

Civil and Architectural Engineering

Influence of Using Various Percentages of Slag on Mechanical Properties of Fly Ash-based Geopolymer Concrete

Sarah Sameer Hussein *
Department of civil engineering
university of Baghdad
Baghdad, Iraq
s.huessein1901m@coeng.uobaghdad.edu.iq

Prof. Dr. Nada Mahdi Fawzi
Department of civil engineering
university of Baghdad
Baghdad, Iraq
nada.aljalawi@coeng.uobaghdad.edu.iq

ABSTRACT

In order to implement the concept of sustainability in the field of construction, it is necessary to find an alternative to the materials that cause pollution by manufacturing, the most important of which is cement. Because factory wastes provide siliceous and aluminous materials and contain calcium such as fly ash and slag that are used in the production of high-strength geopolymer concrete with specifications similar to ordinary concrete, it was necessary for developing this type of concrete that is helping to reduce CO₂ (dioxide carbon) in the atmosphere. Therefore, the aim of this study was to study the influence of incorporating various percentages of slag as a replacement for fly ash and the effect of slag on mechanical properties. This paper showed the details of the experimental work that has been undertaken to search and make tests the strength of geopolymer mixtures made of fly ash and then replaced fly ash with slag in different percentages. The geopolymer mixes were prepared using a ground granulated blast-furnace slag (GGBFS) blend and low calcium fly ash class F activated by an alkaline solution. The mixture compositions of fly ash to slag were (0.75:0.25, 0.65:0.35, 0.55:0.45) by weight of cementitious materials respectively and compared with reference mix of conventional concrete with mix proportion 1:1.5:3 (cement: sand: coarse agg.), respectively. The copper fiber was used as recycled material from electricity devices wastes such as (machines, motors, wires, and electronic devices) to enhance the mechanical properties of geopolymer concrete. The heat curing system at 40 °C temperature was used. The results revealed that the mix proportion of 0.45 blast furnace slag and 0.55 fly ash produced the best strength results. It also showed that this mix ratio could provide a solution for the need for heat curing for fly ash-based geopolymer.

Keywords: sustainable material, geopolymer concrete, alkaline solution, fly ash, ground granulated blast furnace slag (GGBFS).

*Corresponding author

Peer review under the responsibility of University of Baghdad.

<https://doi.org/10.31026/j.eng.2021.10.04>

2520-3339 © 2019 University of Baghdad. Production and hosting by Journal of Engineering.

This is an open access article under the CC BY4 license <http://creativecommons.org/licenses/by/4.0/>.

Article received: 20/5/2021

Article accepted: 27/6/2021

Article published: 1/10/2021



تأثير استخدام نسب مختلفة من خبث فرن الصهر الحبيبي على الخواص الميكانيكية لجيوبوليمر الرماد المتطاير

أ.د. ندى مهدي فوزي
قسم الهندسة المدنية
جامعة بغداد

* سارة سمير حسين
قسم الهندسة المدنية
جامعة بغداد

الخلاصة

من اجل تطبيق مفهوم الاستدامة في مجال البناء والانشاء يتطلب الامر ايجاد بديل عن المواد المسببة للتلوث خلال تصنيعها واهمها هو السمنت ولان مخلفات المصانع توفر مواد سيليكية والومينية وتحتوي على الكالسيوم مثل الرماد المتطاير وخبث فرن الصهر الحبيبي التي تستخدم في انتاج الخرسانة الجيوبوليمرية بمواصفات تضاهي الخرسانة العادية كان لا بد من تطوير هذا النوع من الخرسانة الذي ساعد على تقليل انبعاث غاز ثاني أكسيد الكاربون في الجو لذلك كان الهدف من هذه الدراسة هو دراسة تأثير استخدام نسب مختلفة من خبث فرن الصهر الحبيبي كبديل عن الرماد المتطاير على الخواص الميكانيكية للخرسانة. أظهرت هذه الدراسة تفاصيل العمل التجريبي الذي تم القيام به لتحقيق في قوة خلطات مونة الرماد المتطاير وخبث الافران . تم تحضير عينات الخرسانة الجيوبوليمرية باستخدام مزيج من خبث أفران الصهر الحبيبي (GGBFS) والرماد المتطاير من نوع (F) منخفض الكالسيوم والذي يتم تنشيطه بواسطة محلول قلوي. كانت تركيبة الخليط من الرماد المتطاير الى خبث افران الصهر الحبيبي (0.25 : 0.75 ، 0.35 : 0.65 ، 0.45 : 0.55) من وزن المواد السمنتية على التوالي وقد تم مقارنتها بخلطة خرسانة عادية بنسب خلط (1 : 1.5 : 3) (سمنت: رمل: حصى) على التوالي. كما تم استخدام الياف النحاس كمادة معاد تدويرها من المخلفات الكهربائية مثل المكائن واسلاك الكهرباء والاجهزة الالكترونية وذلك لتحسين الخواص الميكانيكية للخرسانة الجيوبوليمرية .تم تطبيق نظام الانضاج بالهواء الحار . أظهرت النتائج أن نسبة المزيج من (0.45 : 0.55) الرماد المتطاير الى خبث الافران أنتجت أفضل نتائج المقاومة وظهرت اعلى كثافة وقابلية التشغيل اعلى. كما تم التوصل أيضاً الى أن مزيج الرماد المتطاير: خبث فرن الصهر الحبيبي 0.45 : 0.55 وفرت حلاً للحاجة إلى الانضاج الحراري للرماد المتطاير .

الكلمات الرئيسية:المواد المستدامة، الكونكريت الجيوبوليمري، محلول قلوي، رماد متطاير، خبث أفران الصهر الحبيبي .

1. INTRODUCTION

Environmental change forces the human population to seek novel materials, technologies, and solutions, which are more sustainable and ecological (Abeer, 2019). At present, the backbone construction material of most countries' infrastructure is concrete. It is the second most used product in the world, just after water. The amount of OPC (ordinary Portland cement) consumed reached 3800 tons in 2018 (Yifei Cui, et al., 2020). However, the availability of the basic raw materials of traditional concrete worldwide, from its major drawbacks with respect to sustainability. Concrete made of Portland cement deteriorates when exposed to harsh environments, under either normal or severe conditions. Cracking and corrosion have a significant influence on service behavior, design life, and safety (Zongjin Li, 2011).

In recent years, to overcome these problems, remarkable improvement of substances activated by alkalis as a replacement class of concrete that uses sustainable materials such as fly ash as a total replacement of cement (Linda and Fausto, 2015). To decrease the environmental influences and high consumptions energy of methods manufacturing, cement had been used to find alternatives to OPC. Between these investigations, substances activated by alkalis have attracted significant attention nowadays. from an energy cost and environmental point of view, substances of alkali-



activated, which are considered the primary material of geopolymer concrete, are prepared to get nearly 80% less CO₂ than Portland cement (**Arie Wardhonoa, et al., 2015**)

In addition, the global warming potential of geopolymer concrete is 70% minimize than Portland cement concrete (**Liwei Yao, et al., 2020**). Other different cementitious materials have been developed. One of them to be discussed in this research is a geopolymer. It is a newly developed inorganic binder produced from any pozzolanic compound or source of silicates or aluminosilicates that concern sustainable material that is readily dissolved in alkaline solution will suffice as a source for the production of a geopolymer (**Ahmed Mushrif, 2017**).

GGBFS It is a by-product produced from iron factories in the blast furnace, which was first discovered by Emile Langen in Germany in 1862, after which it expanded and spread in Europe. After the slag is obtained, when the iron is manufactured, it is cooled, and glass granules with a diameter of 5 mm or less are formed. The chemical composition of the GBFS is different according to the variety of sources of raw materials, the conditions, and the nature of the blast furnace. The basic oxides are formed due to the rapid cooling of slag clinker and form a network of aluminum, silicon, calcium, and magnesium ions in an unordered manner with oxygen. The slag does not react when water is added to it or reacts very slowly, which is not useful in practice. The reason for this is that the hydraulic slag is confined within its glass structure, so it must be activated with activators such as sulphates and alkalis, which are more common, as they react with it chemically and produce a cement gel (**John Newman, et al., 2003**).

2. LITERATURE REVIEW

(**Chien-Chung Chen, et al., 2015**) made an experimental study on geopolymer concrete consisting of fly ash type C and replaced fly ash with slag granular blast furnaces to study the effect of slag to fly ash ratio and its effect on the mechanical properties of concrete. The percentage used the slag/fly ash ratio 25/75%, 50/50%, and 75/25%. Until the setting time became about 20 minutes with a slag/fly ash ratio of 50/50% and 25/75%, as for the density, it ranged between 2387 kg/m³ to 2393 kg/m³. The results also showed that an increase in the percentage of slag leads to increased compressive strength at the age of 7 days.

(**Qais and Ahmed, 2018**) summarized the work of practical study that they carried out proved that adding granular blast furnace slag as a partial substitute for fly ash works to develop and improve the properties of geopolymer concrete under ambient temperature conditions. It showed better results even at room temperature.

(**Ambily, et al., 2012**) made a research to study the strength of geopolymer concrete that could be better by mixing 20 % slag and 80 % fly ash, the alkaline liquid to cementitious was 0.6. From the results, induced best workability ranged between 225-250 mm; compressive strength ranged between 30 to 44 MPa at the age of 28 days of casting have resulted.

(**Nath and Sarkar, 2014**) investigated the effect of adding a small quantity of slag on setting time, workability and mechanical properties of fly ash-based geopolymer concrete. They found that adding slag made no need to heat curing and enabled curing at ambient conditions, and blending slag with fly ash would enhance geopolymer concrete's engineering properties and durability.

(**Abhilash, et al., 2017**) evaluated the resistance of geopolymer concrete in an acid environment in the experimental study. The low-calcium fly ash was used, slag added as fine aggregate, and crushed stone used up to 70% by weight as coarse aggregate. Designing M25 grade concrete was poured, and six molarity of alkaline solution was used. The conclusion showed that the weight of geopolymer concrete decreased with increasing the acid concentration and the compressive



strength of geopolymer concrete decreased to 0.61%, while in cement concrete, it was 0.69%. Hence it has been proven that geopolymer concrete has a good wear resistance to the acidic environment.

3. EXPERIMENTAL WORK

3.1 Materials

3.1.1 Fly ash and blast furnace slag

The basic substances used were a low calcium class F fly ash with high silica content mixed with slag (GGBFS), with different percentages. The chemical composition of these substances is confirmed to (ASTM C618, 2015), as illustrated in Table 1.

Table 1. Chemical compositions of fly ash and GGBFS (mass %).

Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	K ₂ O	Na ₂ O	TiO	P ₂ O ₅	Mn ₂ O ₃	SO ₃	LOI
GGBFS	46.87	24.23	0.32	36.0	5.05	0.05	0.00	0.63	0.36	0.39	5.0	2.4
	(SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃) = 71.42											
Fly ash	66.65	25.06	1.68	2.03	0.1	1.01	0.39	1.25	1.23	0.05	0.62	3.57
	(SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃) = 93.39											
chemical requirement according to ASTM C618	SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃			-	-	-	-	-	-	-	Max %	Max %
	70										5	6

3.1.2 Cement

The ordinary Portland cement produced in the AL- Kebisa Factory was used for the reference mixture. The cement's chemical analysis and physical properties were used to confirm the Iraqi specifications (IQS No. 5/2019) (type / 42.5 N), as shown in Table 2., Table 3.

Table 2. Chemical analysis of cement.

Oxides	Percentage %	Limitations of the Standard IQS/5/ 2019
Calcium Oxide (CaO)	62.6	
Silica oxide (SiO ₂)	21	
Aluminum Oxide (Al ₂ O ₃)	4.92	
Magnesium oxide (MgO)	3.33	5 (max)
Iron Oxide (Fe ₂ O ₃)	3.08	-



Third sulfur dioxide (SO ₃)	2.16	2.8 (max.)
Loss of ignition (LOI)	1.5	4 (max.)
Insoluble residue (IR)	0.6	1.5 (max.)

Table 3. Physical tests of cement.

Characteristics	Test results	Limitations of the Standard IQS /5/2019
Fineness (m ² /kg) by Blaine method	348	250
Setting time Initial (minute) Final (hour)	106 3:36	45 minutes (min.) 10 hours (max.)
loading strength rate (MPa) 2 days 28 days	12.5 33.63	10 (min.) 32.5 (min.)

3.1.3 Water

Water that is confirmed by the Iraqi standards (IQS No. 1703, 1992) was used, and distilled water was used to prepare the alkaline solution (NaOH).

3.1.4 Aggregate

The fine aggregate used was natural sand supplied from Al-Eakhadir. The results show that the fine aggregate grading (zone2) and natural gravel was used such coarse aggregate have a nominal aggregate size of (5-14 mm) for all mixes. The physical and chemical properties of aggregate within the requirements of the Iraqi Specification (IQS No.45/1984). **Table 4., Table 5., Table 6.** and **Table 7** summarizes test results.



Table 4. Sieve analysis of fine aggregate.

Sieve size (mm)	Cumulative percentage passing	Limits of Iraqi Standard IQS 45-1984
10	100	100
4.75	100	90-100
2.36	82.7	75-100
1.18	66.9	55-90
0.6	51.8	35-59
0.3	18.8	8-30
0.15	3.37	0-10

Table 5. Physical and chemical properties fine aggregate.

Physical properties	Test results	Limits of Iraqi Standard IQS 45-1984
Specific gravity	2.6	----
Fineness modulus	2.8	----
Density (kg/m ³)	1580	----
Absorption (%)	1.8	----
Sulfate content (%)	0.12	0.5 % (max.)

Table 6. Grading of coarse aggregate.

Sieve Size (mm)	%Passing	Specification limits according to IQS No. 45/1984
20	100	100
14	100	90-100
10	55.5	50-85
4.5	0.42	0-10



Table 7. Physical and chemical properties of coarse aggregate.

Properties	Test results	Specification Limits According to IQS No. 45/1984
Specific gravity	2.58	-
Absorption	1.1%	-
SO ³	0.04%	≤ 0.1%
Dry density	1600 kg/m ³	-

3.1.5 Alkaline activator

The activated precursors used an alkali solution. The alkali solution is made by blending sodium hydroxide with anhydrous flakes form and deionized water with sodium silicate solution available commercially.

3.1.6 Sodium hydroxide, NaOH

The sodium hydroxide with flake formed, of 99 % purity, is commercially available. Before geopolymer casting, NaOH should be dissolved in distilled water, forming a solution with a certain concentration. Molar concentration could be produced depending on the different percentages of caustic soda flake to water. Sodium hydroxide concentration usually varied from (5–16) in molarity. The percentage used in this study is 8 Molar. Properties for using sodium hydroxide solution in the mixture were according to (ASTM.E291, 2009).

3.1.7 Sodium silicate, Na₂SiO₃

Sodium silicate used in the study was manufactured in the United Arab Emirates; the concentration of sodium silicate depended on the percentage of Na₂O to SiO₂ and H₂O.

3.1.8 Prepare the alkaline liquid

The sodium silicate solution is commercially available. In this research, sodium silicate solution had a percentage of SiO₂ to Na₂O by mass equal (2). The proportions, by mass of ingredients, are SiO₂ =31.5 %, Na₂O = 14. %, and water = 55.1 %. The NaOH solution is added to the Na₂SiO₃ solution after it has been prepared as a solution. To be used in cast geopolymer concrete, the alkaline solvent should be prepared by combining all solutions for at least 24 hours. (Lloyd and Rangan, 2010).



3.1.9 Copper wire fiber

Copper wire is a sustainable fiber that could be found in many electronic and electrical devices applications, such as computer and whole accessories, windings of electrical machines, refrigerators, and other devices. The fiber length used was (15 ± 2) mm and diameter 0.25mm, so the aspect ratio is equal to 60.



Figure 1. Copper fiber.

3.1.10 Superplasticizer

Master Glenium 51 superplasticizer was used to produce the required flowing ability and chemistry. It has a special carboxylic ether polymer with long lateral chains as its mode of action. Cement dispersion is significantly improved as a result of this. It is free from chlorides and confirm with (ASTM C494, 2005) types A and F, the quantity used in the study was 0.5litre per 100 kg cement.

3.2 MIX PROPORTIONS

Under (ACI 211, 2008), the mix design ratio for both reference mixture (cement: fine agg.: coarse agg.) and (fly ash and slag: fine agg.: coarse agg.) mixture with ratio 1: 1. 5: 3. The water to binder ratio was 0.45 for whole mixes. Design compressive strength was 48 MPa for ordinary concrete. The mix compositions of fly ash to slag were: (0.75:0.25, 0.65:0.35, 0.55:0.45), respectively. **Table 8** summarizes the mix design.



Table 8. Mix design of geopolymer concrete for 1 m³.

Mix	Cement kg/m ³	Fine agg. kg/m ³	Coarse agg. kg/m ³	Water kg/m ³	FA to GGBS Ratio	GGBFS kg/m ³	Fly ash kg/m ³	Sodium silicate solution kg/m ³	NaOH	fiber (%)
MR ₀	395	605	1174	178	-	-	-	-	-	0
MR ₁	395	605	1174	178	-	-	-	-	-	0.5
MG ₀		605	1174	3.95*	0.75:0.25	98.75	296.25	118	59	0
MG ₁	-	605	1174	3.95*	0.75:0.25	98.75	296.25	118	59	0.5
MG ₂	-	605	1174	3.95*	0.65:0.35	138.25	256.75	118	59	0.5
MG ₃	-	605	1174	3.95*	0.55:0.45	177.75	217.25	118	59	0.5

* extra water (10% by weight of cementitious material) was added to geopolymer concrete in addition to alkaline solution to enhance workability (Zaid, 2016).

The same mixing method was used for normal concrete and geopolymer concrete, depending on previous research by researchers who confirmed that the same technique could be used for regular concrete in manufacturing geopolymer (Lloyd and Rangan, 2010). The dry ingredients are placed in the mixer for three minutes in order to mix well. Then the water is added with the superplasticizer, and the mixing continues for two minutes with respect to normal concrete according to specification (ASTM C 192). As for the geopolymer, the alkali solution was mixed with the superplasticizer with the extra water and left for two minutes. Then, the solution was added to the dry mixture, and the mix continued. After that, the mixture is poured into the molds and compacted manually to be closer to field pouring conditions to get rid of air/voids in specimens and left for 24 hours. After which, it was opened from the mold, and the ordinary concrete samples are placed in water for curing at a temperature of 20 ± 2 °C until testing according to (ASTM C 192). The geopolymer samples were placed in the oven at 40 degrees Celsius for 48 hours.

3.3 Tests

3.3.1 Compressive strength test

The mixing for both reference and geopolymer concrete specimens was performed using a mixer. The mixtures were cast in 100× 100 × 100 mm³ cubes molds. Compressive strength measurement of cubes was carried out according to (EN BS 12390-4, 2000) testing method on a Universal Testing Machine. Three cubes were tested for each data point. The specimens were tested at 7, 28 and 90 day after casting. The test continued until the failure of the concrete specimens.



Figure 2. Geopolymer cubes before the compressive test (left), after the compressive test (right).

3.3.2 Splitting tensile strength

The splitting tensile strength test indicated the crack resistance of the concrete. It was measured indirectly, and the test was performed according to the procedure of (ASTM C496, 2011). The tensile splitting strength test couldn't conduct as a direct tensile test due to difficulty to conduct on concrete specimens. The average of two cylinders specimens used for each data point with dimensions of 150 mm × 300 mm were poured and tested after 7, 28 days of curing for each mix. The splitting tensile strength (T) is calculated by the following equation:

$$T = \frac{2p}{\pi dl} \quad (1)$$

Where:

T = Splitting tensile strength, (MPa).

P = Max. applied load (N).

d = Cylinder diameter, (mm).

l = Cylinder length, (mm).

3.3.3 Flexural Strength Test

Flexural strength was measured using (BS 1881-118, 1983) (74) (100*100*400) mm prisms. The basic beam bending formula is used to measure the flexural strength:

$$F_{cf} = \frac{fl}{d_1 d_2^2} \quad (2)$$

Where:

F_{cf} = flexural strength, (MPa)

f = breaking load, in (N).

l = distance between supporting rollers, in (mm).

d_1 and d_2 = lateral dimensions of the cross-section, (mm)



If the failure line is within the third middle span, this equation can be adopted.

4. RESULTS AND DISCUSSIONS

4.1 Compressive Strength

The compressive strength results are reported in **Table 9** for normal concrete and geopolymer concrete specimens for all mixes and development of strength with age, respectively, represented in **Fig. 3** and **Fig. 4**.

Table 9. Compressive strength test results for reference and geopolymer concrete.

Mix type	Compressive strength (MPa)		
	Age of concrete (day)		
	7	28	90
MR ₀	30.7	48.8	52.16
MR ₁	39.7	50.03	54.3
MG ₀	33.04	43.13	49.12
MG ₁	36.3	44.7	49.81
MG ₂	41.1	45.4	52.63
MG ₃	44.7	50.36	55.91

4.1.1 Effect of percentage of GGBFS

For MG₁, MG₂, and MG₃, the results showed a general increase in initial strength and final strength when the GGBFS content increased. The same was the result obtained by (**Chien-Chung, 2015**), in addition to high activity index to GGBFS make it good cementitious material to produce high strength concrete (**Nada and Zain, 2009**). However, great variability is found within the consequences. This is because that the GGBFS is the number one contributor to the initial strength, with the fly ash contributing to the strength gain with time. This is consistent with the reported information for alkali-activated materials that have been located to present excessive initial energy, which typically gains little further energy earlier than showing a discount in strength with time. This maximum possibly suggests that the hydration response has two viable mechanisms: (1) the hydration reaction of slag and the polymerization of fly ash is going on one after the other one, or (2) the two reactions are occurring concurrently (**Wardhono, et al., 2012**), (**Wardhono, et al., 2014**). In the first case, miles hypothesized that the GGBFS reacts first to form a matrix across the fly ash and the fly ash then fills within the pores to offer the increased power. In the second mechanism, the two reactions occur simultaneously with the GGBFS

reaction activating the fly ash even at the ambient temperature.

One of the main reasons GGBFS improved the compressive strength was the activity index that was higher than fly ash (Wrood h.,2020).

In addition to the role of calcium oxide in the chemical composition of slag, as an increase in this compound means an increase of calcium silicate hydrate gel and calcium aluminate, which increases the gel formed from slag (C-A-S-H) along with the gel formed from fly ash (N-A-S-H) leading to the microstructure becomes denser and the compressive strength increases in early ages (Mohammed H. et al.,2018) (Wrood h.,2020). Finally, for slag significant to enhance characteristic, it enabled reactions to take place at ambient temperature without heat curing. (Mohammed H. et al.,2018), (Omer Arioz, 2020).

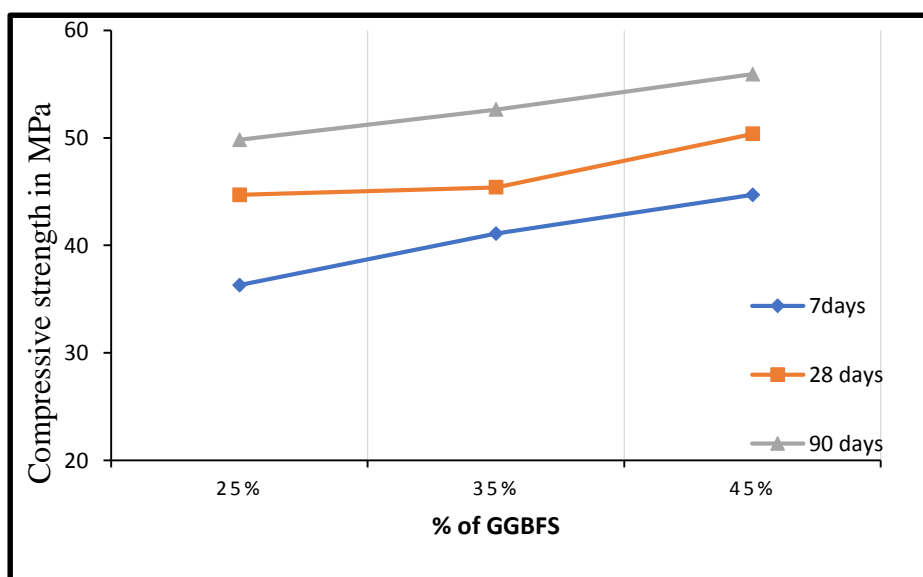


Figure 3. Relationship between compressive strength and percentage of GGBFS of geopolymer concrete mixes.

4.1.2 Comparison between normal concrete and geopolymer

Geopolymer specimens showed the best development in compressive strength at early ages compared to normal concrete, made with copper fiber of 0.5% percentage, because of differences in the formation process of products of fly ash-slag geopolymer concrete and normal concrete.

The formation process-induced products of geopolymer concrete called geopolymerization affect the temperature “higher than an ambient degree from 32 to 48 it’s the optimum range to reach higher strength” (Zaid, 2016). Normal concrete hydration would not need a high temperature in it. Results have good agreement with previous results (Joseph et al., 2012), and the heat curing provided higher strength values when the Na_2SO_3 dose was a higher percentage, which can be related to a further increased dissolution rate of the GGBFS and additionally accelerated chemical processes that are confirmed with (Abeer, 2019). Compressive strength showed a considerable uniform increase of strength until reaching 28 days. The addition of fine cementitious materials strengthened the concrete structure, which leads to blocking many voids in the concrete structure and reducing the absorption of the concrete, thus increasing the resistance and durability this conclusion was found by (Nada Mahdi Fawzi, 2009). It can be observed that geopolymer mixtures showed higher compressive strength than the normal concrete mixture, **Fig. 4.**

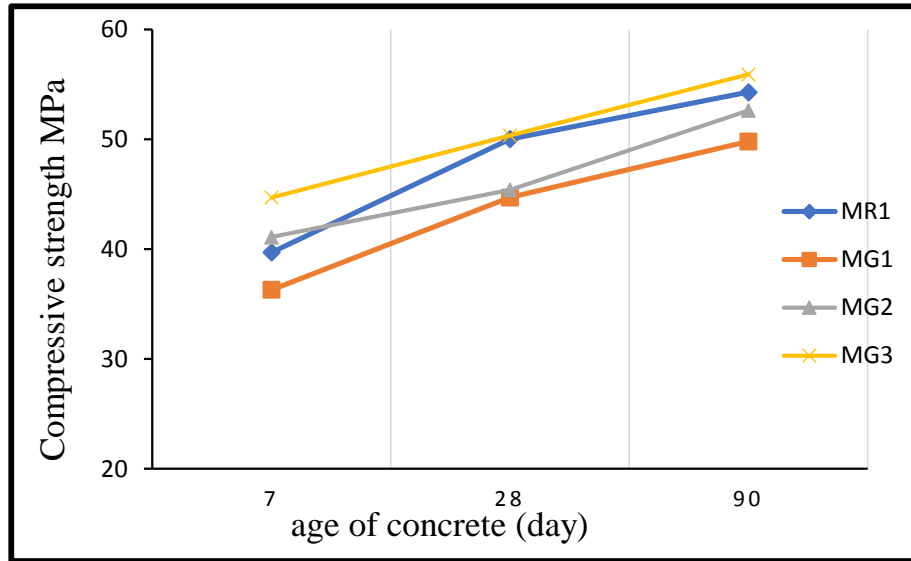


Figure 4. Relationship between compressive strength and age for normal and geopolymer concrete (MPa).

4.2 Splitting Tensile Strength

It is an indirect tensile test. The results are given in **Table 10** and **Fig. 5**. The optimum percentage of geopolymer compressive strength was used for this test which, at earlier ages, the geopolymerization process gives better properties for fly ash- slag 0.55:0.45 percentage-based geopolymer concrete. Splitting tensile strength at 7 days reached 76% of the maximum value at 90 days.

The ratio of splitting tensile strength to the compressive strength was 10.2 percent. This percent was higher than Portland cement concrete (9.7) percent which ranged (7-11) percent (**Neville, 2010**).

4.3 Flexural Strength

The flexural strength test method measures behavior of materials subjected to simple beam loading. Prisms (100×100×400) mm were used to conduct the test. Different ages tested (7, 28, 90) days. The results are summarized in **Table 11**. and **Fig 6**. The optimum mix MG3 adopted to study flexural strength when fly ash to slag is 0.55:0.45, respectively.



Table 10. Splitting tensile strength results for reference and geopolymer concrete.

Mix type	Splitting tensile (MPa)		
	Age of concrete (day)		
	7	28	90
MR ₁	3.3	4.5	5.32
MG ₃	4.4	5.4	5.73

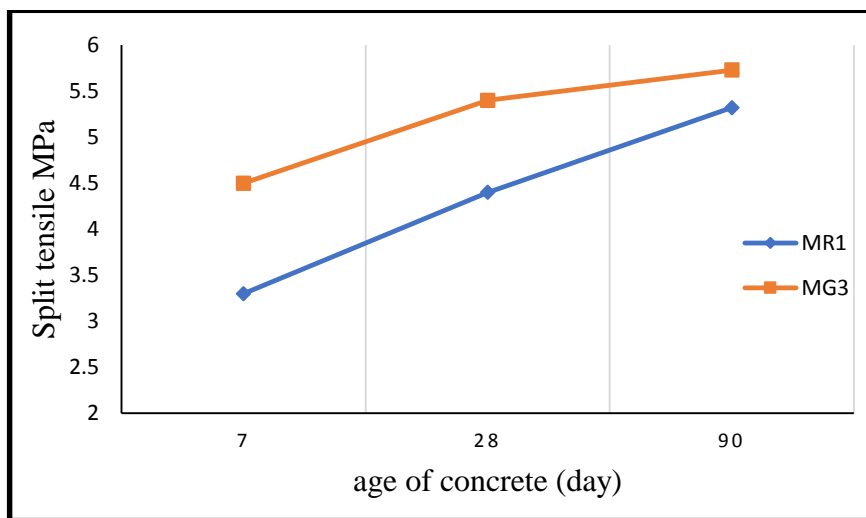


Figure 5. Relationship between Splitting tensile strength and age of concrete for reference and geopolymer concrete (MPa).

Table 11. Flexural strength results for reference and geopolymer concrete.

Mix type	Flexural strength (MPa)		
	Age of concrete (day)		
	7	28	90
MR1	3.33	4.8	5.48
MG3	4.41	5.8	6.16

The geopolymerization process continued with age, under appropriate heat of curing for the optimum mix strength to be improved. At seven days, only flexural strength reached 71 percent as



compared with the maximum value at 90 days. A ratio of flexural strength to compressive strength for geopolymer concrete (11.8%) was higher than normal concrete (10.09 %) (Neville, 2010).

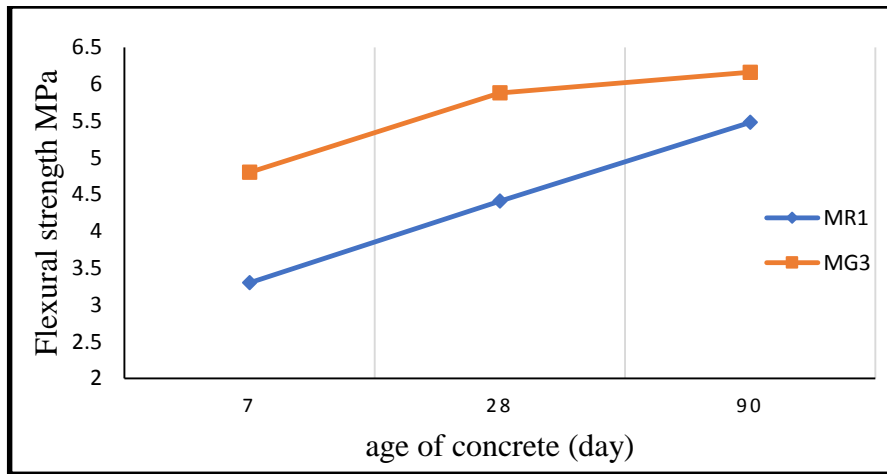


Figure 6. Relationship between flexural strength and age of concrete for reference and geopolymer concrete (MPa).

5. CONCLUSIONS

1. Sustainability is the solution to save the environment, economy, and society from various types of pollution, such as cement manufacturing that causes adverse effects of CO₂ emissions.
2. Geopolymer concrete based on fly ash and slag is one of the strong alternatives to normal concrete due to sustainable and varied constituents and properties superior to normal concrete.
3. Incorporating GGBFS in geopolymer concrete as a replacement of fly ash improves the mechanical properties and provides a variety of cementitious materials sources.
4. The mechanical properties of Geopolymer concrete can be improved by increasing GGBFS until it reached 45% slag and 55% fly ash with mix MG₃ that had the highest characteristics at all ages.



REFERENCES

- Abeer Mohammed Humad, December 2019. Shrinkage and Related Properties of Alkali-Activated Binders Based on High-MgO Blast Furnace Slag Building Material, Department of Civil, Environment and Natural Resources Engineering, Luleå University of Technology, SE-97187 Luleå, Sweden.
- Abhilash, P., Sasidhar, C., and Ramana Reddy I.V., 2017. Evaluation of Performance of Geopolymer Concrete in Acid Environment”, *International Research of Engineering and Technology (IJRET)*, vol.4 Issue: 7/July.
- ACI 211 4R, 2008. Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement and Other Cementitious Materials.
- Ahmed Mushrif Swaif, 2017. Production of geopolymer boards reinforced with carbon or polypropylene fiber, University of Technology, Building and Construction Engineering Department.
- Ambily P. S., Madheswaran C. K., Lakshmanan N., Dattatreya J. K., and Sathik SA., 2012. Experimental Studies on shear behaviour of reinforced Geopolymer Concrete thin webbed T-Beams with and without fibers *International Journal of Civil and Structural Engineering IJCASE* Vol. 3, No.1: pp 128–40.
- Arie Wardhonoa, David W. Lawb, Anthony Stranob, 2015. The strength of alkali-activated slag/fly ash mortar blend at ambient temperature, aUniversitas Negeri Surabaya, Kampus UNESA Ketintang, Surabaya 60231, Indonesia.
- ASTM C 192/C, 192M, 1998. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.
- ASTM C494 / C494M, 2005. Standard Specification for Chemical Admixtures for Concrete.
- ASTM C496, 2011. Standard Test Method for Splitting Tensile Strength for Cylindrical Concrete Specimens.
- ASTM C618, 2015. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.
- ASTM E291, 2009. Standard Test Methods for Chemical Analysis of Caustic Soda and Caustic Potash (Sodium Hydroxide and Potassium Hydroxide).
- BS 1881-118, 1983. Method for determination of flexural strength,
- Chien-Chung Chen, Ivan Diaz, Kathleen Menozzi, and Luis Muriloan, 2015. Experimental Study on Slag/Fly Ash Based Geopolymer Concrete, *International Journal of Mechanical and Production Engineering*, vol.3, Issue-8.
- EN BS 12390-4, 2000. Compressive strength specification for testing machine.



- Iraqi Specification, No. 5, 2019. Portland Cement, Ministry of Planning, Central Organization for Standardization and Quality Control.
- Iraqi Specification No.1703/(1992). Used water in concrete.
- Iraqi Specification, No.45/1984. Aggregate from Natural Sources for Concrete and Construction.
- John Newman, Ban Seng Choo, 2003. *Advanced Concrete Technology*, Department of Civil Engineering Imperial College London, ISBN 0 7506 5103 2.
- Linda Monfardini, Fausto Minelli, 2015, Experimental study of alkali activated concrete Structural applications .
- Liwei Yao, Degang Liu, Yong Ke, and Yuancheng Li, 2020. Synthesis and Hydration Characteristic of Geopolymer Based on Lead Smelting Slag, *International Journal of environmental research and public health*.
- Lloyd, N. A., and Rangan, B. V., 2010. *Geopolymer Concrete with Fly Ash*, Second International Conference on Sustainable Construction Materials and Technologies, Vol. 3, pp. 1493-1504.
- Mohammed H. et al., 2018. Effect of pozzolanic material on compressive strength of geopolymer concrete, *Kufa Journal of Engineering*, vol 9, no 3, p.p. 26-36.
- Nada Mahdi Fawzi, Zain Al-Aabidin Raauf, 2009. Pozzolanic Activity Index of local Feldspar, *journal of engineering*, university of Baghdad, college of engineering, no. 2, vol. 15.
- Nada Mahdi Fawzi, 2009. Producing high-performance concrete using different types of local pozzolans”, *journal of engineering*, university of Baghdad, college of engineering, no. 1, vol. 15.
- Nath P and Sarkar P. K., 2014. Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition, *Construction and Building materials Journal*, Vol. 66: pp 163–71.
- Neville, A.M., 2010. *Properties of Concrete*, 5th edition, Publisher: Prentice-Hall.
- Omer Arioz, 2020. Properties of slag-based geopolymer pervious concrete for ambient curing condition, materials Science and Engineering, DOI:10.1088/1757-899X/737/1/012068.
- Qais J., Frayyeh Ahmed M. Swaif, 2018. Mechanical properties of fly ash geopolymer mortar reinforced by polypropylene fiber, Department of Building and Construction



Engineering, Building Materials, *Engineering Journal of University of Babylon*, Engineering Sciences, Vol. (26), No. (1).

- Wardhono, A., Law D.W., and Molyneaux T.C.K., 2014. The mechanical properties of fly ash geopolymer in long term performance in The CIC 2014, Concrete Innovation Conference, Oslo, Norway.
- Wardhono, A., Law D.W., and Molyneaux T.C.K., 2012. Strength of alkali activated slag and fly ash-based geopolymer mortar, in *Microdurability 2012*, The 2nd International Conference on Microstructural-related Durability of Cementitious Composites, Amsterdam, Netherlands: RILEM Publications.
- Wood H. Sachet, 2020. Experimental investigation on compressive strength enhancement of geopolymer paste fly ash / slag based cured at ambient condition, *Diyala Journal for Engineering Sciences*, vol. 13, no. 02.
- Yifei Cui, Kaikai Gao, and Peng Zhang, 2020. Experimental and Statistical Study on Mechanical Characteristics of Geopolymer Concrete”, Center for Durability and Sustainability Studies of Shandong Province, Qingdao University of Technology, Qingdao 266033, China; Materials.
- Yost, J., Radlińska, A., Ernst, S., and Salera, M., 2012. Structural Behavior of Alkali Activated Fly Ash Concrete. Part 1: Mixture Design, Material Properties and Sample Fabrication. “Materials and Structures, vol 46, no. 3, pp. 435-447. Springer Nature, DOI:10.1617/s11527-012-9919-x.
- Zaid Ali Hasan, 2016. Effect of curing system on metakaolin based geopolymer concrete, *Journal of Babylon University/Engineering Sciences/ no. (3)/ vol. (24)*.
- Zaid Ali, 2016. Manufacturing and Studying Properties of Geopolymer Concrete Produced by Using Local Materials, University of Technology, Building and Construction Engineering Department.
- Zongjin Li, 2011. *Advanced Concrete Technology*, John Wiley and Sons, Inc., Hoboken, New Jersey, Published simultaneously in Canada.