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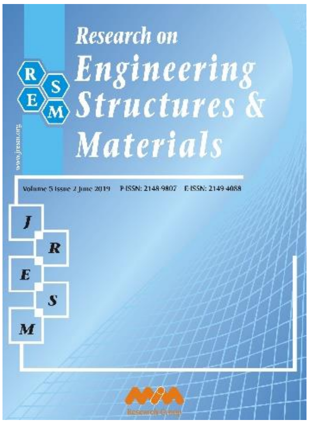

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Research Article

Performance evaluation of geopolymer concrete using E-waste and M-sand

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Abstract

This study has been conducted to diminish the carbon footprint of concrete and to assess the performance of geopolymer concrete by completely replacing river sand with Manufactured sand (M-Sand) and Electronic Waste (E-waste). Fly ash and Ground Granulated Blast Furnace Slag (GGBFS) are used in various combinations as a cementitious material in geopolymer concrete. The characteristic strength of geopolymer concrete is obtained by completely replacing fine aggregate with E-waste and M-sand with different percentages. An optimum percentage replacement is arrived at by studying the physical, chemical, and mechanical characteristics. The sizes of the E-waste particles used in this research are between 0.3mm and 0.15 mm and it has a deep colour with a specific gravity of 2.68. Maximum compressive strength of 35.8 N/mm^2 on 28 days is achieved for the optimal mix proportion of 80% fly ash, 20% GGBFS, 80% M-sand, and 20% E-waste as fine aggregate. Maximum flexural strength obtained is 6.54 N/mm^2 for mix proportion 1 and split tensile strength is 4.75 N/mm^2 resulted in mix proportion 2. The use of fly ash, E-waste, and M-sand in geopolymer concrete reduce the environmental pollution and depletion of natural river sand. The results of this experimental study very well match with Indian standards of concrete.

1. Introduction

The most popular artificial construction material on earth is concrete. Concrete is used in construction to build structures for thousands of years. The invention of high-strength concrete is a breakthrough in the field of materials used for construction. Usually, conventional concrete is associated with Portland cement as the main constituent for making concrete. In the modern world, most structures are built using concrete which creates a huge demand for concrete.

The disposal of e-waste is another worldwide environmental problem and public health issue [1]. Direct disposal of E-waste is not possible since it contains composite materials. Impacts of river mining include changes in floodplains profile, river hydraulics, sediments, and the climate [2]. To analyze the nature of binding with fine and coarse aggregates different proportions of binding materials added to the geopolymer concrete.

Global warming and climate change pose a threat to our environment. About 65% of global warming is due to the emission of CO_2, one of the greenhouse gases. Cement factories are accountable for around 6% of all CO_2 emissions. Approximately one ton of Carbon-di-oxide

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is released when one ton of Portland cement is produced. The term 'geopolymer' was coined by Davidovits in 1978 [3]. Geopolymer is synthesized from silicon and aluminium rich material either of the geological origin or industrial by-products like fly ash. Zeolite and geopolymer have similar chemical compositions but geopolymers exhibit amorphous microstructure and hence stronger compared to zeolites. Alkaline solutions aid the dissolution of Si and Al in the source materials and form a gel. The polymerisation process is quickened by curing at elevated temperatures.

The Egyptian pyramids were built using geopolymer methods of construction as presented by Davidovits in his research. Davidovits has proved that geopolymer material has good mechanical properties, high resistance to acidic solutions, and no alkali-aggregate reaction even in the occurrence of high alkalinity. Geopolymers are beneficial in structures exposed to harsh environments such as marine locations and sewers. Precast railway sleepers and hazardous waste encapsulation are some of the immediate applications of geopolymer concrete.

The geopolymer research work carried out by Palomo et al [4] is related to binder paste or mortar in a small size sample. The form of activator, curing temperature, and curing time were found to be the controlling factors for the mechanical strength of a fly ash-based geopolymer binder in their research. The alkaline solution to fly ash ratio had no influence. An increase in curing temperature has exhibited an increased compressive strength. Alkaline activator, which contains soluble silicates, reacts faster than the solution containing hydroxide only.

While Van Jaarsveld et al [5] ensured the importance of curing at a superior temperature for FA-based geopolymer material, they also insisted that curing for a prolonged period at superior temperature weakens the microstructure. Barbosa et al [6] stated that the total water quantity influences the characteristics of geopolymer binders, besides the chemical composition of the oxides employed as activators.

Lenin Sundar et al [7] studied the Geopolymer concrete with E-Waste as a partial replacement of fine aggregate. Their research is to replace the sand with E-waste at 10%, 20%, and 30%. 12 M Sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution are used as alkaline liquids. 90 % of fly ash and 10 % of GGBS are used as binders. He conducted the research to better understand the relationship between geopolymer concrete compressive and tensile strength and E-waste. It was discovered that substituting 20% E-Waste for standard geopolymer concrete of M40 grade resulted in a higher intensity. Mahaboob Basha et. al. [8], have studied the effect of E-waste and M-sand as a replacement for river sand and arrived at the optimum percentage level to improve the characteristic strength of geopolymer concrete, replaced with 10%, 20%, 30%, 40%, and 50 % of E-waste and M-sand as a fine aggregate, and find out the optimum percentage replacement.

Gayathri et al. [9] investigated the effect of e-waste in concrete on the mechanical properties of geopolymer concrete. In this study, e-waste was used to substitute sand in the following proportions: 0%, 10%, 20%, 30%, 40%, and 50%. Furthermore, the strength characteristics of geopolymer concrete cubes, beams, and cylinders with varying E-waste mix ratios were investigated. Balasubramanian et. al., [10], have studied the mechanical strength of cement concrete with E-Waste as coarse aggregate, partially replacing conventional coarse aggregate. Different forms of traditional concrete cubes were partially replaced with E-waste at a rate of 10%, 15%, 20%, 25%, and 30% to coarse aggregate with a water-cement ratio of 0.5.

The aim of Kale and Pathan [11] was to compare the strengths of concrete with fresh concrete, waste concrete, and E-waste concrete. Various mix ratios are adopted by varying

Cement, sand, and aggregates for a design mix M25. Krishna Prasanna [12] looked into the output of concrete that included E-waste as part of the coarse aggregate. In an experiment, specimens were prepared using E-waste as coarse aggregates in concrete up to 20% of the amount of traditional coarse aggregate. Sourav Kr. Das et al., [13], gave an overall view of the process and parameters which affected the geo-polymer concrete. It was found that geopolymer concrete made of fly ash as the binder or GGBS and fly ash as the binder, resulted in an 80% reduction in CO_2 emission compared to OPC, even though the alkaline solution pollutes the environment to some extent. Ganapati Naidu [14] studied the mechanical properties of geopolymer concrete using Class F fly ash and slag in different percentages. Sodium silicate and sodium hydroxide solutions were used as activators. With 28.57% replacement of slag, maximum compressive strength of 57MPa in 28 days in ambient curing and 43.56 MPa when cured in 500°C for 2 hours was attained.

The performance of geopolymer concrete with steel slag as coarse aggregate was investigated by Palankar and Ravi Shankar [15]. GGBFS-FA geopolymer concrete with steel slag coarse aggregates was made by substituting natural granite aggregates for 0%, 25%, 50%, 75%, and 100% of the time, and the mechanical properties of the concrete were investigated. Mechanical intensity had decreased slightly as a result of the experiment. The water absorption and volume of permeable voids of Geopolymer concrete with FA-GGBS as binder and steel slag as coarse aggregate had a little higher value but within permissible limits. Steel slag as coarse aggregate was satisfactory for structural and pavement applications. Felixkala and Partheeban [16] carried out an experimental study on high-performance concrete made using granite powder as fine aggregate. They have achieved the highest compressive strength that contains 25% granite powder.

Smit and Kearsley [17] studied the influence of paste content on the properties of HSC used in UTCRCP. Two pieces of concrete were tested. The paste quality of the first package was from 23 percent to 37 percent by quantity, using Multivariate Analysis in combination with a superplasticiser (SP) dosage. The paste quality of the second package was from 25 percent to 60 percent by bulk, with only differing SP dosage to monitor workability. It could be seen from the findings that the rise in the paste content of HSC usually has a negative effect. The paste content of HSC used in UTCRCP should be reduced while preserving reasonable workability. Kessy et al., [18] suggested the means of redrafting and incorporating the reliability requirements of every revamped edition of SANS 10100-2, taking into consideration both the prescriptive and the performance alternatives. Besides, a framework for designing sustainable standards suitable for the South African concrete industry is suggested and proposals for potential improvements are made.

Assaggaf et al. [19] proposed an experimental study to assess the effect of Accelerated Carbonation Curing (ACC) on the performance of two concrete mixtures of identical proportions but different cement materials (plain-cement and fly-ash-blended-cement). When ACC-treated specimens were exposed to sunlight, the intensity increased significantly, lasting up to seven days for plain concrete and up to 28 days for fly ash-blended concrete. ACC-treated concrete was found to have a slightly lower long-term strength than moist-cured concrete (15 percent for plain cement and 5 percent for fly ash-concrete). Nonetheless, the ACC-treated concrete mixtures' average output was comparable to that of the corresponding moist-cured concrete mixtures.

Kannan and Ganesan [20] investigated the fresh condition and mechanical properties of self-compacting concrete (SCC) made with binary and ternary cement mixtures of metakaolin (MK) and fly ash (FA), as well as the interrelationships between them. For this reason, various mixtures were prepared with different amounts of MK and fly ash by substituting 5 to 40 percent of ordinary Portland cement (OPC) for MK or FA. As a result of the increase in the proportion of MK, FA, and MK+FA, the mechanical properties of SCC increased considerably. It was observed that the specimen containing the ternary mixture of cement with 15 percent MK and 15 percent FA exhibited greater workability and mechanical properties than that of the standard SCC specimen without MK or FA.

Shinde et al. studied the mechanical properties of geopolymer concrete made from fly ash [21]. For preparing geopolymer concrete with fine fly ash, they used a 13 molar concentration solution. They also performed compression, split tensile, and flexural strength tests on specimens that had been cured in an oven at 110^{o}C for 7 hours and tested after 7 and 28 days.

Ahmet Emin Kurtoglu et al. [22] performed a report on the mechanical and toughness properties of fly ash and slag-based geopolymer concrete. The study's aim was to equate geopolymer concrete to traditional Portland cement concrete. Because of its more robust and strong cross-linked alumina silicate polymer structure, slag-based Portland cement concrete is found to be stronger and more reliable than fly ash-based geopolymer concrete in this report.

The review of the literature indicates that the construction sector will gain more importance soon due to economic and industrial development. Based on the literature review the following objectives are framed:

- To assess the mechanical properties of geopolymer concrete by replacing fine aggregate with M-Sand and E-waste and using different binders such as fly-ash and GGBFS.
- To investigate the durability of fly ash, GGBFS-based geopolymer concrete containing M sand and E-waste.
- To assess the maximum amount of E-waste that can be replaced without compromising strength.

The hypothesis of the research is to find out the relationship between various mix proportions of the concrete and the strength of the geopolymer concrete. The use of fly ash and GGBFS in geo-polymer concrete and replacing M-sand and E-waste in the place of fine aggregates drastically reduces the energy involved in producing the construction materials. Molarity of sodium hydroxide (NaOH) solution was chosen in the range of 14M. The ratio of activator solution-to-fly ash is used in this study is 0.40. Ambient curing is adopted. The aim of this research is to investigate the use of M-sand and E-Waste as a complete substitute for fine aggregate in Geopolymer concrete in order to reduce contamination, reduce natural river sand depletion, and allow use of non-biodegradable waste.

The use of M-sand and E-waste in place of fine aggregate, as well as fly ash, is the subject of an extensive experimental investigation on eco-friendly geopolymer concrete. In this experimental study, the alternative binders, fly ash, and GGBFS in the combination of (90:10), (80:20), (70:30), (60:40), and (50:50) percent are used. Fine aggregate is replaced by crushed granite called Manufactured sand **(** M-sand) and Electronic Waste (E-waste), which is almost impossible to dispose of and hazardous to the environment, in combinations of (90:10), (80:20), (70:30), (60:40) and (50:50) percent respectively. The general alkaline liquid used in geo polymerisation is a 2.5:1 mixture of sodium silicate (Na2SiO3) and sodium hydroxide (NaOH).

2. Properties of Materials

2.1. Properties of Fly ash and M-sand

Depending on the type of fly ash and its degree of reactivity, it is used in concrete. Fly ash is divided into two types: Class F (low calcium) and Class C (high calcium). Class F fly ash is used in this study, as described by IS 3812 (Part 1) [23], and the properties are mentioned in Table 1.

Table 1. Physical Properties of Fly Ash

Sl. No.	Test	Results	Requirements as per IS 3812
1	Normal consistency (%)	31.98	Not specified
2	Initial Settings time (min)	326	-
3	Final settings time (min)	513	-
4	Soundness (%)	0.6	0.8
5	Comparative compressive strength at 28 days (min) %	81.56	Not less than 80% of the strength corresponding to plain cement mortar cubes
6	Residue on 45-micron (max) %	25.56	34 and 50 (IS 3812(Part2)-2013

GGBFS may be used to make a strong concrete foundation when combined with ordinary Portland cement and/or other pozzolanic materials. GGBFS may be replaced with cement varying from 30 % to 85 %. The GGBFS used in this research is as per the BS: 6699-1992. Coarse aggregates used in this research are 20 mm and 12 mm and their properties are within the range as per IS 2386 (part 3 and part 4) [24 and 25]. Crushing granite stones to fine aggregate size results in Manufactured sand, which can replace the conventional one. Fine aggregate within the size of 4.75 mm to 0.075 mm is used in this investigation. Properties of M- sand are arrived at in confirmation to relevant code and tabulated in Table 2.

Table 2. Properties of M Sand

SI. No.	Properties	Values	Code used
1	Specific Gravity	2.72	IS:2386(Part 3)
2	Water Absorption	2.18 %	IS:2386(Part 3)
3	1.Bulk Density (Loose)	15561856Kg/m^3	IS:2386(Part 3)
	2.Bulk Density (Rodded)	17421856Kg/m^3	IS:2386(Part 3)
4	Silt Content by Volume	3.16 %	IS:2386(Part 2)
5	Bulkage	2.0 %	IS:2386(Part 1)
6	Moisture Content	1.41 Ton	IS:2386(Part 4)
7	Organic Impurities	Nil	IS:2386(Part 4)
8	Deleterious Materials		
	a) Clay Lumps	Nil	IS:2386(Part 2)
	b) Materials Finer than 75µ	Nil	IS:2386(Part 2)
9	Chloride	0.016 %	IS:2386(Part 1)
10	Sulphate	0.22 %	IS:2386(Part 1)

2.2. Properties of E-waste

Electronic wastes are generated from circuit boards of discarded electronic devices and toughened glass from display units. These waste materials, mostly printed circuit boards and glass in the pulverised form, are used in concrete to decrease environmental pollution. The sizes of the particle are in the range between 0.3 mm and 0.15 mm and have a dark colour. The most important process in this research is the collection and grinding of E-Waste into the required size. In this study, E-Waste replaces fine aggregate. E-waste products used in this investigation are outlined in Table 3.

Table 3. Properties of E-Waste

Sl. No.	Properties	Values
1.	Specific gravity	2.68
2.	Water absorption	0.121%
3.	Fineness modulus	2.507
4.	Bulk density (loose)	1856Kg/m^3
	Bulk density (rodded)	2089Kg/m^3
5.	Lead content	4.28
6.	Type	Crushed
7.	Grade	III

2.3. Properties of Alkaline Solution and Superplasticisers

For their consistency, sodium silicate and sodium hydroxide (NaOH) solutions are favoured over potassium silicate and a mixture of potassium hydroxide (KOH). 14M Sodium hydroxide (NaOH) solution is employed in this research. Auramix 500 is a polycarboxylic ether polymer-based superplasticiser, with long lateral chains. Upon mixing with concrete, the occurrence of electrostatic dispersion allows cement particles to separate each other. The above procedure reduces the water demand in making flowable concrete. It helps with high workability in manufacturing high-performance concrete. Auramix 500 complies with IS: 9103-1999 [26]. It also meets Type F and G of ASMT C494 [27], depending on the dosage used. The standard dose range is from 0.3 to 2.0 kg/100 kg of cemented material (see Table 4).

Table 4. Properties of Superplasticisers (Auramix 500)

Description	Parameter
Appearance	Light yellow coloured liquid
pH	Minimum 6.0*
Volumetric mass @ 200 C	1.100 ± 0.02 kg/litre
Alkali content	Typically, less than 1.5 g Na2O equivalent/litre of admixture.

2.4. Experimental Investigation

Davidovits [28] proposed combining the sodium silicate and sodium hydroxide solutions a day ahead of time. Table 5 shows the proportions of the blend used in fly ash replacement and GGBFS. The different mix quantities used to prepare geopolymer concrete are shown in Table 6. Fly ash and GGBFS are used in varying amounts as binding materials, while manufactured sand and electronic waste are used as fine aggregate.

Table 5. Mix Proportion Adopted for Various Design Mix

Sl. No.	Mix	Fly ash (%)	GGBFS (%)	M-sand	E-waste
1	M1	90	10	90	10
2	M2	80	20	80	20
3	M3	70	30	70	30
4	M4	60	40	60	40
5	M5	50	50	50	50

Table 6. Mix Quantity for 1M^3 for Concrete

Sl. No.	Materials	Mix1 (kg)	Mix2 (kg)	Mix3 (kg)	Mix4 (kg)	Mix5 (kg)
1	Fly ash	150	130	120	100	85
2	GGBFS	20	40	50	70	85
3	Coarse aggregate 20mm	280	280	280	280	280
4	Coarse aggregate 12mm	190	190	190	190	190
5	M-sand	271	247	214	185	152
6	E- waste	33	57	90	119	152

Dry mix with fly ash, GGBFS, and aggregates blended in a mixer machine for around 5 minutes. The alkaline solution is mixed with the dry mix for another 5 minutes. The cube and cylinder specimens are compacted by tamping each layer 35 times into three layers. Further specimens are compacted for 10 seconds using a vibrating table. Specimens such as cubes, cylinders, and prisms are cast and tested. After casting the concrete, a mix could be settled down in the moulds for 30 minutes.

Two forms of curing are used in this study, namely, curing at room temperature and curing for laboratory ovens at an elevated 60^{o}C temperature. The concrete is kept in the mould for 30 minutes. The specimens are permitted to cool in air, demoulded, and kept open until the day of testing. The specimens are kept at 60°C in the hot air to be cured; the geopolymer concrete experiences polymerisation processes when the specimens keep curing. The specimens are cured at elevated temperature and due to that, the concrete attains 70% of its strength within 3 to 4 hrs of curing. GPC's compressive strength depends on both curing time and temperature. Having a curing temperature in the range of 60°C to 90°C for 24 to 72 hours, the concrete's compressive strength can be obtained from about 400 to 500 kg.

2.5. Preparation of Tests Specimens

Specimens were cast in three layers, giving proper compaction. The specimens were demoulded and held at room temperature for 7, 14, and 28 days after casting. The test specimens such as a cube, cylinder, and prism are cast for studying the mechanical and chemical properties. Table 7 lists the measurements of the different specimens used in the current study. Specimens were designed according to the following testing conditions:

- Mix ratios used: M1, M2, M3, M4, M5.
- Curing duration: 7, 14, and 28 days.
- Concentration NaOH used: 14M.
- Curing: at room temperature.
- The ratio of alkaline activator solution-to-FA, by mass: 0.40.
- Mix Ratio: The trial ratio used 1: 1.84: 3.02.
- The ratio of sodium silicate -to-sodium hydroxide solution used: 1:2.5.

Table 7. Details of Specimen

Material Properties	Shape	Dimensions of the Specimens (mm)
Compressive Strength	Cube	150 × 150 × 150
Flexural Strength	Prism	100 × 100 × 500
Split Tensile Strength	Cylinder	100 × 150

2.6. Mechanical Properties of Concrete

A detailed experimental study on eco-friendly concrete that replaces fine aggregate with M-sand and E-waste was conducted. This investigation is performed with FA and GGBFS as binders in the combination of (90:10), (80:20), (70:30), (60:40) and (50:50) percent, respectively, and similarly fine aggregates are replaced in the same proportion by M-sand and E-waste. The strength of Geopolymer concrete in compression, tension, and flexure is found as per IS 516-1959 [29].

Compressive strength checks are carried out at 7, 14, and 28 days of age. Concrete resists compression and offers much less resistance to tension. Concrete roads subjected to flexural loading experience high tensile stresses. Flexural strength testing in the laboratory was carried out by beam test. According to IS 516-1959 [29], if the aggregate's largest nominal size does not exceed 20 mm, a prism of about 100 mm /100 mm /500 mm may be employed. Third point loading is used in a flexural strength test to replicate pure bending conditions. In the third point loading method, a crack may appear somewhere in the middle third of the span where the bending moment is maximum.

To determine split tensile strength of concrete, a Universal Testing Machine (UTM) with a capacity of 1000 kN, 100 mm diameter, and 150 mm height cylinder sample is used. Four-cylinder test specimens are averaged for split tensile power.

2.7 Durability Tests on Concrete

The durability of concrete is tested to ascertain its performance over time and in harsh climatic conditions. The following experiments were carried out to determine concrete's durability.

- Water Absorption
- The resistance of GPC blocks in 3% sulphuric acid.
- Residual Compressive Strength
- Residual Split Tensile Strength
- Change in Weight
- pH value of the solution

The water absorption test was carried out on 100 mm cubes according to ASTM C 642 [30] to determine the permeability characteristics of the geopolymer concrete over a span of 7, 14, and 28 days. Both the specimens which are cured at room temperature and 60°C are tested for the criteria for water absorption. The absorption percentage was calculated using equation (1). Table 8 shows the recommendations given by the Concrete Society Board.

$$\text{Absorption Percentage} = \frac{W2-W1}{W1} \times 100 \qquad (1)$$

where

W1 = Weight of specimen after complete drying at 105°C (kg).

W2 = Final weight of the surface dry sample after immersion in water (kg).

Table 8. Assessment Criteria for Absorption

Absorption (%)	Absorption Rating	Concrete Quality
<3.0	0	Low Good
3.0 to 5.0	Average	Average
>5.0	High	Poor

The durability of e-waste and M-sand geopolymer concrete under severe exposure conditions was tested by immersing 28 days ambient temperature and elevated temperature cured 15 cm concrete cubes in 3% H_2SO_4 solution. In-room temperature conditions, the acid immersion test was conducted, and the acid solution was regularly stirred to ensure consistency. To maintain a constant concentration at regular intervals, the acidic solution was substituted. The cubes were separated from the solution after 7, 14, and 28 days of immersion. The surface is dressed in a nylon brush to remove any loose material and allow the surface to dry. The weights of the cubes were compared to the weights of respective concrete geopolymer cubes before immersion. After 7, 14, and 28 days of acid immersion, the cubes were tested for residual compressive and tensile strength.

Hardened concrete ought to be alkaline. Reduction in alkalinity caused damage to concrete and therefore a pH of 28 days cured Geopolymer concrete was tested. The mortar portion of the hardened concrete was crushed to ≤ 4 mm size. 20 grams of crushed mortar sample was diluted in 200 ml demineralized water or distilled water (15°C). The liquid is stirred for ±10 min before measurement of pH using a pH meter.

3. Results and Discussion

Geopolymer concrete workability with fly ash and GGBFS as binders has been studied and the slump values for four mixes are given in Table 9. With the increase in concrete grade, the water-to-geopolymer solids ratio decreases, and hence the workability decreases. With the NaOH solution's increased molarity, the water content decreases, and hence the geopolymer concrete's workability is good. From Table 9, the mix of M1 is a higher slump value and gradually decreases the slump values with other mix proportions. This is due to adding a higher percentage of GGBFS, the binding is good.

Table 9. Slump Values for Different Grades

Sl. No.	Mix Designation	Slump(mm)
1	CM	120
2	M_1	112
3	M_2	110
4	M_3	104
5	M_4	100
6	M_5	98

4. Mechanical Properties

Strength of ambient cured GPC in compression, tension and flexure were evaluated at 7, 14, and 28 days of age using appropriate specimens and tested as per IS 516-1959 [29].

4.1. Compressive Strength

The side cube of 150 mm is used to check geopolymer concrete compression, and the specimens are filled before failure. The results were obtained from the tests conducted and presented in Fig. 1.

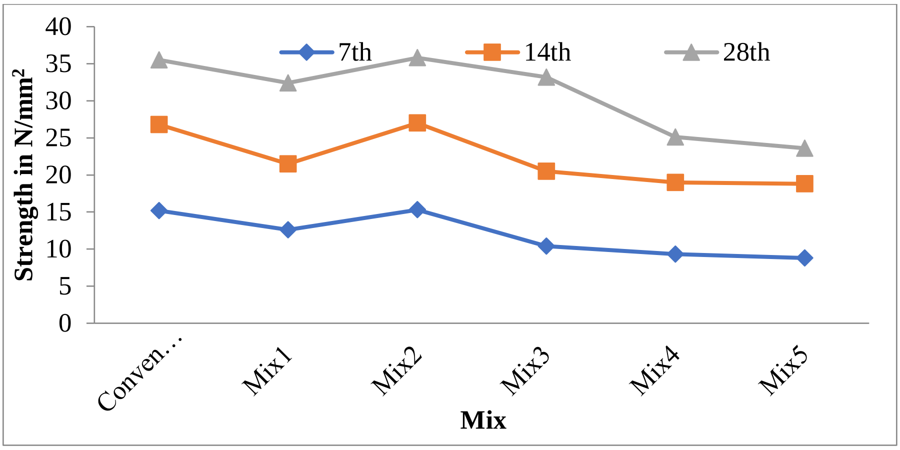

Fig. 1 Compressive Strength of Concrete

Mix 2 is more compressive than the other blends. At 28 days, the GPC compression power of Mix 2 is equivalent to standard concrete. For mix proportion 2, Figure 1 indicates that the compressive strength of the concrete increases as the concrete ages. The remaining amounts of the blend will be reversed. The maximum compressive strength of the E-waste and M-sand-based geopolymer concrete is 12.5 % less than the study results of Nagajothi Subramanian and Elavenil Solaiyan [31 and 32]. The low compressive strength is due to the addition of electronics waste in concrete.

4.2. Flexural Strength

Strength of GPC in flexure is tested using 500 x 100 x 100 mm prism specimen. The prism is then loaded at its centre point until failure. The flexural strength values obtained from the test are presented in Fig. 2.

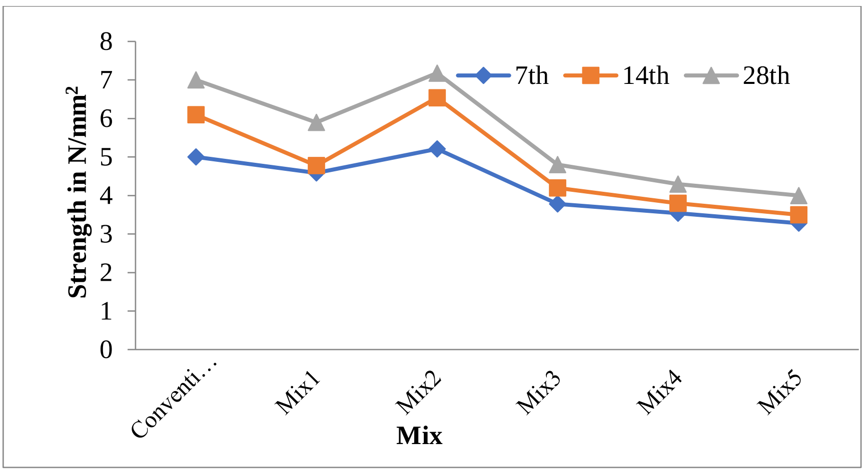

Fig. 2 Flexural Strength of Concrete

Mix 2 shows better flexural Strength than other mixes. Mix 2 and conventional concrete mix shows similar Flexural Strength of about 5 N/mm^2. Mix 1 too, yields better flexural strength approx. 5 N/mm^2 (on 7th day). The mix 2 proportion is achieved maximum flexural strength concerning the age of the concrete as like conventional concrete. The flexural strength of concrete results very well matches with results of [31, 32].

4.3. Split Tensile Strength

A 150 mm diameter and 300 mm height cylindrical concrete specimen is used to determine the split tensile strength. The cylinder is then subjected to a tensile load until failure. The Split tensile strength of all the blends was depicted in Figure 3. Split tensile strength is higher in Mix 2 than in the other blends. Mixes 3, 4, and 5 have low break tensile strength. Mix1, Mix2, and conventional concrete mix show similar split tensile strength of 3 – 3.5 N/mm^2 on the 7th day. Split tension test results are slightly higher than test results of [31, 32].

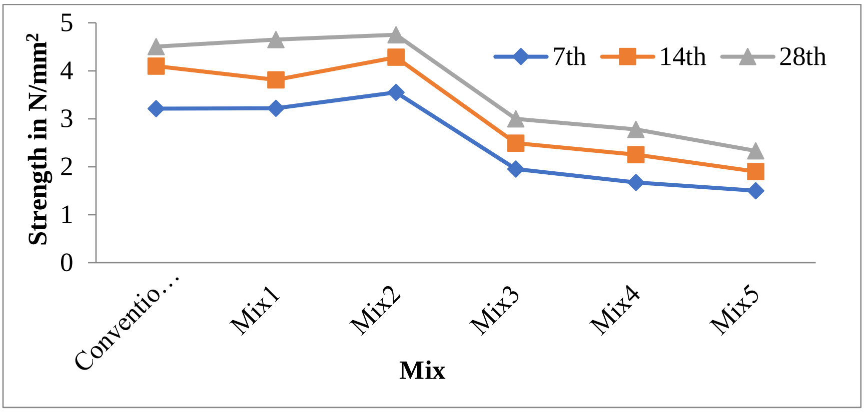

Fig. 3 Split Tensile Strength

5. Durability Properties

5.1. Water Absorption Test

The concrete cubes are immersed in water for 24 hrs and then the cubes are taken out and wiped, then weighed, again. The percentage of water absorption decreases with a rise in NaOH concentration from M1 to M4 as seen in Table 10.

Table 10. Percentage of Water Absorption of Concrete

Sl.No.	Mix	Weight of concrete before immersing water	Weight of concrete after immersed in water for 28 days	% of water absorption
1	Conventional Mix	8.82	8.90	4.50
2	Mix 1	8.70	8.79	4.24
3	Mix 2	8.48	8.60	4.15
4	Mix 3	7.81	7.80	3.85
5	Mix 4	7.66	7.79	3.74
6	Mix 5	6.79	6.96	3.44

5.2. Residual Compressive Strength

Cubes specimen are tested for residual compressive strength on the 7th, 14th, and 28th day of immersion in 3 % H2SO4 solution. The residual compressive strength of concrete with various mix ratios is depicted in Figure 4. The compressive residual strength of Mix 2 is higher than that of the other blends. Since E-waste combines slowly with an alkaline solution and reduces mortar binding strength, Mix 3, Mix 4, and Mix 5 have low residual compressive strength. Mix 2, which had the same compressive strength as traditional concrete at 28 days, had less residual compressive strength at 28 days than conventional concrete.

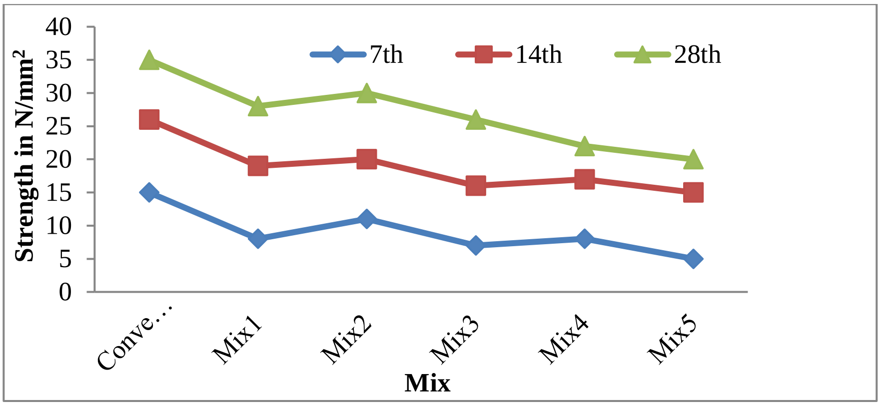

Fig. 4 Residual Compressive Strength

5.3. Residual Split Tensile Strength

The residual split tensile strength of a cylindrical concrete specimen with a diameter of 150 mm and a height of 300 mm is determined after immersion in acid for 7 days, 14 days, and 28 days. The cylinder is then subjected to tensile load until it fails. From the tests conducted, the results obtained are presented in Fig. 5.

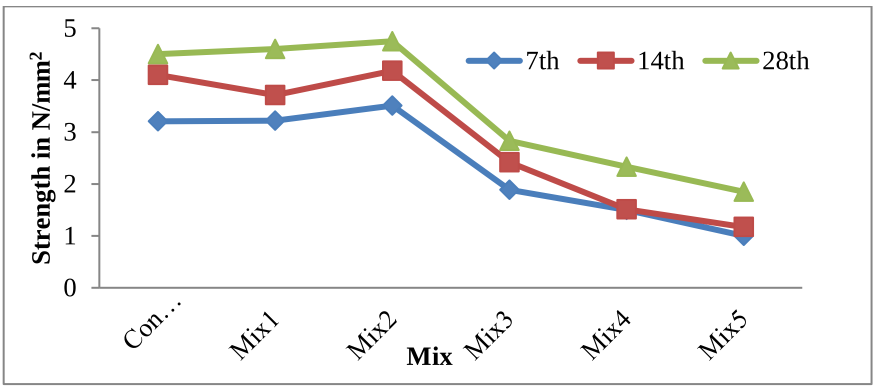

Fig. 5 Residual Split Tensile Strength

Mix 2 shows better split tensile strength than the other mixes. Mix 3, mix 4 and mix 5 show poor residual split tensile strength. Mix 1 and Mix 2 show similar split tensile strength of 3 – 3.5 N/mm^2 (on the 7th day).

5.4. Change in Weight and pH Value

The concrete cubes of various mixes are weighed in a weighing machine and compared with one another. pH measurements on the 28 days hardened mortar samples were measured, by diluting 20 grams of crushed ≤ 4 mm mortar sample in 200 ml demineralized water or distilled water (15°C). The total liquid is stirred for ±10 min before pH measurement and a pH meter is used for measuring pH values. Table 11 shows the change in weight and pH values of the specimen.

Table 11. Change in Weight of Concrete

Sl. No.	Mix	Mean Weight of Concrete in Kg	pH value
1	Conventional mix	8.88	12.80
2	Mix 1	8.74	12.62
3	Mix 2	8.5	12.58
4	Mix 3	7.33	12.46
5	Mix 4	7.68	12.41
6	Mix 5	6.86	12.37

The strength of the concrete is 35 N/mm^2 is above the standards of nominal concrete.

6. Conclusions

Eco-friendly concrete based on GGBFS and fly ash has gained strength at ambient temperature with an earlier period. High-temperature curing is eliminated due to adding GGBFS. Workability of E-waste and M-sand based geopolymer concrete is in the range 98 mm to 112 mm and it is less than the conventional concrete 120 mm when Geopolymer concrete's strength was more due to the higher percentage of GGBFS in the mix. Mix 1 had a higher compressive strength at first. Mix 2 was found to have a maximum compressive force of 35 N/mm^2 after 28 days. Furthermore, as the mix proportion is increased, the compressive strength of concrete reduces. The findings of the compressive strength test are consistent with those of other related tests. The results of the flexural and split stress tests were 7 N/mm^2 and 5 N/mm^2, respectively, and they were in fair agreement with other trials. Water absorption test results range from 3.44 % to 4.24 %, which is better than standard concrete water absorption.

Mix proportion 3, 4 and 5 show poor performance in all its experimental properties as E-waste steadily reacts with the alkaline solution and changes the colour of the concrete and does not allow the cementitious material to bind with one another. Thus, it results in lower strength of the hardened mortar. As a result, mix 2, consisting of 80 percent fly ash, 20 percent GGBFS, 80 percent M-sand, and 20 percent E-waste, is found to be the optimum mix proportion for eco-friendly concrete that provides outstanding strength and properties. Furthermore, geopolymer concrete made with GGBFS and fly ash has high compressive strength and is suitable for structural applications. Fine aggregates and binding materials are important in concrete but utilising many natural resources and polluting the environment. There are both environmental and economic benefits of using fly ash and GGBS. At this optimum ratio, the electronic waste used to create the binding device in concrete has environmental benefits. However, the use of E-waste is ecologically advantageous but economically fails. This study will be useful in many ways namely, reduces the carbon footprints, reduces the use of river sand, maximum use of fly ash, and environmentally friendly construction material. Hence this research can be highly useful to society to the large extent. Finally, E-waste, M-sand, and fly ash used in the concrete will bring better living conditions.

Nomenclatures

Al;	Aluminium
CO_2;	Carbon Dioxide
H_2SO_4;	Sulphuric Acid
KOH;	Potassium Hydroxide
NaOH;	Sodium Hydroxide
Na_2SiO_3;	Sodium Silicate
Si;	Silicon

Abbreviations

E-waste;	Electronic Waste
FA;	Fly ash
GC/GPC;	Geopolymer Concrete
GGBFS/GGBS;	Ground Granulated Blast Furnace Slag
M-Sand;	Manufactured Sand
OPC;	Ordinary Portland Cement
UTM;	Universal Testing Machine

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