

The Effect of Different Curing Temperatures on the Properties of Geopolymer Reinforced with Micro Steel Fibers

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Abstract-In this study, geopolymer mortar was designed in various experimental combinations employing 1% micro steel fibers and was subjected to different temperatures, according to the prior works of other researchers. The geopolymer mortar was developed using a variety of sustainable material proportions (fly ash and slag) to examine the influence of fibers on its strength. The fly ash weight percentage was 50%, 60%, and 70% by slag weight to study its effect on the geopolymer mortar's properties. The optimal ratio produced the most significant results when mixed at a 50:50 ratio of fly ash and slag with 1% micro steel fibers at curing temperature 240°C for 4 hours through two days. The compressive strength of the geopolymer mortar increased by 11%, 11.5%, and 14% after 3, 7, and 28 days when utilizing fibers. The result shows that fly ash with a ratio of 50% by weight of slag improved the compressive strength of the mixture. It was discovered that a combination with 50% of the weight of fly ash with micro steel fibers, when treated at 240°C for curing age of 3, 7, and 28 days, had a flexural resistance rate of 28%, 30%, 33% higher than a mixture without fibers.

Keywords-sustainable material; geopolymer mortar; fly ash; ground granulated blast furnace; slag

I. INTRODUCTION

The primary binder used in concrete production is Ordinary Portland Cement (OPC). The environmental concerns surrounding the manufacturing of OPC are well-known. Furthermore, the amount of energy needed to manufacture only steel and aluminum is equal to that necessary to build OPC [1]. Cement production varies widely due to differences in the availability of raw materials [2]. Sustainable materials are being developed to limit the emission of CO₂ from the cement industry and help recycle the industrial waste by incorporating environmentally friendly materials into civil engineering project [3]. Many cement composites may be found in addition to regular concrete. Various byproducts may be employed to produce blended cement classified as supplementary cementitious materials, such as GGBFS, Fly Ash (FA), and Silica Fume (SF) [4]. FA and slag waste from thermal power plants pose a severe environmental hazard if not treated and repurposed. Since the FA from thermal power plants is buried,

it does long-term damage to the environment by polluting the groundwater and harming the farmlands [5]. The byproduct of combustion is a fine powder. A significant amount of this garbage is produced every year, creating a substantial environmental threat. Pozzolanic (siliceous and aluminous) materials may be utilized to minimize waste to some degree [6].

In 1978, the term "geopolymer" was developed to designate a group of mineral binders having a similar chemical makeup to zeolites. On the other hand, geopolymers use polycondensation of silica and alumina precursors instead of traditional Portland/pozzolanic cement to form the matrix. Geopolymers are mainly composed of source materials and alkaline liquids. Alumino-silicate-based raw materials with high silicon (Si) and aluminum (Al) content should be used. Byproducts like FA and SF may be added to the mix. As opposed to other alumino-silicate compounds, geopolymers are a unique creation (e.g. alumino-silicate gels, glasses, and zeolites). Geopolymerization produces higher concentration of solids than alumino-silicate gels or zeolite synthesis [7]. Geopolymer concrete, made from FA and slag, is an excellent alternative to conventional concrete because it is more environmentally friendly and has diverse ingredients and qualities [8]. Therefore, in this paper, the effect of different proportions of FA by weight of slag with different curing temperatures is studied.

II. EXPERIMENTAL SETUP

A. Fly Ash

The acquired FA is a fine, glassy powder produced by coal combustion throughout the generation of electrical energy at the ISKEN-MENT-Turkey power station. The chemical composition of the FA used in this research is shown in Table I.

B. Slag

The slag utilized in this study complied with ASTM C618 [8] requirements, as shown in Table II.

TABLE I. FLY ASH CHEMICAL COMPOSITION

Oxide	Content %	(ASTM C618) requirements [9]
Fe ₂ O ₃	5.35	Sum of value more than 70%
Al ₂ O ₃	17.59	
SiO ₂	65.63	
SO ₃	0.21	Max. 5%
MgO	0.84	--
CaO	0.98	--
L.O. I	2.76	Max. 6%
K ₂ O	2.33	--
Na ₂ O	1.36	--

TABLE II. GGBFS CHEMICAL COMPOSITION

Oxide	Content %	(ASTM C618) requirements [9]
Fe ₂ O ₃	0.35	Sum of value more than 70%
Al ₂ O ₃	25.53	
SiO ₂	45.88	
SO ₃	4.98	Max. 5%
MgO	4.95	--
CaO	37.21	--
L.O. I	3.89	Max. 6%
K ₂ O	2.10	--
Na ₂ O	0.96	--

TABLE III. PHYSICAL CHARACTERISTICS OF THE FINE AGGREGATES

Sieve size, mm	Cumulative percentage pass	IQS (45-1984), zone 2
10	100	100
4.750	91	90-100
2.360	80	75-100
1.180	71	55-90
0.60	53	35-59
0.30	22	8-30
0.150	7	0-10

TABLE IV. MECHANICAL PROPERTIES OF MICRO STEEL FIBERS ACCORDING TO THE MANUFACTURER

Properties	Micro steel fibers
Tensile strength (MPa)	2600
Diameter (mm)	0.2
Density(kg/m ³)	7800
Length (mm)	13
Aspect ratio	65
Modulus of Elasticity (GPa)	250

C. Sodium Hydroxide

Commercially available NaOH flakes have a 98% purity. NaOH is used to make geopolymer mortar solutions. NaOH is made by melting caustic soda flakes with water. Based on the ratio of the soda flakes added to the water, different molar concentrations may be obtained.

D. Sodium Silicate

The concentration of Na₂SiO₃ is determined by the ratio of Na₂O to SiO₂ and H₂O. The Na₂SiO₃ used in this formulation was produced in the United Arab Emirates.

E. Water

Distilled water was used to dissolve the caustic soda flakes to make the NaOH solution. Tap water was added to the geopolymer mix to improve workability. It conforms to IQS 1703 [10].

F. Fine Aggregates

This research used natural sand from the Al-Ekhadir (Karbala city) area as fine aggregates. It belongs to zone 2 and complies with the physical and chemical characteristics of the Iraqi standard requirements IQS (No.45/1984) [11] as shown in Table III.

G. Micro Steel Fibers

Table IV shows the properties of the micro steel fibers utilized in this research.

H. Superplasticizer

A high range water reducer (superplasticizer) based on modified sulfonated naphthalene formaldehyde condensate was used to improve the geopolymer mortar's workability. It confirmed to ASTM C494 [17].

III. GEOPOLYMER MANUFACTURING

A. Alkaline Solution Preparation

The sodium hydroxide molar concentration was set to 12 molars when making the geopolymer mortar in this experiment. The sodium silicate-to-sodium hydroxide ratio was set at 2:1, and the solution-to-cementitious-material ratio was set at 0.45. Table V shows the sodium hydroxide flakes weight.

TABLE V. AMOUNT OF SOLID NaOH FOR 1kg OF SOLUTION AT SPECIFIED MOLARITY AND WEIGHT CONCENTRATION [1, 12]

Molarity (mole/L)	NaOH concentration (w/w%)	Weight of NaOH flakes (g)	Weight of Water (g)
8	26.2	262	738
10	31.4	314	686
12	36.2	362	638
14	40.4	404	596
16	44	440	560

B. Mixing

The day before it was utilized, the alkaline liquid was produced and then mixed with the superplasticizer before the mixing procedure. The dry components (GGBS, FA, fibers, and sand) were first incorporated by hand for about 2 minutes before the alkaline liquid and superplasticizer were combined at a 75% concentration. After 5 minutes of mixing, the mixture was left for roughly 15 seconds before the remaining 25% of the mixed alkaline liquid was added and then it was re-combined for another 5 minutes. Approximately 10 to 15 minutes of mixing time were required to achieve homogeneity as shown in Table VI.

TABLE VI. MIX DESIGN OF 1m³ GEOPOLYMER MORTAR

Mix	Fine aggregates	Water *	FA/Slag ratio	Slag	FA	Sodium silicate solution	NaOH	Micro steel %
G1	1400	75	0.5:0.5	375	375	225	112.5	-
G2	1400	75	0.5:0.5	375	375	225	112.5	1
G3	1400	75	0.6:0.4	450	300	225	112.5	-
G4	1400	75	0.6:0.4	450	300	225	112.5	1
G5	1400	75	0.7:0.3	525	225	225	112.5	-
G6	1400	75	0.7:0.3	525	225	225	112.5	1

weight in Kg/m³

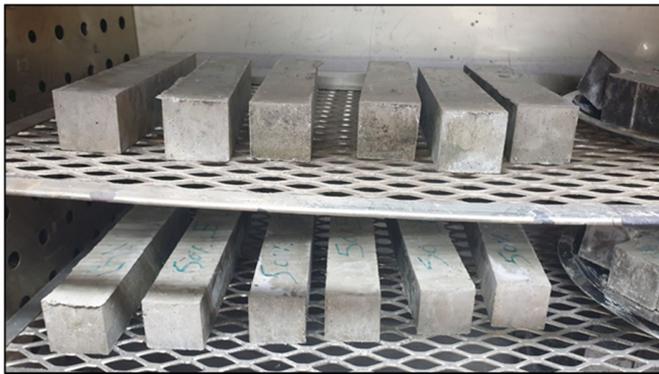


Fig. 5. Geopolymer prisms during curing.

V. CONCLUSION

The main conclusions according to the results of the current study on geopolymer mortar are:

- Geopolymer is an ecologically acceptable substitute for OPC in structural applications.
- FA and slag-based geopolymer mortar are preferable to conventional concrete because of their sustainable ingredients and improved characteristics.
- Best geopolymer mortar qualities may be achieved by adding 1% by volume micro steel fibers to the mixture.
- The additional micro steel fibers in geopolymer mortar increase strength by 10%, improving bond strength.
- The optimum strength of geopolymer mortar was acquired with proportions of 50% of FA: 50% of GGBFS with 1% of micro steel fibers (Mix G2).
- The addition of GGBFS to geopolymer concrete as an alternative to FA improved compressive strength in mixtures G2, G4, and G6 with ratios of 11%, 8.5%, and 5% respectively, with 240°C curing temperature at 28 days.
- Geopolymer mortar can develop high early strength by using high curing temperatures.
- By increasing temperatures of curing age from 80°C to 240°C, the compressive strength increased by about 25% without fibers and 28.5% with micro steel fibers (at 28 days).
- The flexural strength increased by 28%, 30%, and 33% by additional micro steel fiber for 3, 7, 28 days of curing respectively.

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