Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada
June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

Compressive and Tensile Properties of Self Consolidating Concrete Made with Copper Slag as Part of Cement

Fadaeefath Abadi, Mostafa[1,4], Mohammadi, Zahra[2] and Fadaee, Mohammad Javad[3]
[1] Ph.D. Student of Building Engineering, Concordia University, Montreal, Canada
[2] Graduate Student of Architecture Engineering, Islamic Azad University, Kerman, Iran
[3] Professor of Civil Engineering, Shahid Bahonar University, Kerman, Iran
[4] mostafa.fadaee@concordia.ca

Abstract: Self-consolidating concrete (SCC) is a highly flowable concrete which doesn't need any vibration and can fill the formworks automatically. Replacement of cement as the most expensive part of concrete with industrial materials such as slag, can reduce the cost and help to have a green construction industry. To consider sustainability issues, replacing part of cement with industrial waste and slag materials due to the economic and environmental benefits has been increased. This paper reports the results of an experimental study on the physical and chemical properties of the mineral complex copper slag as a by-product, and analysis it's effect on the mechanical properties, including the compressive and tensile strength of SCC. At first, the physical and chemical analyses were performed on the slag and cement. To evaluate properties of SCC, several cylindrical samples with the diameter of 15cm and height of 30cm were manufactured. The compressive strength test and the Brazilian test were performed on these SCC cylindrical samples. To achieve the optimum mix design with the most appropriate percentage of the copper slag the tests results were measured and determined. The results showed that compressive and tensile strength of SCC with a specific amount of copper slag didn't have a significant difference comparing to the SCC samples made without any slag. Therefore, this waste material could be introduced as a suitable alternative for part of cement in SCC. In other words, using SCC with industrial slag because of it's characteristics and features could develop and improve the sustainability of concrete structures.

1 Introduction

One of the advanced construction materials which have been recently introduced is the self-consolidating concrete (SCC). This type of concrete, as a fresh concrete, can easily flow around the dense reinforcements and consolidate under it's self-weight without being vibrated. It encapsulates areas with congested reinforcement. This phenomenon is nearly two-decade-old and with it's special features, provides new possibilities to overcome problems resulted from the lack of proper density in concrete such as reduction of longevity and durability. Therefore, SCC is an attractive concrete for many contractors according to it's various features.

Many researchers have been studying on this issue to find the possibility of using copper slag, fly ash or other industrial waste as a partial replacement of cement or other materials. In order to enhance the performance of construction materials and in terms of economic aspects, alternative approaches such as using proper materials for replacement of cement have been explored and studied by researchers.

The main objective of this study is to evaluate mechanical properties of self consolidating concrete which includes the copper slag as a partial replacement of cement.

The slag of Sarcheshmeh copper complex in Iran has been utilized as replacement materials for part of cement. Copper slag is a waste material which could be considered a pozzolanic material.

To fulfill the main requirements for an acceptable SCC, some important tests have been conducted on this type of concrete in this research and the results are compared and discussed. In the next section, some studies in this area which have been conducted by researchers are presented and discussed.

2 Literature review and background

About utilizing substitute materials, many studies have been performed for both concrete and the self-consolidating concrete. In these experimental works, a wide range of waste materials have been used instead of part of cement or other components in concrete such as micro silica and aggregates.

an overview of previous research studies about the use of waste materials in SCC and the performance of SCC under several experimental tests will be discussed:

A research was conducted on the mechanical and durability properties of self consolidating high performance concrete incorporating fly ash. In this study, the effect of natural zeolite, silica fume and fly ash on fresh and hardened concrete was evaluated. Based on their results, mechanical and durability characteristics of mixes were improved. Some materials used in the research were more effective in improving the durability aspects while another one was more cost-effective (Sabet, F. A. et al. 2013). The effect of different mineral additions on rheology and compressive strength of self-compacting concrete was studied and evaluated by investigating the workability of fresh SCC and performing tests on SCC samples. The results indicated that superplasticizer (SP) increased concrete's fluidity but reduced it's stability and compressive strength. Therefore, a viscosity modifying agent (VA) with sufficient dosage was added to have the best properties including proper fluidity and strength (Nécira, B. et al. 2015). Several experimental works on fresh and hardened self-consolidating concrete (SCC) consisting of copper slag were performed by M. Fadaee and his research team. The results of their study presented that compressive strength of cubic SCC samples at the age of 28 days, did not have a significant difference comparing with SCC samples which were made without slag (Fadaee, M. et al. 2015). Evaluation of using waste materials such as recycled asphalt pavement (RAP) in order to replace a percentage of the conventional aggregates was studied by researchers. Their objective was investigating the SCC which contains both supplementary cementitious material (SCM) and RAP. They founded that by increasing amount of RAP, the compressive and tensile strength of concrete decreases. Also, the fly ash reduces the concrete strength more comparing with the slag material (Abdel-Mohti, A. et al. 2016). The durability properties of lightweight self-consolidating concrete (LWSCC) was evaluated by applying different types of lightweight aggregates. The study and analysis showed that the resistance of mixtures was enhanced against sulfuric acid attack due because of the proper formation of cementitious paste matrix (Lotfy, A. et al. 2016). In addition, Mirhosseini, S. R. and his colleagues evaluated the properties of ordinary concrete made of copper slag as a partial substitution for the cement. They analyzed the compressive strength of 10 cm cubic samples and by comparing the results, the mix design was optimized for the best use of this industrial waste material (Mirhosseini, S. R. et al. 2017).

The American Concrete Institute (ACI) have applied the Brazil Bahia copper slag as a construction material. By evaluating this type of copper slag, it was noticed that the features of these materials were equal or better than other traditional types. Therefore, there might be a potential of replacing it in mixtures used in concrete or mortar. In addition, Studies have been done on using smelter copper slag as particles in concrete (Akihiko Y, Takashi Y 1996).

An investigation on the technical feasibility of using copper slag as a fine aggregate replacement in ultra high-performance concrete (UHPC) was performed. The research work considered an alternate aggregate system for ultra high-performance concrete and conducted a Complete replacement of natural aggregate by waste copper slag in this type of concrete (Ambily, P. S. 2015).

In addition, using copper slag and cement was reviewed in order to obtain the characteristics of copper slag and it's effects on the engineering properties of cement, mortars and concrete. They performed this study to find the environmental and economic benefits of copper slag used in cement and concrete (Shi, C. et al. 2008).

As it can be observed, although there are many studies that have been reported by investigators on the use of copper slag in cement and concrete, not much research has been carried out concerning the incorporation of mechanical properties effect of copper slag in SCC. Therefore, to generate specific experimental data on properties of copper slag as a part of cement replacement in SCC, the present study has been conducted.

3 Materials

In this section, main materials which were used in the mix design of SCC are presented and their features and specifications are discussed.

3.1 Cement

Portland cement is a product that comes from grinding the clinker which is made of hydraulic calcium silicates and calcium sulfate. It is commonly used as an 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 aluminates and four calcium aluminate ferrites.

3.1.1 Standard technical specifications of cement

The standard specifications for this cement are indicated in ASTM[1] C 150 Portland cement Type 2 (PC - type II). Due to certain limitations which are applied to the components of the cement, the resistance against sulfate attack is moderate and reasonable. In addition, it’s heat generation is between the amounts for cement type 1 and type 4.

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. In all mix designs and tests, the type 2 of Portland cement manufactured in Kerman, Iran, was used.

In the following tables (Tables 1 & 2), physical and chemical characteristics of cement type 2 are presented, respectively.

Table 1: Physical properties of cement type 2

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

[1] American Society for Testing and Materials

Table 2: 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
cement used in this study	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

3.2 Copper Slag

Copper slag production history returns to the beginning of extracting metals from ores by biological processes. It is obtained during the refining of crude copper smelting. There is a large amount of copper slag production in different mining complexes in the world. Especially, in the USA and Japan million tons of this product have been produced (Collins, R. J., and Stanley K. C. 1994). Recycling, metal recovery and depo-out, are some of the management methods related to copper slag.

In addition, it is made during the process of iron sulfide oxidation, utilization of materials for melting, impurities in the concentrate and when a part of the furnaces super alloys lining crushes during melting operations.

3.2.1 Properties

During the cooling process of copper slag, it appears glassy with black color. The unit weight of copper slag is more than ordinary rock fragments. It has a very low absorption capacity. Because of the porousness of granulated copper slag, it's specific gravity is lower than the air-cooled slag (Gorai, B. and Jana R. K. 2003). But the absorption capacity is higher. Tests and analysis were conducted by the Hydrometallurgical Research Department Lab of Sarcheshmeh Mine Complex. Based on the results, the reverb copper slag of Sarcheshmeh Mine Complex smelter factory mainly has 4-5% alumina, 4-6% calcium oxide, 35-37% Fe, 30-34% silica and an average of 0.7% copper. The physical and chemical properties of copper slag were also evaluated in the Shahid Bahonar University of Kerman. The physical and chemical specifications of Sarcheshmeh Mine Complex smelter factory copper slag are illustrated in table 3.

Table 3: Physical specifications of Sarcheshmeh Mine Complex smelter factory copper slag

Parameter	Quantity
D	4.45 gr/cm^3
LOI	5.73 %
H_2O	0.10 %
Al_2O_3	3.71 %
CaO	5.80 %
Cu	0.54 %
Fe_2O_3	46.37 %
K_2O	1.15 %
SiO_2	28.83 %
TiO_2	0.34 %
SO_3	3.26 %

3.3 Micro silica

During the Ferro silica manufacturing process, the micro silica or silica fume is generated as a by-product. The powder has pozzolanic aspects and it has benefits for concrete structures against chemicals such as chlorides and sulfates. Other benefits of using this material are increasing the durability of concrete, reducing the shrinkage of fresh concrete and preventing the corrosion of reinforcement in reinforced concrete. The main properties of the micro silica powder used in this research work are shown in table 4.

Table 4: Physical properties of micro silica

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

3.4 Superplasticizer

In order to prepare the SCC samples, one of the most important materials, which is the superplasticizer, was utilized. This superplasticizer was a special liquid based on polycarboxylate and it's color was dark brown. It contains chemical base polymer dispersions carboxylate salt and has almost 40% solid materials. The specific gravity was about 1.03 kg/liter.

4 Methodology & experimental program

In this section, details of the experimental study such as mix design of SCC samples, dimensions of the samples and different tests which were perfumed on SCC are elaborated and discussed.

4.1 Mix design and sample details

For conducting the experiments, six series of mix design of SCC were considered. Amounts of gravel, sand and cementitious materials (cement + waste) in the mix design of all SCC samples were fixed and considered as 850, 1000 and 450 kg per cubic meter, respectively. Also, the water/cement ratio was fixed on 0.35 in all SCC samples.

To evaluate the mechanical properties of hardened SCC, including the compressive strength and the tensile strength, cylindrical SCC samples based on ASTM standards with the height of 30 cm and diameter of 15 cm were made. Six SCC specimens were created with various percentages of copper slag as follows:

SCC with no copper slag (100% cement) indicated with the symbol of SCC.

SCC with 20% copper slag (80% cement) indicated with the symbol of SCC +20% CS

SCC with 25% copper slag (75% cement) indicated with the symbol of SCC +25% CS

SCC with 30% copper slag (70% cement) indicated with the symbol of SCC +30% CS

SCC with 35% copper slag (65% cement) indicated with the symbol of SCC +35% CS

SCC with 40% copper slag (60% cement) indicated with the symbol of SCC +40% CS

4.2 Tests on fresh Self Consolidating Concrete

First, to evaluate the special capacities of SCC and to measure this concrete's characteristics, different tests were performed. These tests which are designed especially for SCC, are the slump flow, J-ring, V-funnel and the U-box test. In this paper, a summary of the slump flow test for SCC is presented and, in the results section, the quantities of the results for the slump flow test are shown.

4.2.1 Slump flow test on fresh Self Consolidating Concrete

This test is one of the most commonly used tests to measure the properties of SCC. It determines SCC's ability to deform under it's own weight without any constraints except the friction between concrete and the bottom plate.

The test method is based on slump test for normal concrete. First, the fresh SCC is poured into the cone until its completely full. Then, the cone is pulled upward with a constant speed (not too slow and not too fast). The time for reaching SCC to a radius of 50cm is reported. After the full stop of SCC, a circle is formed. Two perpendicular diameters of the circle are measured and the average number is noted.

The diameter of the circle created after the diffusion represents the fresh SCC stress and is measurement criterion for SCC's filling ability. If the average number of the circle's diameter is less than 550 millimeters, it shows high yield stress and low workability of SCC. In addition, the average number is higher than 850 millimeters, it means that yield stress is low and the separation of SCC particles is possible.

In this research, the average numbers for all mix designs were within the normal range. In figure 1, concrete's behavior after slump flow test is shown. Results are presented later in this paper.

Figure 1: Slum flow test on SCC

4.3 Compressive strength test on Self Consolidating Concrete

After conducting special tests on fresh SCC, the mixtures were carefully cured for 48 hours. Then, the cylindrical specimens were removed from the molds and stored according to standard conditions. The compressive strength test was conducted on the six series of SCC sampled at the age of 42 days.

The rupture behavior of SCC cylindrical samples in this research after their failure under compressive strength test are presented in figure 2. Complete test results are illustrated in section 5.1.

Figure 2: Rupture behavior of SCC caused by compressive strength test

4.4 Tensile strength test on Self Consolidating Concrete

In addition to the compressive strength test, the indirect tensile strength test was performed on SCC samples to have a more accurate evaluation of mechanical properties of SCC samples made with copper slag. This test is also called the Brazilian test.

In this test method, by applying a diagonal pressure force on a concrete cylindrical sample which is placed horizontally between the two plates of the test apparatus, the tensile strength is determined by dividing the sample into two parts.

After the failure of concrete sample, the tensile strength (σ) is calculated as follows:

$$\sigma = \frac{2 * P}{\pi * L * D}$$

Where,

P is the applied load,

D is the diameter of the sample (D=2R) and

L is the thickness of the sample.

The above equation uses the theory of elasticity for isotropic continuous media and gives the tensile stress perpendicular to the loaded diameter at the center of the disc at the time of failure. In figure 3, the special restrainer for concrete sample in the indirect tensile strength test is shown. Also, the failure behavior of SCC cylindrical sample indirect tensile strength test is illustrated in figure 4.

Figure 3: Sample restrainer

Figure 4: SCC sample after splitting

5 Results

After performing experiments on six mix design series of fresh and hardened SCC, the test results are presented and discussed.

For the hardened SCC, more than one specimen was tested per experiment. Therefore, the average amount of the compressive strength and tensile strength was calculated and obtained. For these two tests, in most cases, the difference between results for each sample was approximately 4 to 6 %. In some cases that the standard deviation was more than 10%, the test was repeated in order to reduce the standard deviation and to have more accurate results.

5.1 Slump flow test results

The results of the slump flow test which was performed on fresh SCC in this research, are given in table 5.

Table 5: Slump flow test results

Mix Design	Slump Flow (mm)
SCC	620
SCC +20% CS	630
SCC +25% CS	600
SCC +30% CS	600
SCC +35% CS	570
SCC +40% CS	580

5.2 Results for the compressive strength test

In this section, the results for compressive strength test at the age of 28 days which were obtained for all six series of mix designs for SCC (applying different percentages of copper slag), are presented in figure 5. As mentioned, more than one concrete sample was tested for each mix design. Thus, the presented compressive strength amounts are average.

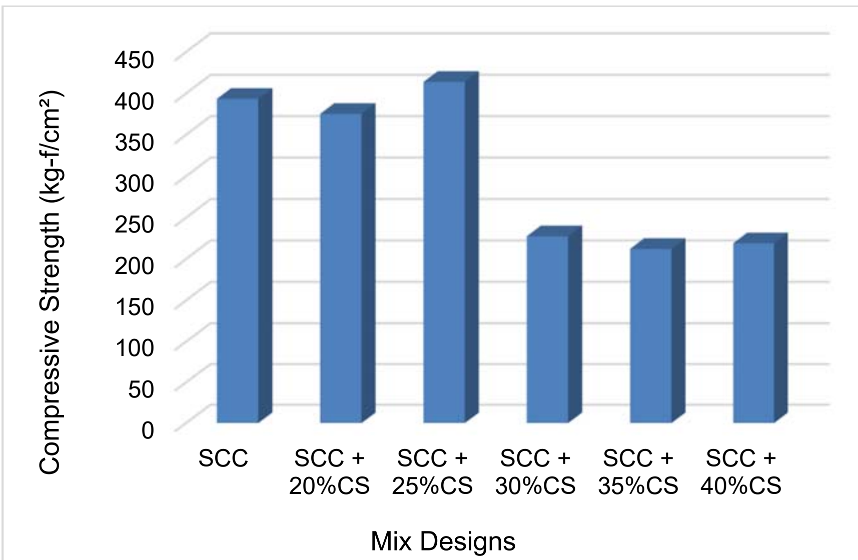

Figure 5: Bar chart of SCC compressive strength test results

5.3 Results for the tensile strength test

In figure 6, the quantities of indirect tensile strength test results which were obtained for SCC with various percentages of copper slag (six mix design series) at the age of 42 days, are shown.

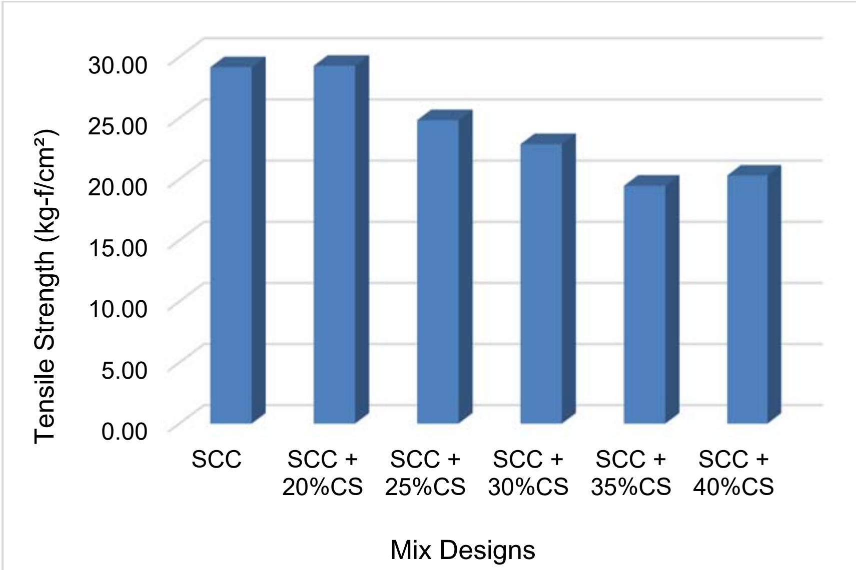

Figure 6: Bar chart of SCC tensile strength test results

6 Conclusions

In this experimental research, several tests were conducted on various SCC samples utilizing copper slag extracted from Sarcheshmeh Mine Complex. According to the engineering specifications of copper slag and the effects that it has on the mechanical properties of SCC and due to the final test results, following conclusions are achieved:

1. When the copper slag is used to replace part of the cement, SCC containing different percentages of copper slag could have good performance compared to SCC without any coppers slag.

2. In the experiments, it was observed that the compressive strength of SCC with 20% of copper slag, is approximately the same as the compressive strength of main SCC sample, which is made without copper slag (almost 6% difference). Also, the SCC sample made up of 25% copper slag instead of cement has almost 5% more compressive strength than the one without slag.

3. Based on obtained results, SCC samples using 20% and 25% copper slag instead of cement, had almost the same tensile strength as the SCC specimen which had no copper slag. But, in SCC samples which substituted 30% and more copper slag with cement, a reduction of tensile strength was noticed.

4. Since usage of copper slag as a partial alternative of cement could decrease the slump flow of SCC noticeably, substituting more copper slag with cement could lead to less slump flow in SCC. Therefore, by consuming proper superplasticizer in SCC mix design, the adherence capability of SCC could be maintained.

5. Due to the high price of cement, utilizing this material in order to replace part of cement in SCC could have economic benefits by reducing the final cost of SCC production. Thus, using copper slag to produce SCC, considering proper and standard mix design is recommended.

6. Considering the high production amount of copper slag in different mine complexes such as Sarcheshmeh copper complex, using industrial waste materials could be helpful in terms of reducing environmental issues and to improve sustainability in construction materials and technology.

7 References

Abdel-Mohti, Ahmed, Hui Shen, and Yasser Khodair. "Characteristics of self-consolidating concrete with RAP and SCM." *Construction and Building Materials* **102** (2016): 564-573.

Akihiko Y, Takashi Y. Study of utilization of copper slag as fine aggregate for concrete, *Ashikaya Kogyo Daigaku Kenkyu Shuroku*, **23** (1996) 79-85.

Ambily, P. S., C. Umarani, K. Ravisankar, Prabhat Ranjan Prem, B. H. Bharatkumar, and Nagesh R. Iyer. "Studies on ultra high performance concrete incorporating copper slag as fine aggregate." *Construction and Building Materials* **77** (2015): 233-240.

Collins, Robert J., and Stanley K. Ciesielski. *Recycling and use of waste materials and by-products in highway construction*. **No. 199**. (1994).

Fadaee, M., R. Mirhosseini, R. Tabatabaei, and M. J. Fadaee. "Investigation on using copper slag as part of cementitious materials in self compacting concrete." *ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC)* **16** (2015): 368-381.

Gorai, Bipra, and R. K. Jana. "Characteristics and utilisation of copper slag—a review." *Resources, Conservation and Recycling* **39** (2003): 299-313.

Lotfy, Abdurrahmaan, Khandaker MA Hossain, and Mohamed Lachemi. "Durability properties of lightweight self-consolidating concrete developed with three types of aggregates." *Construction and Building Materials* **106** (2016): 43-54.

Mirhosseini, Seyed Reza, Mostafa Fadaee, Ramin Tabatabaei, and Mohammad Javad Fadaee. "Mechanical properties of concrete with Sarcheshmeh mineral complex copper slag as a part of cementitious materials." *Construction and Building Materials* **134** (2017): 44-49.

Nécira, B., A. Guettala, and S. Guettala. "Effect of the viscosity modifying agent and the different mineral additions on rheology and compressive strength of self-compacting concrete." *ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC)* **16** (2015): 111-126.

Sabet, Fereshteh Alsadat, Nicolas Ali Libre, and Mohammad Shekarchi. "Mechanical and durability properties of self consolidating high performance concrete incorporating natural zeolite, silica fume and fly ash." *Construction and Building Materials* **44** (2013): 175-184.

Shi, Caijun, Christian Meyer, and Ali Behnood. "Utilization of copper slag in cement and concrete." *Resources, Conservation and Recycling* **52** (2008): 1115-1120.