Behavior of Geopolymer Concrete Reinforced by Sustainable Copper Fiber

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Abstract. The execution of sustainable expansion in civil engineering scope has led to the employment of new materials with a reduction in environmental influence. Ordinary Portland cement (OPC) is the essential material in the production of concrete traditionally. But, the industry of OPC causes environmental consideration by producing of CO\textsubscript{2}. Recycled fly ash and blast furnace slag, the most in common use industrially by-products and sustainable material as a replacement to Portland Cement, helps to reduce CO\textsubscript{2} in the atmosphere. This paper showed the results exhibit enhances in characteristics of two types of concrete. The geopolymer mixes had prepared using a blend of slag (ggbs) and low calcium fly ash class F, which act by alkaline solution. The mixture compositions of fly ash to slag were (0.75:0.25, 0.65:0.35, 0.55:0.45) %, respectively. Then select the best percentage between them that achieves the goal, which is to produce green concrete that is less expensive and environmentally friendly, and its mechanical properties higher than conventional concrete. Conventional concrete mix proportion 1:1.5:3 (cement: fine agg.: coarse agg.) Respectively. The copper fiber was used as recycled material from electricity devices waste such as (machines, motors, wires, and electronic devices) to enhance the mechanical properties of concrete and used with the percentage of 0.5% by volume of concrete for all mixes. The heat curing system at 40\textdegree}C temperature was used for geopolymer and water curing for normal concrete. The results revealed that the mix proportion of 0.45 blast furnace slag: 0.55 fly ash produced the best findings of strength and showed a denser and workable mixture.

Keywords: Geopolymer concrete; sustainable fiber; fly ash; alkaline solution; blast furnace slag.

1. Introduction.
Concrete is a primary component in building manufacturing; but, producing process of concrete has an important effect on global warming; that is because of the use of (OPC). Cement manufacturing is actually responsible for 6-7% of CO\textsubscript{2} emissions to the atmosphere. This production of OPC was over 3800 million tons in 2018. It revealed that the production of 1 ton of cement releases approximately 1 ton of CO\textsubscript{2} [1]. In recent years when the remarkable improvement of substances activated by alkalis as a replacement class of concrete. Which uses fly ash as a totally replacement of cement. Substances of alkali-activated are artificial powder with a high percentage in alumina and silica, which is soluble in high alkaline solution producing geopolymer concrete. Rest materials of the mix are coarse, fine aggregates, and more water for developing workability [2].

In order to decrease the environmental influences and high consumptions energy of methods manufacturing, cement has been conducted for finding alternatives to OPC. Between these investigations, substances activated by alkalis have significant attention nowadays. From an energy cost
and environmental point of view, substances of alkali-activated, which is considered the primary material of geopolymer concrete, are prepared to get nearly 80% less CO₂ than Portland cement [3]. That's lead to minimize the global warming potential to 70% less than Portland cement concrete. Concerning the concrete performance, the uses of substances of alkali-activated appear many advantages. For example, the polymerization process releases heat slower than the hydration process for Portland cement, the mechanical characteristics, in general, higher than cement basic materials, particularly the development of early strength, very well durabilities so reported like the best sulfate resistance and acid attack [4], developed freeze and thaw resistance through the refined pore structure [5], important high fire resistance [6], high resistance of chloride penetration, improved interface transition zones through aggregate and matrix [7,8]. Generally, geopolymer concrete showed great environmentally friendly replacement to ordinary Portland cement with similar and better performances [9]. The use of different types of fibers to strengthen concrete and improve its mechanical properties, especially the fibers resulting from electronic waste such as copper fiber [10], which is more toxic than other waste, and thus we will solve the problem of solid waste and get green concrete at the lowest cost and high resistance [11].

The objective of this study is to produce green, environmentally friendly fiber reinforced concrete from recycled industrial such as copper produced from electronic and electric devices and by-products like slag and fly ash. The most important goal is the environmental benefit is getting rid of the carbon dioxide produced by the cement industry and produce concrete with high strength and quality and less in cost.

2. Experimental work

2.1 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 (ggbs), with different percentages. The chemical composition of these substances is confirmed to ASTM C618[12].

2.2 Cement

The ordinary Portland cement produced in Kebisa factory is used for reference mixture. The chemical analysis and physical properties of the cement were used to confirm to the Iraqi specifications IQS No. 5/2019 type / (42.5 N) [13].

2.3 Water

Use water which confirmed to the Iraqi standards IQS No. 1703 [14], and use distilled water for preparing the alkaline solution for (NaOH).

2.4 Aggregate

The fine aggregate in this research used was natural sand supplied from Al-Eakhdar. 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 is within the requirements of the Iraqi Specification (IQS No.45/1984) [15].

2.5 Alkaline activator

The precursors activated uses an alkali solution. The alkali solution made by blend sodium hydroxide with anhydrous flakes forms and deionized water with sodium silicate solution, which available commercially.

2.6 Sodium hydroxide, NaOH

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

2.7 Sodium silicate, Na$_2$SiO$_3$
Sodium silicate used in study manufactured in the United Arab Emirates, The concentration of sodium silicate depended on the percentage of Na$_2$O to SiO$_2$ and H$_2$O.

2.8 Prepare the alkaline liquid
The sodium silicate solution is commercially available. In this research, using sodium silicate solution has a percentage of SiO$_2$ to Na$_2$O by mass equal (2). The proportions, by mass of ingredients, are SiO$_2$ = 31.5%, Na$_2$O = 14%, and water = 55.1%. The NaOH solution is added to the Na$_2$SiO$_3$ solution after it has been prepared as a solution. Until using in cast geopolymer concrete, the alkaline solvent should be prepared by combining all solutions for at least 24 hours [17].

2.9 Copper Wire Fiber
Copper wire is a sustainable fiber that got it from many applications of electronic and electrical devices, such as computer and whole accessories, windings of electrical machines, refrigerators, and other devices. The length of the fiber used was (15± 2) mm and diameter 0.25 mm, so the aspect ratio equal 60.

2.10 Superplasticizer
During this study, Glenium 51 superplasticizer (SP) was used to produce the required flowing ability and its chemistry, and 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 [18]. Types A and F, the quantity used in the study was 0.5 liter per 100 kg cement.

2.11 Mix design
In accordance with ACI 211-4R [19], design compressive strength was 50 MPa, the mix design ratio for reference mixture (cement: fine agg.:coarse agg.) mixture with ratio 1:1.5:3. Water to binder ratio was 0.45 for whole mixes. For geopolymer concrete, the mixing ratios were chosen by cast a group of experimental mixtures based on the previous experiments, and experimental mixtures were made in the laboratory in addition to completely replacing the existing cement in the reference mixture with pozzolanic substances and replacing the water with the alkaline solution, on this basis the best mixture was chosen. The mix compositions of fly ash to slag were (0.75:0.25, 0.65:0.35, and 0.55:0.45) respectively. Table 1 summarizes the mix design.

**Table 1. Mix design of geopolymer and reference concrete in (kg/m³).**

| Mix | Cement | FA: GGBS Ratio | GGBS | Fly ash | Sodium silicate solution | NaOH (%) by vol of conc. |
|-----|--------|----------------|------|---------|--------------------------|-------------------------|
| MR$_0$ | 395 | 605 | 1174 | 178 | - | - | - | - | 0 |
| MR$_1$ | 395 | 605 | 1174 | 178 | - | - | - | - | 0.5 |
| M$_2$ | - | 605 | 1174 | 3.95* | 0.75:0.25 | 98.75 | 296.25 | 118 | 59 | 0.5 |
| M$_3$ | - | 605 | 1174 | 3.95* | 0.65:0.35 | 138.25 | 256.75 | 118 | 59 | 0.5 |
| M$_4$ | - | 605 | 1174 | 3.95* | 0.55:0.45 | 177.75 | 217.25 | 118 | 59 | 0.5 |

*extra water (10% by weight of cementitious material) added to geopolymer concrete in addition to an alkaline solution to enhance workability [31].
3. Compressive strength test
The mixing for both reference and geopolymer concrete specimens was blended by a mixer. The mixes were cast in 100x100x100 mm³ cubes molds and compacted manually by rod for being closer to field pouring conditions and to guarantee that the specimens were free of air/voids. The geopolymer concrete specimens were cured for 24 hours at 40 degrees Celsius. After that, the reference specimens are stored in water at a temp. Of 20 ± 2 °C before testing time. Compressive strength measurement of cubes was carried out according to EN BS 12390-4:2000 [20] testing method on a Universal Testing Machine. For each data point, three cubes were prepared. At 7 and 28 days, after casting, the specimens were examined. The test was carried out until the concrete specimens failed.

4. Splitting tensile strength
Splitting tensile strength indicated the crack resistance of the concrete. It was measured indirectly. The test was performed according to the procedure of (ASTM C496) [21]. The tensile splitting strength test couldn’t be conducted as a direct tensile test due to difficulty conducting on concrete specimens. The average of two-cylinder specimens used for each data point with dimensions of 150 mm x 300 mm were poured and tested after 7 and 28 days of curing for each mix. The splitting tensile strength (T) is calculated by the following equation:

\[ T = \frac{2P}{\pi dL} \]  

where
- \( T \): Splitting tensile strength (MPa).
- \( P \): Max. applied load (N).
- \( d \): Cylinder diameter (mm).
- \( L \): Cylinder length (mm).

5. Flexural strength test
Flexural strength was measured using (ASTM C78) [22] (100x100x400) mm prisms. The basic beam bending formula is used to measure the flexural strength:

\[ R = \frac{PL}{bd^2} \]  

where
- \( R \): flexural strength (MPa).
- \( P \): Max. applied load (N).
- \( L \): Span length (mm).
- \( b \): specimen width (mm).
- \( d \): specimen depth (mm).

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

6. Workability
Workability is described as the convenience of handling freshly organizing concrete or mortar, and which its ability to be without problems in transporting, placing, and compacting with no segregation. Slump cone check turning into utilized in the research for assessing the workability following the ASTM C143-a15[23] fashionable. In this modern mission, the hunch of the freshly organizing concrete turned into determined as in step with ASTM.C143 standards, which is accepted via both subjects with atmospheric laboratory conditions.

7. Results and Discussions
7.1 Compressive Strength
The compressive strength results in Table 2 for both reference (with and without copper fiber) and geopolymer concrete specimens (with copper fiber) for all mixes and development of strength with age, respectively which represents in Figure 1.
Table 2. Compressive strength test results for reference and geopolymer concrete.

| Mix type | Age of concrete (days) |
|----------|------------------------|
|          | 7                      | 28                   |
| MR₀      | 30.7                   | 48.8                 |
| MR₁      | 39.7                   | 50.03                |
| M₂       | 36.3                   | 41.7                 |
| M₃       | 41.1                   | 45.4                 |
| M₄       | 46.7                   | 50.36                |

Figure 1. Relationship between compressive strength and age of concrete curing.

The MR₁ specimens show significantly increased strength than MR₀ specimen this due to the role of copper fiber in developing compressive strength, which works as bridges causes preventing or delay in creation of cracks and reduce the width of crack to a certain percentage of fiber because of more fibers addition would induce nonhomogeneous mix and form weak points which decrease compressive strength. The same conclusions were reached by reference [24,25]. The development in compressive strength after adding copper fiber to traditional concrete MR₁ increase by 29%, for 7 days more than MR₀ (normal concrete with no fiber). Geopolymer specimens M₂, M₃, M₄ show the best development in compressive strength at early ages, that's made by traditional concrete with the copper fiber of 0.5% percentage, that is because of differences in the formation process of products of fly ash-slag geopolymer concrete and OPC. The formation process-induced products of geopolymer concrete are polymerization that affects the temperature (higher than an ambient degree from 32 to 48). It's the optimum range to reach higher strength [26], while in OPC concrete hydration would not need high temperature.

Results have good agreement with previous results of reference [27], and the heat curing provided higher strength values when the Na₂SO₃ 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 reference [28]. Compressive strength shows a considerable uniform increase of strength until reaching 28 days, an addition of fine cementitious materials strengthens the concrete structure, which leads to blocking many voids in the concrete structure and reducing the absorption and porosity of the concrete, thus increasing the resistance and durability this conclusion found in reference [29].
7.2 Split tensile strength Test
The result in Table 3 and Figure 2, 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 reaches 81% percent of the maximum value at 28 days, the split tensile strength to the comp. Strength for fly ash-slag Geopolymer concrete was higher than traditional concrete by 1.2 times. The experimental results were confirmed with reference [31].

Table 3. Splitting tensile strength results for reference and geopolymer concrete.

| Mix type | Splitting tensile (MPa) | Age of concrete (days) |
|----------|-------------------------|------------------------|
|          |                         | 7          | 28          |
| MR₁      | 3.3                     | 4.5        |
| M₄        | 4.4                     | 5.4        |

![Figure 2. Relationship between splitting tensile strength and age of concrete.](image)

7.3 Flexural Strength Test
The flexure strength test method shows the behavior of materials subjected to simple beam loading. Prisms (100×100×400) mm were used to conduct the test. Different ages tested (7, 28) days. The results are summarized in Table 4 and Figure 3. The optimum mix M₄ adopted for studying flexural strength that the percentage of fly ash to slag is 0.55:0.45, respectively.

Table 4. Flexural strength results for reference and geopolymer concrete.

| Mix type | Flexural strength (MPa) | Age of concrete (days) |
|----------|-------------------------|------------------------|
|          |                         | 7          | 28          |
| MR₁      | 3.33                    | 4.8        |
| M₄        | 4.41                    | 5.8        |

The Geopolymerization process continues with age; under appropriate heat of curing for the optimum mix, strength gets improved. at 7 days, only flexural strength reaches 75 percent as compared with the maximum value at 28 days. A ratio of flexural strength to compressive strength for geopolymer concrete
was higher than traditional concrete (11.4%) [30]. The flexural strength to the compressive strength for Geopolymer concrete was higher than traditional concrete by 1.22 time. Figure 3 illustrates flexural strength developing with the time that is due to the role of copper fiber which reduces the number and width of crack [9].

![Figure 3](image-url)

**Figure 3.** Relationship between flexural strength and age of concrete.

Table 4 shows the experimental effects of flexural and compressive strength, which clearly demonstrates that rising compressive strength leads to an improvement in flexural strength. According to the experimental results, the bending resistance of geopolymer concrete reinforced with copper fiber was 4.4 and 5.8 MPa at 7 and 28 individually days age concrete dry heat curing for an optimum percentage of fly ash-slag that is 0.55:0.45 is 40°C. In addition, as compared to standard concrete, both mixes demonstrated quicker strength growth at 7 days. This improvement in flexural consistency is attributed to the fibers' restricting and bridging of cracks. This was also concluded by Vignesh et al. [32]. With respect to MR1, which had relatively high compressive strength but flexural strength was low, which related to micro-cracking within the binder matrix. This tendency same observed in PC based systems [33].

### 7.4 Workability

The slump varying among (230-245) mm for whole mixtures due to excessive NaOH amount and (240-250) mm for reference conventional concrete mixtures [25].

### 8. Conclusions

- The potential of copper fiber slag and fly ash to replace cement in concrete can potentially lessen the environmental effects over the manufacturing of CO₂.
- The workability of geopolymer concrete (after adding 10% extra water) is close to the workability of traditional concrete.
- Traditional concrete MR₁ (made with 0.5% copper fiber) demonstrates the highest preliminary compressive strength than one, which made from traditional concrete without fiber.
- Geopolymer mix M₄ (made through 45% slag and 55% fly ash) famous the highest compressive strength at 28 days.
- Split tensile strength and flexural strength for specimens contains fiber show higher results than normal specimens; additionally, whole geopolymer concrete shows higher results than traditional concrete.
Acknowledgments

This work carried out in the scope of "sustainable," to produce efficient concrete, to protect the environment from pollution and its benefits countries economy, and limits the housing problem in the manufacture of low cost and sustainable building units, and this research serves the Ministry of Construction and Housing, Ministry of Industry and Minerals because industrial waste (fly ash, ggbs, and copper fiber) is deposited of promising to be recycled and Ministry of Environment.

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