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Split tensile strength of slag-based geopolymer composites reinforced with steel fibers: Application of Taguchi method in evaluating the effect of production parameters and their optimum condition

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Abstract

In the present study, split tensile strength of slag based geopolymer composite reinforced with steel fibers has been designed by Taguchi method. In this ceramic matrix composite, furnace metallurgical slag of rockwool acts as an aluminosilicate source. Four main parameters including water curing regime, sodium hydroxide concentration, alkali activator to cement weight ratio and steel fibers weight percent, each at three different levels, were considered for examination. A total number of 9 experiments were performed according to L9 array which was proposed by the Taguchi method. The obtained results were evaluated by analysis of variance (ANOVA) method to determine the optimum level of each factor. ANOVA revealed that specimen with curing regime of 14 days, sodium hydroxide concentration of 14 M, Alkali activator to cement weight ratio of 0.24 and steel fibers with 5 wt% was potential of highest strength (8.87 ± 1.71 MPa) in considered procedure. Based on achievements, it is possible to produce high strength geopolymer composite reinforced with steel fibers. Also, it was shown that split tensile strength of slag based geopolymer composite reinforced with steel fibers could be suitably designed by the Taguchi method.

Keywords: Geopolyme; Composite; Split tensile strength; ANOVA; Design of experiment (DOE)

1. Introduction

Geopolymers are a new form of binders that used in cement and concrete composite. This group of materials is an amorphous aluminosilicate network produced by reaction of aluminosilicate material with alkaline solution [1]. In addition to excellent mechanical properties, fire resistance, low shrinkage, application of waste and/or by-product materials as an aluminosilicate source is purpose of many researches [2–4]. Furnace metallurgical slag is one of the suitable sources for production of geopolymers. Most of the recent studies are focused on production of geopolymers with slag aluminosilicate sources [5–9]. Also, the mechanical properties) compressive strength(of geopolymer produce with blast furnace slag source have been studied [10].

The concept of using steel fibers as reinforcement geopolymers concrete in order to improve mechanical properties have studied in several researches, but in many of them effect of fibers in concrete consisting of cement or fly ash have investigated [11,12]. However, investigation of the mechanical properties in slag based geopolymer composites may be of interest in the recent studies.

The main factors affecting the geopolymer properties generally depend on the utilized aluminosilicate source. For example, slag and fly ash may have different affecting [6,13] several works have been carried out on geopolymers and there is no unanimity on the effects of various factors for upsetting these materials. The important factors of geopolymer production could be categorized

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into aluminosilicate source type and size, water curing regime, alkali activator, concentration of alkali activator, oven curing temperature and its time, and the alkali activator to cement weight ratio. Also in steel fibers reinforced geopolymer composites, volume or weight fraction (percent) and aspect ratio of fibers are effective parameter. It might be impossible to investigate all of the parameters' effect by conducting a single work. However, by using a suitable design of experiment method (DOE) one may consider some of the factors affecting properties. Taguchi method as the most famous method utilized for designing the parameters of an engineering problem could be employed. Submission of this method to geopolymers is limited [14–16].

The aim of this work is to design a suitable procedure for production of slag geopolymer reinforced with steel fibers (Slag Geopolymer Composite) by considering most frequent factors resulting in highest split tensile strength. Four main production parameters, including water curing regime (at three levels of 3, 7 and 14 days), sodium hydroxide concentration (at three levels of 12, 14 and 16 M), alkali activator to cement weight ratio (at three levels of 0.24, 0.26 and 0.28), and the weight percent of fibers (at three levels of 1%, 3% and 5%) were considered. Also, oven curing temperature at 70 °C, oven curing time for 6 h, Water glass (WG) to the sodium hydroxide weight ratio equal to 2.5 and the fibers aspect ratio equal to 20 were assumed constant. A total number of 9 experiments were conducted according to the L9 array proposed by acquired DOE method. The superiority of this work to the previously published one [17] is the consideration of weight percent of steel fibers among important influencing factors which may significantly reduce the number of empirical tests. Meanwhile, the results of split tensile strength test were analyzed by ANOVA as supplementary work to determine and anticipation of optimum production procedure.

2. Experimental procedure

The used cementitious material for the aluminosilicate source in this research was furnace metallurgical slag of rockwool production. Slag of rockwool production was bulk solid, so it was milled to powder with 50 meshes. Chemical composition of slag after milling has been listed in Table 1. Micrographs of Scanning Electron Microscope (SEM) of slag after milling is illustrated in Fig. 1

Sodium silicate solution containing water glass (WG) and sodium hydroxide (NaOH) were used as the solvable part of the mixture. Sodium hydroxide was diluted up to different concentration before using, but WG was used without mentioned modification. The chemical composition of the utilized WG is also given in Table 1. Flat end steel fibers made with low carbon steel with dimension of 16 × 0.8 mm (thus giving

Table 1
Chemical composition of Slag and WG (wt%).

Material	SiO_2	Al_2O_3	Fe_2O_3+FeO	CaO	MgO	TiO_2	Na_2O
Slag	46	14	7.5	18	10	1.5	–
WG	36.8	–	–	–	–	–	14.7

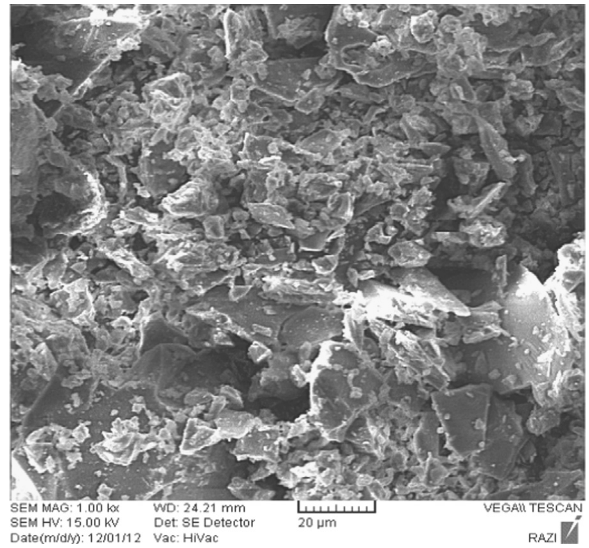

Fig. 1. SEM micrographs of slag.

Table 2
Chemical composition of steel fibers (wt%).

C	Si	Mn	Cu	Fe
0.08	0.9	1.5	0.2	rest

an aspect ratio of 20) were used. Chemical composition and mechanical properties of steel fibers are presented in Tables 2 and 3, respectively.

Four main considered parameters for the Taguchi experimental design were comprised of: “water curing regime”, “sodium hydroxide concentration”, “alkali activator to cement weight ratio”, and “steel fibers weight percent” while each implemented at three different levels. Oven curing time and oven curing temperature and aspect ratio of steel fibers were assumed constant. The variation levels of each parameter have been presented in Table 4. The Taguchi experimental design was performed by Qualitek 4 software. The suggested design by Taguchi method for four factors at three levels is L9 array in accordance with Table 5. Totally 9 series of geopolymer specimens with different mixture proportions (Table 5) were prepared for split tensile strength testing. The mixed alkali activator of sodium silicate solution and sodium hydroxide was used. Sodium hydroxide was diluted by tap water to have the concentrations of 12, 14, 16 M. The advantage of using tap water rather than distilled water is to introduce commercial geopolymers with lesser production cost. The solution was left in ambient conditions until their excess heat had completely dissipated. This was to avoid setting acceleration of the geopolymeric specimens. The sodium silicate solution without preparation was mixed with sodium hydroxide solution. Pastes were vibrated for 5–10 min to achieve complete homogenization. The mixtures were cast in available 33 mm × 66 mm polypropylene cylinder molds. Steel fibers were added to the mixtures just before casting in molds. Specimens were then preserved for 24 h at room temperature because this precuring time has been found to be beneficial to