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Experimental Investigation of Geopolymer Concrete with E-Waste

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Abstract: The major problem the world is facing today is the environmental pollution. The pollution effects on environment can be reduced by increasing the usage of industrial by-products in construction industry. Geo-polymer concrete in the present study, to produce the geo-polymer concrete in which Portland cement is fully replaced by fly ash and GGBS (Ground granulated blast furnace slag). Sand is replaced with E-Waste at 10, 20 and 30percentage. The alkaline liquids are used for the activation of these materials. The alkaline liquids used in this study are the solutions of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). Molarity of sodium hydroxide (12M) is considered.90 percent fly ash and 10 percent GGBS were used in this study. Rapid growth of technology and a high rate of obsolescence in the electronics industry have led to one of the fastest growing waste streams in the world, simply called as E-waste. The present study covers the use of E-Waste as partial replacement of fine aggregate in geopolymer concrete. This project work is to make and to study the compressive and tensile strengths of Geopolymer concrete and Geopolymer concrete with E-waste as a partial replacement of the fine aggregates ranging from 0 to 30 percentage, on the strength criteria of M40 of grade concrete. It has been proved that 20 percentage replacement of E-Waste achieved higher strength of geopolymer concrete than the normal geopolymer concrete. As per the results from the strength tests carried out the strength was found to be achieved with 20% replacement of E-Waste. Beam will be casted for this percentage and will be tested for flexure. SEM analysis test will be carried out for the specimen of increased strength.The experimental results were compared with the results obtained from Finite Element Analysis Software (ANSYS).

Keywords: *Geopolymer, Fly Ash, GGBS, E-Waste, Hardened properties*

1. Introduction

Concrete is the most widely used construction material in the world. Ordinary Portland Cement (OPC) has been traditionally used as the binding material for concrete. The manufacturing of OPC requires the burning of large quantities of fossil fuels and decomposition of limestone which results insignificant emissions of carbon-di-oxide (CO_2) to the atmosphere. This CO_2 emission is the main cause for global warming, which have become a major concern. In order to reduce this, Geopolymer technology was introduced. New electrical and electronic products have become an integral part of our daily lives providing us with more comfort, security, easy and faster acquisition. Due to technological growth, there is a high rate of obsolescence in the electronic equipments which leads to one of the fastest growing waste streams in the world. This waste stream consists of end of life electrical and electronic equipment products. The European Union (EU) defines this new waste stream as Waste Electrical and Electronic Equipment (WEEE). Since there is no definition of the WEEE in the environmental regulations in India, it is simply called E-waste. E-waste encompasses ever growing range of obsolete electronic devices, such as computers, servers, main frames, monitors, TVs and display devices, cellular phones, calculators, audio and video devices, printers, scanners, copiers, refrigerators, air conditioners, washing machines, microwave ovens, electronic chips, processors, mother boards, printed circuit boards (PCBs), industrial electronics such as sensors, alarms etc.., Electronic and electrical equipment's are made up of several components, many of which contains toxic substance, like lead, chromium, mercury, beryllium, cadmium, acids and plastics etc.

The processing of electronic waste in developing countries causes serious health and pollution problems due to electronic equipment contains serious contaminants such as lead, Cadmium, Beryllium, Arsenic, Mercury, Nickel, Silver, Zinc, Copper, Chrome, Cobalt etc. Pollutants or toxins in e-waste are typically concentrated in circuit boards, batteries, plastics and LCDs (liquid crystal displays). This paper deals with the nonhazardous and inert components of E-waste generated out of Obsolete Computers, TV Cabins, Refrigerator, Mobile phones and washing Machine etc. Postconsumer components of above mentioned appliance have traditionally been disposed off either in domestic refuse, which ends up in landfill, were collected in designated collection spots for reuse or recycling. Iron and Steel are the most common materials found in electrical and electronic equipments and amounts to nearly half of the total weight of WEEE. Plastic are the second largest component by weight representing nearly 21 % of WEEE. Since many research works were carried out using E-Waste as a partial replacement of coarse aggregate. The major objective of this project is to reduce as far as possible the used and discarded electronic and electrical equipments and convert waste into socially and industrially beneficial and used raw material with low cost and environmental friendly technology.

2. Geopolymer Concrete

Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in byproduct materials such as fly ash, blast furnace slag, and rice husk ash to produce binders. Unlike ordinary Portland cement, Geopolymer do not form calcium silicate hydrates for matrix formation and strength but utilize the polycondensation of silica and alumina to attain strength. Two main constituents of Geopolymers are source materials and alkaline liquid. The source material should be alumino-silicate based and rich in both silica and alumina. In Geopolymer concrete, supplementary cementing materials such as Fly ash, Silica fume, Rice husk ash, Ground Granulated Blast furnace Slag (GGBS) and metakaolin are used as alternative binders to Portland cement. In this project, Fly ash and Ground Granulated Blast furnace Slag (GGBS) are used as alternative binders.

Geopolymer is an excellent alternative which transform industrial waste products like GGBS and fly ash into binder for concrete. Geopolymer binders are used together with aggregates to produce geopolymer concrete. They are ideal for building and repairing infrastructures and for pre-casting units, because they have very high early strength. Their setting times can be controlled and they remain intact for very long time without any need for repair. Geopolymer, with properties such as abundant raw resource, little CO_2 emission, less energy consumption, low production cost, high early strength and fast setting. Geopolymer concrete is inorganic polymer composites, which are prospective concrete with the potential to form a substantial element of an environmentally sustainable product by replacing the Conventional concrete. The major benefit of the geopolymer is polymer is making use of industrial products.80% to 90% reduction in CO_2 emission can be achieved by the replacement of ordinary Portland cement (OPC) with geopolymer cement.

Geopolymer indicates transformation of geomolecules through geochemical process during diagnosis and can be classified into two major groups, pure in organic and organic containing synthetic analogues of naturally occurring macromolecule. Geopolymers as initially proposed refers mainly to pure inorganic material but could be extended to include geomaterials with organic content. It is therefore important during geopolymerisation to consider cross link between inorganic and organic species. It has good potential for production of green concrete and construction material with lower carbon foot print. Geopolymer technology has wide variety of applications in the field of industries such as automobiles, aerospace, metallurgy, civil engineering and plastic industries. It is used for coating and adhesive new binder for fiber composites, waste encapsulation and new cement for concrete.

2.1 Constituents of Geopolymer Concrete

The Constituents of Geopolymer concrete are listed below.

(1) Fly ash
(2) Ground Granulated Blast furnace Slag (GGBS)
(3) Alkaline activators

Fly ash is a finely divided residue resulting from the combustion of pulverized coal. Class F fly ash is adopted and is pozzolonic in nature. Class F fly ash requires a cementing agent such as Portland cement, quicklime or hydrated lime mixed with water to react and produce cementitious compounds. Adding a chemical activator such as sodium silicate (water glass) to a Class F ash can form a geopolymer.

Granulated Blast furnace Slag (GGBS) is obtained by quenching molten iron slag (a by-product of iron and steel making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. It has almost the same particle size as cement. GGBS is often blended with Portland cement as low cost filler, enhances concrete workability, density, durability and resistance to alkali-silica reaction. Alternative but promising gainful utility of FA and GGBS in construction industry that has emerged in recent years is in the form of Geopolymer cement concretes which by appropriate process technology utilize all classes and grades of FA and GGBS; therefore there is a great potential for reducing stockpiles of these waste materials. It is possible to make open air cured geopolymer paste with the combination of fly ash and GGBS.

The most common alkaline solution used in geopolymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (K_2SiO_3). In this project, the combination of Sodium hydroxide and Sodium silicate is preferred. Alkaline liquids are prepared by mixing of the Sodium hydroxide and Sodium silicate solutions at the Room temperature at least one day prior to adding the liquid to the dry materials. Sodium hydroxide is available in solid state by means of pellets and flakes. The cost of Sodium hydroxide is mainly varied according to the purity of the substance. In this project, Sodium hydroxide pellets is used. Sodium silicate is also known as water glass or liquid glass. It is available in liquid (gel) form. Silicates were supplied to the detergent company and textile industry as bonding agent.

3. Materials

3.1 Fly Ash

Fly ash is a byproduct of electricity producing plant using coal as fuel. It is obtained in the form of powder. It is a good pozzalona the colour of fly ash is either grey or blackish grey.The chemical composition is mainly composed of the oxides of silicon (SiO_2), aluminum (Al_2O_3), iron (Fe_2O_3), and calcium (CaO), whereas magnesium, potassium, sodium, titanium, and sulphur are also present in a lesser amount.

3.2 Ground Granulated Blast Furnace Slag (GGBS)

Granulated Blast furnace Slag (GGBS) is obtained by quenching molten iron slag (a by-product of iron and steel making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder.

3.3 Alkaline Activators

The combination of Sodium hydroxide and Sodium silicate is used as the alkaline activator in this study. Alkaline liquids are prepared by mixing of the Sodium hydroxide and Sodium silicate solutions at the room temperature at least 24 hours prior to use.

3.4 Super plasticizer

Conplast SP430 is a chloride free, superplasticising admixture based on selected sulphonated naphthalene polymers. It is used where a high degree of workability is required and to facilitate production of high quality concrete of improved durability and water tightness.

3.5 E-Waste

Rapid technology change, low initial costs have resulted in a fast growing surplus of electronic waste around the globe.E- waste available in the form of loosely discarded, surplus, obsolete, broken, electrical or electronic devices from commercial recyclers have been collected which were crushed to the particle size. The physical properties are given in Table 1.

3.6 Fine Aggregate

Fine aggregate is a naturally occurring granular material composed of finely divided rock and mineral particles. The locally available River sand of grade II conforming to the requirements of IS 383 is used. The physical properties are given in Table 1.

3.7 Coarse Aggregate

Coarse aggregates are produced by disintegration of rocks and by crushing rocks. Coarse aggregates are usually those particles which are retained on an IS 4.75mm sieve. The physical properties are given in Table 1.

Table 1 *Physical Properties*

Tests	E-Waste	Fine Aggregate	Coarse Aggregate
Specific gravity	2.38	2.67	2.66
Fineness modulus	2.9	2.25	3.2

4. Experimental Program

4.1 Mix Design

As the Geopolymer concrete are new construction materials they don't have any standard mix design. To identify the mix ratios for different grades of Geopolymer Concrete the trial and error method is followed shown in Table 2. To identify the best mix or optimum mix for the Geopolymer with E-Waste the various parameters and ingredients are varied. The parameters changed in the mix proportions are Density, Molarity and percentage ratio between the Fly ash and GGBS. Design of geopolymer concrete mix, coarse and fine aggregates together were taken as 75%-80% of entire mixture by mass. The density is 2400 kg/m^3.The Molarity or the concentration of sodium hydroxide pellets solution is 12M. And the major parameter is the ratio between the Fly ash and GGBS which is fully replaced for ordinary cement and the percentage is varied in range of 90 percent and 10 percent.

4.2 Mix Ratio

According to B V Rangan (2010) procedure

Mix Ratio 1**:** 90%FLY ASH + 10%GGBS and 100% FA
Mix Ratio 2**:** 90%FLY ASH + 10%GGBS and 90% FA + 10% E-WASTE
Mix Ratio 3**:** 90%FLY ASH + 10%GGBS and 80% FA + 20% E-WASTE
Mix Ratio 4**:** 90%FLY ASH + 10%GGBS and 70% FA + 30% E-WASTE

Table 2 *Mix Proportion*

Mix	Binder Kg/m^3		FA (Kg/m^3)		CA Kg/m^3	NaOH (12M) Kg/m^3	Na_2SiO_3 Kg/m^3
	Fly Ash	GGBS	FA	E-Waste			
M1	354.8	39.43	554.4	0	1293.6	45.06	112.6
M2	354.8	39.43	498.9	55.44	1293.6	45.06	112.6
M3	354.8	39.43	443.5	110.88	1293.6	45.06	112.6
M4	354.8	39.43	388.0	166.32	1293.6	45.06	112.6

Extra Water =39.4
Liquid/binder ratio =0.40
Water /geopolymer solid ratio = 0.21
Ratio of mixture proportion =1: 1.405:3.2
Super plasticizer = 5.91

5. Results and Discussion

5.1 Compressive Strength Test

As per IS 516(1959) the concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours these moulds are removed and test specimens are put in water for curing. The top surface of this specimen should be made even and smooth. This is done by putting cement paste and spreading smoothly on whole area of specimen. These specimens are tested (Fig.1) by compression testing machine after 7 days curing and 28 days curing. The test results are given in Table 3 and Table 4**.** The graph is plotted for the 7th and 28th day result as shown in Fig.2

f_{cy} = Load at Failure/ Area of cross section

Fig. 1 *Compressive Strength*

Table 3 *Compressive Strength on 7th Day in N/mm^2*

Mix Specification	Percentage Of E-Waste	7th Day N/mm^2
Mix 1	0 Percent	23.11
Mix 2	10 Percent	17.55
Mix 3	20 Percent	28.2
Mix 4	30 Percent	16.59

Table 4 *Compressive Strength on 28th Day in N/mm^2*

Mix Specification	Percentage Of E-Waste	28th Day N/mm^2
Mix 1	0 Percent	28
Mix 2	10 Percent	19.83
Mix 3	20 Percent	32.13
Mix 4	30 Percent	22.67

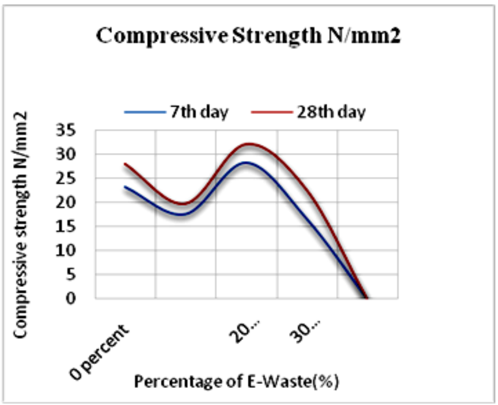

Fig. 2 *Chart for Compressive Strength*

5.2 Split Tensile Test

The splitting tests are well known indirect tests used for determining the tensile strength of concrete cylinders also referred as split tensile strength of concrete. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontally(Fig.3) Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. The magnitude of this tensile stress f_{sp} is given by the formula (IS : 5816-1970).The test results are given in Table 5 and Table 6.The graph is plotted for the 7th and 28th day result as shown in Fig.4

fsp= 2P/πdl N/mm^2

Fig. 3 *Split Tensile Strength Test*

Table 5 *Split Tensile on 7th Day in N/mm^2*

Mix Specification	Percentage Of E-Waste	7th Day N/mm^2
Mix 1	0 Percent	2.83
Mix 2	10 Percent	1.83
Mix 3	20 Percent	3.06
Mix 4	30 Percent	1.22

Table 6 *Split Tensile on 28th Day in N/mm^2*

Mix Specification	Percentage Of E-Waste	28th Day N/mm^2
Mix 1	0 Percent	2.92
Mix 2	10 Percent	2.21
Mix 3	20 Percent	3.11
Mix 4	30 Percent	1.69

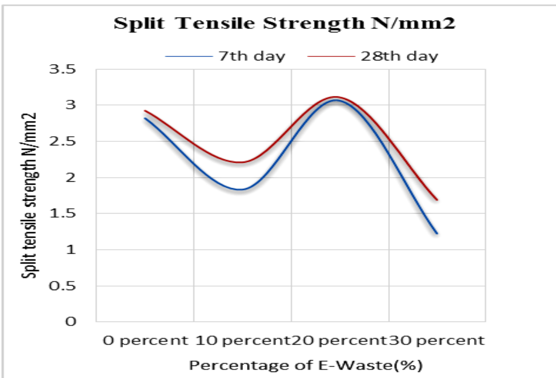

Fig. 4 *Chart for Split Tensile Strength*

5.3 Flexure strength test

The Flexure strength test of Geopolymer Concrete using the optimal percentage value of ewaste was conducted. The strength test was conducted using Beam (1000 x 200 x 100 mm)specimens for 28 days. As expected, the flexural cracks are initiated in the pure bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. In the case of beams with larger tensile reinforcement ratio some of the flexural cracks in the shear span turned into inclined cracks due to shear effect of shear force. Near peak load the beam deflected significantly, thus loading that the tensile steel must have yielded at failure. The final failure of the beams occurred when the concrete in the compression zone crushed, accompanied by buckling of the compressive steel bars. The failure mode was typical of that an under reinforced concrete beam.

The table below shows the results,

Table 5 *Flexure strength results*

Load (kN)	***Deflection (mm)***	***Load (kN)***	***Deflection (mm)***
0	0	0	0
10	0.18	10	0.3
20	1.33	20	1.5
30	2.52	30	3.15
40	3.25	40	3.56
50	4.02	50	4.57
55	4.55	58	5.23
52	12.3	55	10.23

The graph below shows the flexural variations,

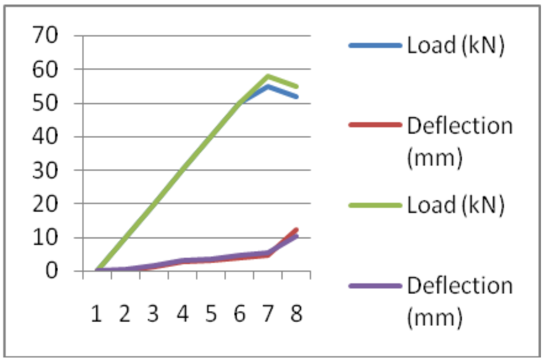

Figure 5 *Flexure strength graph*

6. Conclusion

The Geopolymer mix planned for this study with replacement of E-Waste found possible and economical. In this study the cement is fully replaced by industrial by-products fly ash and GGBS. The following points are arrived from the present study.

- From the past studies it has been proved that using E-waste doesn't affect the properties of geopolymer concrete majorly.
- Geopolymer concrete with E-Waste gives high compressive and tensile strength than conventional geopolymer concrete.
- Compressive and split tensile strength of geopolymer concrete increases by 20 percentage replacement of E-Waste in fine aggregate.
- Use of E-waste as partial replacement of fine aggregate is economical and can be easily used as fine in geopolymer concrete.
- Reuse of E-waste reduces environmental hazards and protects from the toxic substances.
- Increase in E-waste as fine aggregate reduces the strength of concrete.
- Partial replacement of E-waste as fine aggregate proved as well graded aggregate and recent technique for disposal of non-metallic E-Waste.
- Geopolymer concrete represent as a "Green concrete" and also as a "Eco-friendly concrete" as it reduces the CO_2 emission in the world and usage of fly ash reduce the water content.

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