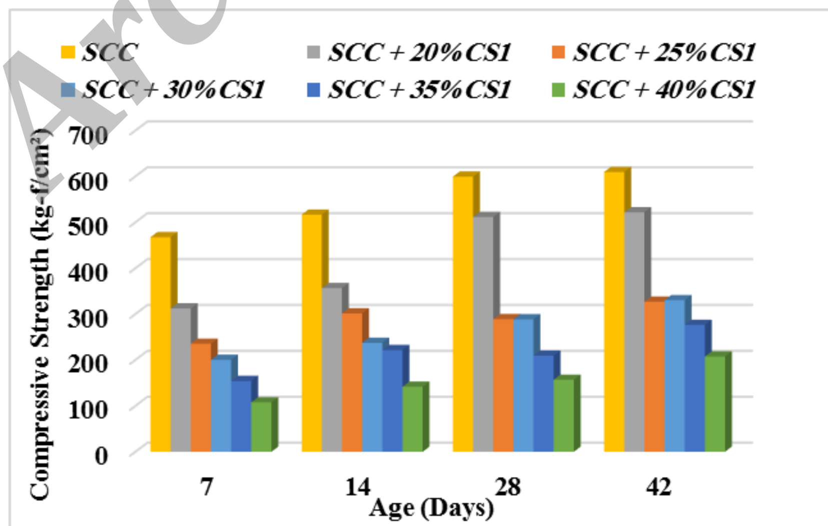

Figure 3. Average compressive strength of samples at different ages

The trend of change of compressive strength based on the percentage of slag replacement is almost the same in all ages. So, while increasing the amount of the slags, loss of resistance was observed compared to the concrete without slag. In addition, the compressive strength of 7, 14, 28 and 42 days up to 20% of slag replacement had a little loss compared to the concrete without slag.

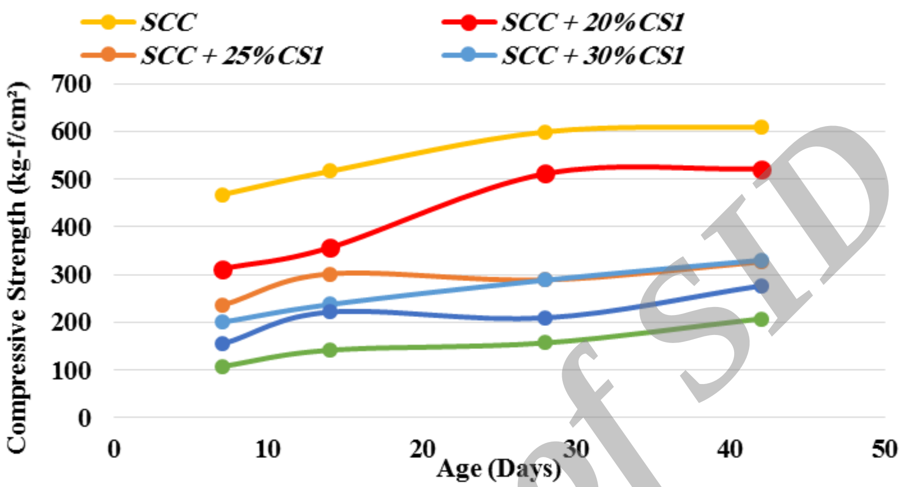

Figure 4. Average compressive strength of samples at different ages

According to the results of compressive strength tests on the samples and selecting the 42-day compressive strength of samples as a criteria, 20 percent of the replacement was chosen as the optimum percentage. The results of the compressive strength of the SCC samples based on percentage of slag at ages 7, 14, 28 and 42 days are shown in Figure 5.

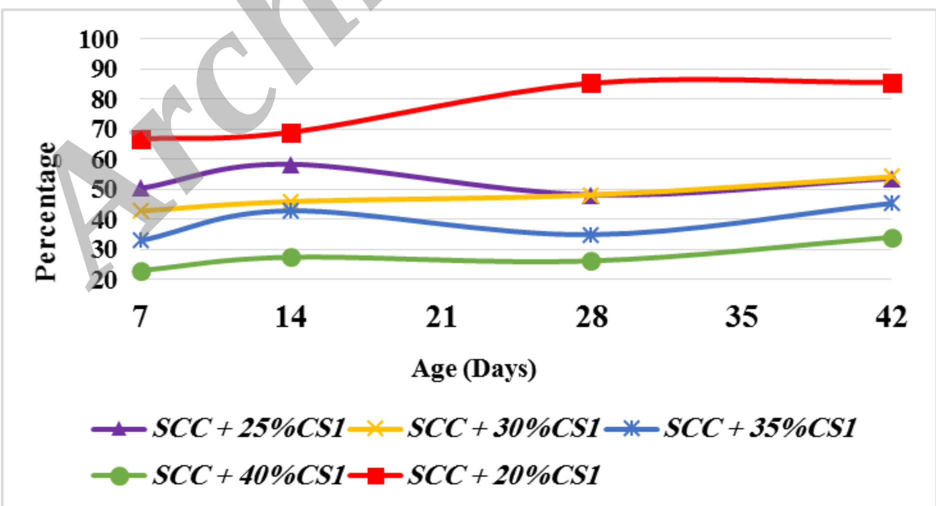

Figure 5. The compressive strength based on percentage of slag at different ages

5. CONCLUSIONS

In this paper, the following conclusions about the engineering specifications of copper slag and its effects on properties of self compacting concrete have been achieved:

- In experimental studies, it was observed that by using 20% of Sarcheshmeh mineral complex copper slag, the 28 day compressive strength of self compacting concrete samples was almost the same as the samples without copper slag (85 percent of compressive strength of self compacting concrete without slag). The strength was obtained 510 kg/cm² which was above the desired final compressive strength.
- When the copper slag is used to replace part of the cement, self compacting concrete containing different percentages of copper slag have good performance compared to the self compacting concrete containing cement only.
- Replacement of copper slag instead of cement causes reduction of compressive strength for the percentages above 20% at different ages.
- In self compacting concrete pasty phase special tests with the use of various amounts of copper slag instead of cement, no significant changes in self compacting concrete functionality was observed.
- Depending on the age of the experiments, the optimum slag replacement for strength is different, but generally, 20% slag is recommended.
- Using industrial waste materials such as copper slag can help to reduce environmental problems and sustainable development in the country.
- Due to the high price of cement, use of this material to replace part of the cementitious materials in self compacting concrete is economically justified and reduces the cost of self compacting concrete. Thus, using the material to produce concrete, considering the appropriate and standard mix design, in concrete industries is suggested.

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