Construction and Building Materials 134 (2017) 44–49

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Mechanical properties of concrete with Sarcheshmeh mineral complex copper slag as a part of cementitious materials

Seyed Reza Mirhosseini [a], Mostafa Fadaee [a], Ramin Tabatabaei [a], Mohammad Javad Fadaee [b,*]

[a] Department of Civil Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran
[b] Department of Civil Engineering, Faculty of Engineering, Shahid Bahonar University of Kerman, Kerman, Iran

## HIGHLIGHTS

- Possibility of using copper slag instead of part of cement in concrete is investigated.
- Compressive strength of cubic samples in different ages were measured and compared.
- By increasing the slag up to 30% of cement, acceptable results were obtained.
- Using industrial wastes such as copper slag has environmental & economic benefits.

## ARTICLE INFO

*Article history:*
Received 13 December 2014
Received in revised form 18 August 2016
Accepted 4 December 2016
Available online 29 December 2016

*Keywords:*
Concrete
Cement
Copper slag
Compressive strength
Mechanical properties

## ABSTRACT

Concrete is widely used in construction industry with an ever increasing rate due to its particular characteristics. Replacement of cement as the most expensive part of concrete with industrial materials such as slag, can reduce the cost and help with a greener construction industry. For sustainable development, as well as enhanced performance and economy, alternative approaches, namely proper material for replacement of cement should be explored. Recently, replacing ordinary cement with mixed cement due to the economic and environmental benefits, has 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 of Sarcheshmeh copper plant, and its effect on the mechanical properties of concrete, for which it constitutes a part of cementitious material. The effects of primary and secondary setting time, and percentage of slag as cementitious material, on the compressive strength of $10 \times 10 \times 10$ cm concrete cubic samples, were measured and compared. The mix was optimized for the best use of tailing material share of total cementitious materials, considering the mechanical properties based on the criteria of compressive strength of 7, 14, 28 and 42 days and the optimum percentage of replacement for this cement-like material was specified.



## 1. Introduction

Concrete is used in many construction activities because it is readily available. However, in the past decade concrete has been used widespread in the industry. Evolving industry causes the increase of product wastes. The use of industrial waste, soil or secondary materials to produce cement and concrete is recommended as it helps to reduce the consumption of natural resources. Copper slag products produced by the chemical industry, can cause environmental problems in the surrounding areas if not properly disposed. The process of manufacturing copper in Sarcheshmeh copper smelter factory is combined with an amount of slag mixed with waste and trash. These by-products can be an option for producing cement mixture. 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. There are many studies undergoing to find the possibility of using copper slag as a part of cement mixture.

## 2. Previous works

In this paper, Sarcheshmeh mineral complex copper slag as a part of cement mixture is considered. Copper slag is a waste material which can be determined as a pozzolanic material. There have been many investigations on industrial slag. An overview of previous research studies regarding the use of waste materials in concrete is discussed as follows:

* Corresponding author.
*E-mail address:* mjfadaee@uk.ac.ir (M.J. Fadaee).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.024
0950-0618/

Karakoç et al. evaluated the mechanical properties of ferrochrome slag based geopolymer paste and mortar [1]. Moreover, the mechanical properties of fly ash-based geopolymer concrete was researched by Ryua et al. [2]. Brindha evaluated the durability of the concrete mixed with copper slag [3]. The use of copper slag in cement were investigated by Nazer et al. [4]. Onuaguluchi and Eren tested the durability characteristics of concrete mixtures containing copper tailings as an additive [5]. Al-Jabri et al. used copper slag as sand replacement for high performance concrete [6]. Al-Jabri et al. examined the effect of copper slag as fine aggregate on the characteristics of cement mortar and concrete with experimental work [7] and also studied on high strength concrete made with copper slag [8]. Pazhani studied the mechanical properties of concrete made of copper slag [9]. Onuaguluchi did experiments on copper tailings as a potential additive in concrete [10]. Wu et al. tested copper slag reinforced concrete under dynamic compression [11] and also achieved the optimum content of copper slag as a fine aggregate in high strength concrete [12]. Khanzadi and Behnood studied the mechanical properties of high strength concrete incorporating copper slag as coarse aggregate [13]. Marku and Vaso performed optimization studies on copper slag content in cement mixed with waste [14]. Farzadnia et al. examined incorporation of mineral admixtures in sustainable high performance concrete [15]. Mobasher et al. discussed the effect of copper slag on the hydration of cementitious mixtures [16]. Gupta et al. conducted an experimental study on clay stabilized with copper slag [17]. 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 [18]. The utilization of steel slag, iron tailings and fly ash as aggregates for mortar was done by Liua et al. [19]. The durability of copper slag contained concrete was tested by Najimi et al. [20]. Behnood et al. investigated the utilization of copper slag in cement and concrete [21]. Copper slag waste was used as a supplementary cementing material to concrete by Moura et al. [22].

The key objective of the present paper is to study the mechanical properties of concrete containing copper slag as replacement of a part of the cement. This research is performed to evaluate the feasibility of utilizing copper slag as a part of cement mixture in concrete and the effects on the mechanical properties of concrete caused by this replacement are investigated. The ability to use copper slag in concrete provides additional environmental as well as economical benefits for all related industries, particularly in areas where a considerable amount of copper slag is produced.

The study is consisted of the following tasks:

1. Investigation on the effects of using copper slag instead of a part of cement on the compressive strength of concrete at different curing periods.
2. Evaluation of the effects of copper slag replacement on the workability of concrete.
3. Conducting compressive strength tests on concrete mixtures concerning the task No. 1.

## 3. Materials

### 3.1. Cement

Portland cement is a production of grinding clinker which is made of hydraulic calcium silicates. Calcium sulfate is commonly used as additive as well.

The particle density of Portland cement is about 3.15 tons per cubic meters and is consisted of four materials: Tricalcium silicate ($C_3S$), Dicalcium silicate ($C_2S$), Tricalcium aluminate ($C_3A$) and Tetracalcium alumino ferrite ($C_4AF$).

**Table 1**
The main components of Portland cement.

| Component name | Constituent oxides | Abbreviations |
|---|---|---|
| Tricalcium silicate | $3CaO.SiO_2$ | $C_3S$ |
| Dicalcium silicate | $2CaO.SiO_2$ | $C_2S$ |
| Tricalcium aluminate | $3CaO.Al_2O_3$ | $C_3A$ |
| Tetracalcium alumino ferrite | $4CaO.Al_2O_3.Fe_2O_3$ | $C_4AF$ |

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

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

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 provided by "Bog" and is known as "Bog equations" (Eqs. (1) to (4)).

These equations show the main cement compounds. Values in parentheses show the cement forming oxides percentage of 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 for cement

The standard specifications for Portland cement is standard in ASTM[1] C 150 Portland cement Type II:

This type of cement shows moderate resistance against sulfate attack due to certain limitations that are applied to its components. The amount of heat generation of Portland cement is between cements type I and type IV (cement type IV is the cement type with low heat generation). Thus, in some cases, this type of cement is known as a moderate heat generation cement. Portland cement can be utilized either for general use or special use where moderate hydration heat is desired. In this research, cement type II was used for performing the tests.

In Tables 2 and 3 physical and chemical characteristics of cement type II are shown, respectively.

### 3.2. Copper slag

Copper slag production was first known at the beginning of extracting metals from ores within biological processes. It was a by-product, obtained during the matte copper refining and copper smelting. The production of one ton of copper generates about 2.2–3 tons of copper slag. In the United States the amount of copper slag produced is about four million tons, while in Japan it is about two million tons per year. Slag management methods include recycling, metal recovery and depo-out [23]. According to official reports, the amount of copper slag produced in the melting factory of Sarcheshmeh mineral complex is about 360,000 tons per year.

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

[1] American Society for Testing and Materials.