COMPRESSIVE STRENGTH OF FLY ASH-BASED GEO-CONCRETE WITH RECYCLED E-WASTE AS A PARTIALLY REPLACED COARSE AGGREGATES

Sagarika Panda[1], M. L. Narasimham[2], and Ramakanta Panigrahi[3]*

[1]Ph.D Scholar, Centurion University of Technology and Management, Odisha, India
sagarikapanda1988@gmail.com
[2]Adjunct Professor, Centurion University of Technology and Management, Odisha, India.
hammln.47@gmail.com
[3] Professor, VSSUT, Burla, Odisha, India
rosy.sibun@gmail.com

ABSTRACT

This research details the mechanical characteristics of geo-concrete and geopolymer concrete based on ground granulated blast furnace slag (GGBFS) and fly ash (FA) with partial substitution of E-wastes as coarse material. A concrete mixture including OPC was used as a point of comparison to test E wastes' impact on geopolymer. The results of using various amounts of E wastes instead of coarse aggregate in cement-based and cement-free concrete were discussed. The experiment used 12 M sodium hydroxide and 2.5 M sodium silicate at a consistent ratio. The ratio of solution to binder in all geopolymer concrete experiments was 0.45. To make productive use of industrial and electronic waste, this research presents experimental data on the compressive strength of green concrete impacted by GGBFS and made from fly ash. The experimental batch was contrasted with the baseline. Geopolymer concrete with 20% GGBFS and 80% fly ash achieved maximum compressive strength, i.e., 36.4 MPa, after 28 days without any hot oven curing. However, with an increase in E-waste content, the concrete deteriorates in compressive strength. However, replacing up to 15% of the coarse aggregate with E trash is a more efficient approach to handling E-waste without significantly weakening the final product. The research also shows that up to 15% of the coarse particles in regular concrete may be made out of E trash. Because of its reduced strength, this material qualifies as "lean concrete."

***Key words**: Fly Ash; GGBFS/GGBS; E Waste; Compressive Strength; Geopolymer Concrete*

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INTRODUCTION

"Concrete as a Construction Material" ranks first as an artificial material. In modern infrastructures, concrete is the only material used when high compressive strength with lower cost is required. It is essential in developing countries like India, where demand for concrete is increasing exponentially due to growth in construction. High energy consumption is required to manufacture cement, the only material responsible for bonding between the inert aggregates. Furthermore, much carbon dioxide is released throughout production, increasing the structure's carbon footprint. So here, geopolymer is used as a replacement for conventional concrete. In addition, as the demand for binders rises, so does the demand for natural aggregates.

We cannot escape electronic waste in the 5G age, which produces geo-environmental difficulties that are a source of concern. According to Bhubaneswar Municipality Corporation (BMC) officials, almost 2,700 tonnes of electronic garbage are generated yearly. According to the survey, institutions, and offices generate the majority of e-waste. Reducing and reusing garbage is always a better method to handle solid waste. The study aims to find a way to reuse recovered E-waste without compromising compressive strength. People are becoming increasingly glued to electronic devices. We increase the number of electronic devices in our lives regularly. Everything from a phone, a television, a washing machine, and a trimmer. Technology is now essential to maintaining our standard of living. Technology is increasingly integrated into our everyday routines. The Waste from Electrical and Electronic Equipment (WEEE) directive classifies ten different types of electrical and electronic equipment (E-waste) that people throw away: large household appliances, electrical and electronic tools, small household appliances, consumer equipment, lighting equipment, information technology (IT) and telecommunications equipment, toys, leisure and sports equipment, medical devices, automatic dispensers, and monitoring and control instruments. For us, gadgets are constantly improving or changing.

As a result, some sectors recycle or reuse it to prevent land disposal issues, while some industries have begun using green electronics to combat leaching hazards. However, because the majority of electronic components are single-use only, the problem of e-waste generation and disposal still needs to be solved. Research is being conducted on creating concrete without using traditional ingredients such as cement, as well as using waste resources to the greatest extent possible. E-waste is employed in various amounts, with aggregates replaced in this study to lower the cost of recycling and disposal of E-waste. This also helps to prevent pollution caused by heavy metal ions leaching from E-waste. According to the study, because natural resources are dwindling and there are no viable alternatives to concrete, we must make concrete green and use sustainable materials. The activation of wastes such as FA and GGBS from thermal power plants and steel plants, respectively, is the primary source of geopolymer binder. This study discusses how E wastes are used in traditional waste management. It reduces environmental pollution caused due to leaching of heavy metal ions from E wastes in open dumping (Figure 1).

Figure 1: Dump yard

When e-waste is burning or warmed up, many toxins are released into the environment. When e-waste is thrown away in dumping ground, harmful toxic materials are soaked into ground-water due to leaching from these.

According to the study, we must make concrete green and sustainable because natural resources are decreasing, and there are no viable alternatives to concrete. The activation of wastes like FA and GGBS from thermal power plants and steel plants, respectively, is the primary source of geopolymer binder. The use of E wastes in traditional concrete and geopolymer is described in this work. Polymerization is forming three-dimensional chains by combining monomer molecules with reaction-initiating substances. Geopolymers are inorganic polymers that develop when an alumina and silica-rich base material combine with a powerful alkaline solution. Geo-polymerization is the name for this process. The geopolymerization reaction mechanism is depicted in Figure 2.

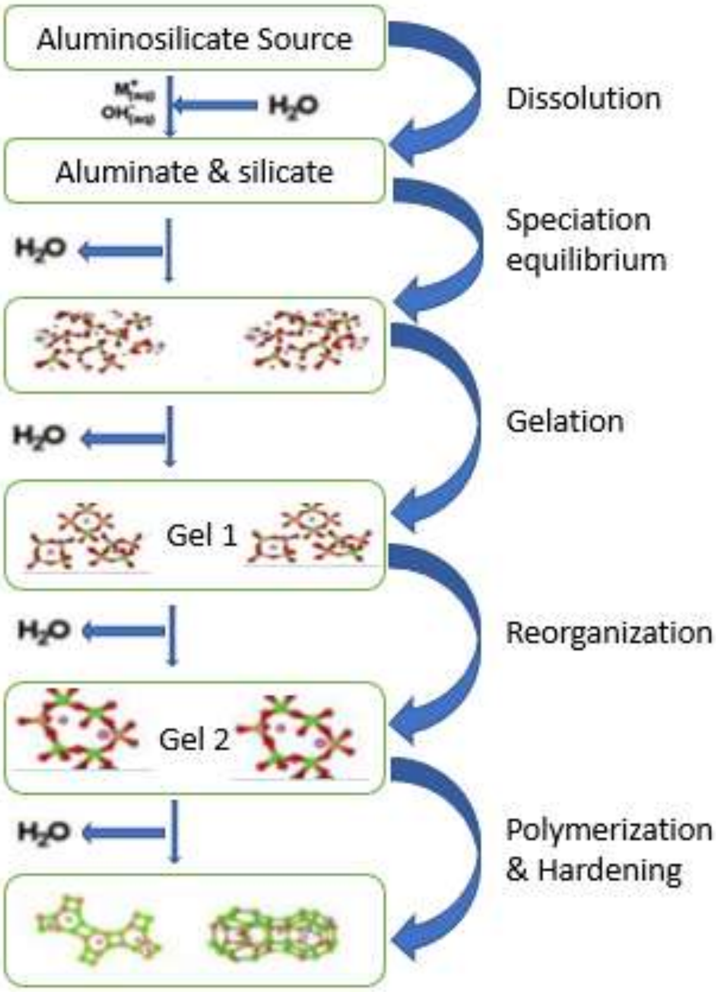


Figure 2. Reaction Mechanism of Geopolymerization (Duxson et al., 2007, pp. 2917–2933)

I. LITERATURE SURVEY

About one tonne of CO2 and three kilograms of NOX are released into the atmosphere during cement production. About 23 billion metric tonnes of carbon dioxide are added annually to the atmosphere. These three components account for around 65% of the total warming effect. Cement production accounts for around 7% of total CO2 emissions (Mccaffrey, 2002).

Geopolymer, named by Davidovits, is a network of chains of inorganic molecules. The production of geopolymer binders is mainly based on the activation of wastes such as FA and GGBS from thermal power plants and steel plants, respectively. Researchers have focused on the new binding material's potential to substitute cement. The geopolymer has also received increased attention due to the reduction of greenhouse gases and the depletion of natural resources. The main constituent of the source material for Geopolymer is alumina silicate, which is found in thermally activated waste materials (FA and slag). The activator solution is required to polymerize the source materials and is found in molecular chains and networks to obtain a binder. This binder is known as geo cement, alkali-activated cement, or inorganic polymer cement.

Experiments for the slump value of the geopolymer with granulated lead smelter slag (GLSS) were done by M. Albitar et al. (2015), and it was discovered that the slump value increases as the % of replacement with GLSS rises. With an increase in Sodium Hydroxide (NH) content from 10 molarities (M) to 20M, Topark-Ngarm et al. (2015) found that the workability of geopolymer decreased, i.e., the slump value decreased from 580 mm to 470 mm. This may be because of the correlation between NH content and viscosity increase. Slump value in geopolymer concrete was shown to be decreased when the amount of steel fiber was increased, as noted by Ganesan et al. in 2015. Slump values in fly ash-based Geopolymer concrete were found to rise by 24% and 28%, respectively, when the water-to-binder ratio was increased from 0.096 to 0.107 and from 0.107 to 0.141 (M Albitar et al., 2015).

Slump values rose from 30 mm to 90 mm with an increase in water amount of 10-35 kg/m3, as Aliabdo et al. (2016) noted. The study indicates that the increased practicability is largely due to people not using the accessible water sources in GPC. Fly ash-based geopolymer was studied by Li and Liu, 2007; they found that the reaction rate was enhanced owing to the more excellent amorphous products when slag was used as an addition. According to research by Temuujin et al. (2009), adding calcium and calcium hydroxide to FA geopolymer paste raises the paste's critical size (CS). It improves its characteristics when used at room temperature. In addition, it was shown by Rashad and Zeedan (2011) to be more resistant to high temperatures than OPC. The elevated reactivity of the material may be attributable to the high concentration of the alkali activator. Compressive Strength was studied by Phoo-Ngernkham et al., (2013) for geopolymer paste in which OPC was replaced with Fly Ash at varying percentages (0%-15% by mass of binder). He found that the strength of the samples improved as the amount of fly ash used in their replacement rose. The 28-day Compressive Strength of specimens made with palm oil fuel ash and an NS to NH ratio of 2.5 was 51% greater than that of specimens made with a ratio of 1. Hadi et al. (2017) determined that the NS/NH ratio of fly ash and GGBS-based geopolymer is optimal at 2. In a 2020 study, Chandan Kumar et al. tested geopolymer concrete made from fly ash by partially substituting E wastes with natural coarse particles. According to his research, the fresh-state workability of geopolymer concrete is improved by incorporating E wastes. The mixture loses its weight. He disclosed that 12% E-waste is the sweet spot for incorporating it into geopolymer concrete.

A. Objective

- To study the consequence of E-waste if partially used as aggregates in conventional and geopolymer concrete.
- To investigate the effect of E-waste on the compressive strength of fly ash and GGBS-based geopolymer concrete.
- To evaluate the optimum use of E wastes in fly ash and GGBFS-based geopolymer concrete.
- Cost reduction of concrete by replacing cement with industrial wastes.

II. MATERIALS and METHODOLOGY

A. Materials

Binders for this geopolymerization included both fly ash and GGBFS. An alkaline sodium hydroxide and sodium silicate solution was employed to initiate polymerization. Natural river sand, coarse aggregate readily available in the area, and E-waste are all examples of aggregates used in geopolymer concrete. Tables 1 and 2 show the results of EDX analyses conducted on GGBFS and Flyash, respectively. Table 3 displays the results of an XRF analysis of GGBFS, FA, and cement to determine their oxide concentration. The aggregates and cement's physical properties are listed in Tables 5 and 6, respectively. Table 7 summarises the fine-aggregate-gradation scale.

B. Ground Granulated Blast Furnace Slag (GGBFS):

GGBFS conforming to ASTM C 989-18, was used as a binder for geo-concrete. MESCO in Jajpur, Odisha, supplied the material. GGBFS is an industrial waste product produced by steel mills. When the blast furnaces burn at 1500 °C, and a controlled mixture of limestone, iron ore, and coke is stuffed, the iron is extracted, and the by-product materials take the form of slag. This slag was quenched with water and turned into granules. Slag has cementitious qualities and can be used as a binder instead of cement up to a certain extent after being ground into fine powder.

It can be classified as 1) palletized slag, 2) foamed or expanded slag, 3) GGBFS, or 4) air-cooled blast furnace slag, depending on the extraction technique. EDX study of GGBS is shown in Figure no-3.

Table 1: EDX analysis of GGBS

Elements	Weight %	Atomic %
O K	45.79	51.88
C K	18.93	27.85
Al K	11.58	7.58
Cr K	0.87	0.28
Si K	17.33	10.92
Ca K	0.46	0.20
Ti K	0.99	0.36
Fe K	1.93	0.52
Cu K	1.08	0.26
K K	0.92	0.42

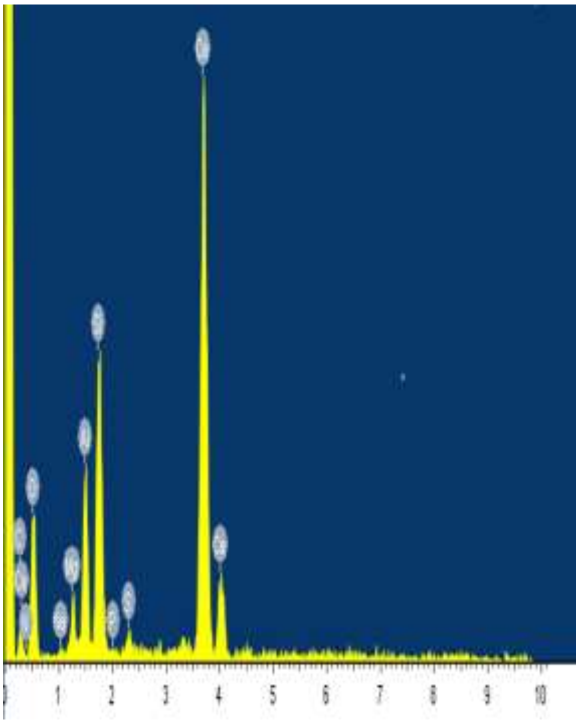


Figure 3. EDX study of GGBS Figure

C. Fly ash:

As a binder for geo-concrete, fly ash (FA), Figure-4, according to ASTM C 618-08, was used. Jindal, Jajpur, Odisha was the source. The XRF test results suggest that the fly ash used is of class F type, containing more than 70% silica, alumina, and ferrite. EDX of fly ash is shown in Figure 5.

Figure 4: Fly ash

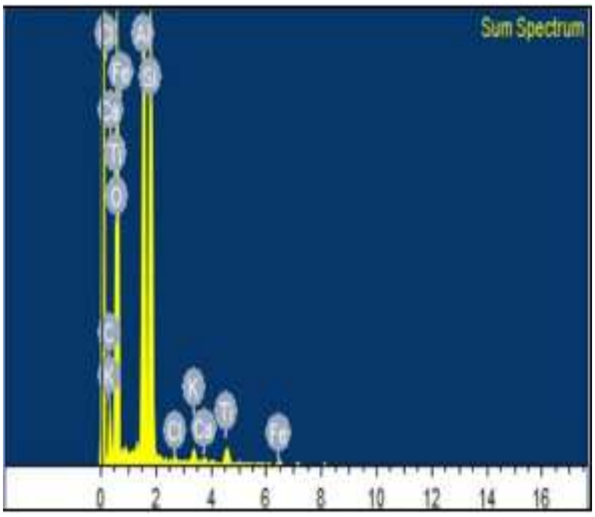


Figure 5. EDX study of FA

Table 2. EDX analysis of FA

ELEMENTS	WEIGHT %	ATOMIC %
C K	18.93	27.85
O K	45.79	51.88
Al K	11.58	7.58
Si K	17.33	10.92
K K	0.92	0.42
Ca K	0.46	0.20
Ti K	0.99	0.36
Fe K	1.93	0.51
Cu K	1.08	0.27
Cr K	0.87	0.28

D. Cement:

This project's reference conventional concrete mix was made with Birla OPC 53-grade cement. The laboratory assessed the physical qualities of cement, such as fineness, standard consistency, specific gravity, and setting time. This cement's compressive strength was determined to be good, with a value of 41 MPa after seven days.

E. Alkaline solution:

To activate the reaction in industrial wastes, sodium silicate (Na2SiO3) (Figure 7) and sodium hydroxide (NaOH) (Figure 6) at a 2.5 mass ratio of silicate to hydroxide were used as alkaline reagent solutions. These compounds have been taken from a commercial source. Because it triggers the polymerisation process, an alkaline solution (Figure 8) is a critical component in the manufacturing of geopolymer concrete. When lab-grade meta-silicates were utilized in the study, no polymerization processes occurred, and the outcome was 0% compressive strength. For this, a combination of NH and NS is commonly employed. Because of their expensive cost, potassium-based alkaline solutions are often avoided. When sodium hydroxide dissolves in water, the reaction is accelerated, and a large amount of heat is released quickly. Therefore, safety precautions should be followed when handling this colorless solution. This study took locally available sodium hydroxide pellets from Kiran Global solution.

Figure 6, 7, 8: Sodium hydroxide, Sodium Silicate, the mix of NaOH and Na_2SiO_3

F. Aggregates:

The experimental mix's coarse aggregates (Figure 12) were made using granite-derived stones quickly sourced from the area. The coarse material was sieved using an IS sieve with openings of 20 mm and 12 mm. Sample E wastes (Figure13) used as coarse aggregate has values of 1.28, 1.23, and 0.17% for fineness modulus, specific gravity, and water absorption, respectively. Electronic garbage (Figures 9 and 10) was gathered from a Bhubaneswar-based electronics store. All fastened metals should be polished. Metals were polished by hand at this facility. The sand was gathered from the Kathajodi River in Trisulia, near Bhubaneswar. Specific gravity was 2.72; fineness modulus was 2.48, water absorption was 0.8%, particle size distribution was Zone II (IS 373:2016), and the sand utilized passed through an IS sieve with a pore size of 4.75 mm (Figure11). Tables 4 and 5 display the characteristics of the aggregates tested in this study.

Figures 9 & 10: E wastes

Figures 11, 12 & 13: Fine aggregates, Coarse aggregates, dry mix with E wastes

G. Water:

Portable water conforming to IS: 3025 is used for the experiments. Source of Water: Under Ground Water at Centurion University of Technology & Management, Bhubaneswar.

Table 3: Oxide conformation of Cement, fly ash, GGBS found from XRF

Material	Al_2O_3	Fe_2O_3	SO_3	SiO_2	Na_2O	CaO	MgO	MnO	K_2O	TiO_2	LOI
Cement	4.18	3.1	1.96	21.47	0.63	65.15	1.97	0	1.01	0	0.53
Flyash	28.809	4.78	0	59.483	0	1.66	0	0.49	1.782	2.048	0.948
GGBS	18.928	0.974	1.716	29.58	0	45.714	0	0.281	0.913	1.366	0.528

Table 4: Physical properties of aggregates

Sl. No	Physical Properties	Natural fine aggregate	Natural coarse aggregates	E aggregate
1	Specific Gravity	2.72	2.8	1.23
2	Water absorption (%)	0.8	0.21	0.17
3	Fineness modulus	2.48	7.20	1.28

Table 5: Physical properties of cement

Sl. No	Physical Properties	Test Result
1	Fineness by Sieving through IS 90 Micro Sieve	7.25
2	Standard consistency (using Vicat apparatus)	30%
3	Specific Gravity (using Pycnometer)	3.146 ≈ 3.15
4	Soundness (using Le- Chatelier apparatus)	5 mm
5	Setting Time	
	Initial-Setting Time	60min
	Final-Setting Time	320min

Table 6: Fine aggregate Gradation

IS Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	Cumulative Retained (%)	Passing (%)	Specified limits as per IS:383 (%)		
					Zone I	Zone II	Zone III
10 mm	0	0	0	100	100	100	100
4.75 mm	16	16	1.6	98.4	90-100	90-100	90-100
2.36 mm	29	45	4.5	95.5	60-95	75-100	85-100
1.18 mm	109	154	15.4	84.6	30-70	55-90	75-100
600 micron	437	591	59.1	40.9	15-34	35-59	60-79
300 micron	278	869	86.9	13.1	May-20	Aug-30	Dec-40
150 micron	119	988	98.8	1.2	0-10	0-10	0-10
Pan	12	1000	100	0			

H. Methodology:

The present study investigates the optimum use of Ewaste in geopolymer concrete based on its compressive strength.

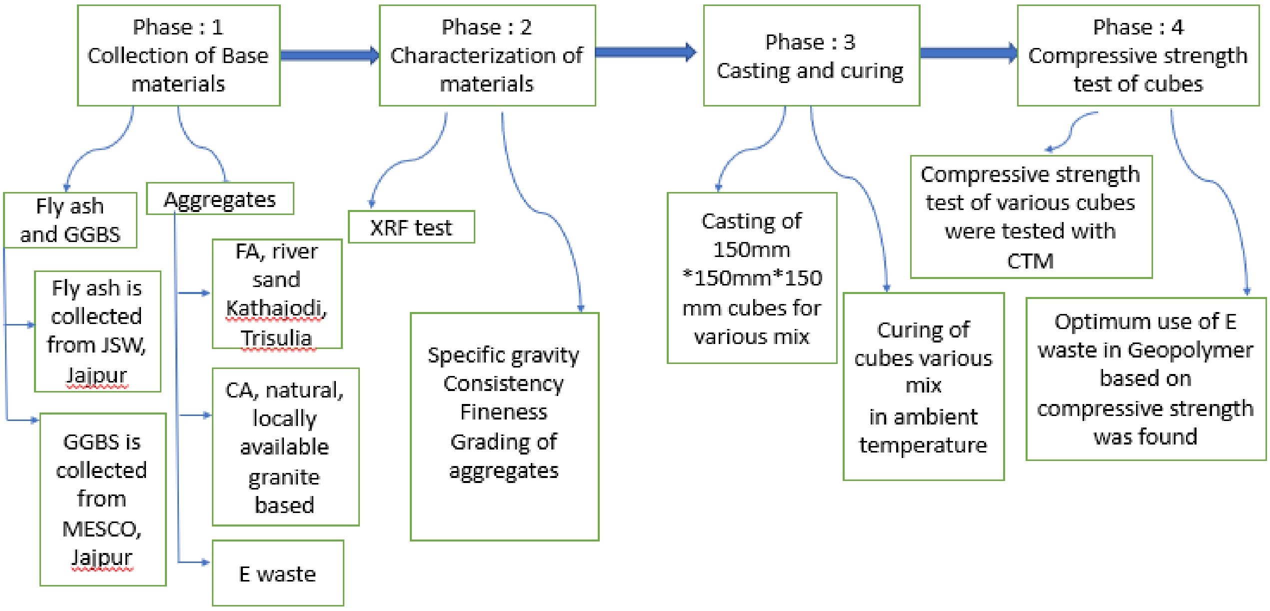


Figure 14: The methodology

I. Mix Ratio

The literature research informed a 20% GGBS and 80% FA experimental mixture. The GC mixture was prepared using 12 M sodium hydroxide and a 2.5 mass/mass ratio of sodium hydroxide to sodium silicate. The ratio of solution to binder remained constant at 4.5. To prepare a 12 M sodium hydroxide solution, 480 g of sodium hydroxide pellets were dissolved in one liter of water. Once the sodium is added, crystal-like solids (Figure-15) will settle to the bottom of the solution if the solution is not continually agitated. Silicate.

Figure: 15

Table 7: Ingredients for trail mix

Mix	Binder (Kg/m^3)			MOLARITY NaOH	NaOH (Kg/m^3)	Na^2SiO^3 (Kg/m^3)	RATIO of Na^2SiO^3 to NaOH	Aggregates			
	FLYASH	GGBS	OPC					FA	CA	EW	S or W/B

TM1	304	76	0	12	48	123	2.5	570	1140	0	0.45
TM2	304	76	0	12	48	123	2.5	570	1083	57	0.45
TM3	304	76	0	12	48	123	2.5	570	1026	114	0.45
TM4	304	76	0	12	48	123	2.5	570	969	171	0.45
TM5	304	76	0	12	48	123	2.5	570	912	228	0.45
TM6	0	0	380	-	-	-	-	570	1140	0	0.45
TM7	0	0	380	-	-	-	-	570	1083	57	0.45
TM8	0	0	380	-	-	-	-	570	1026	114	0.45
TM9	0	0	380	-	-	-	-	570	969	171	0.45
TM10	0	0	380					570	912	228	0.45

Where:

TM1: 80% FLY ASH + 20% GGBFS + 100% NATURAL COARSE AGGREGATE + 0% E-Waste

TM2: 80% FLY ASH + 20% GGBS + 95% NATURAL COARSE AGGREGATE + 5% E-Waste

TM3: 80% FLY ASH + 20% GGBS + 90% NATURAL COARSE AGGREGATE +10% E-Waste

TM4: 80% FLY ASH + 20%GGBS + 85% NATURAL COARSE AGGREGATE + 15% E-Waste

TM5: 80% FLY ASH + 20%GGBS + 80% NATURAL COARSE AGGREGATE + 20% E-Waste

TM6: 100% CEMENT + 100 NATURAL COARSE AGGREGATE + 0% E-Waste

TM7: 100% CEMENT + 95% NATURAL COARSE AGGREGATE + 5% E-Waste

TM8: 100% CEMENT + 90% NATURAL COARSE AGGREGATE + 10% E-Waste

TM9: 100% CEMENT + 85% NATURAL COARSE AGGREGATE + 15% E-Waste

TM10: 100% CEMENT + 80% NATURAL COARSE AGGREGATE + 20% E-Waste

J. Casting and Curing

Compressive strength was investigated by casting cubes of 150mm150mm150mm with varying trial proportions. The GC samples were left in the open air for 24 hours after casting (i.e., demolding), whereas the OPC cubes were soaked in water for 28 days to cure.

Figure 16: Compressive strength test in CTM

III. RESULTS AND DISCUSSION

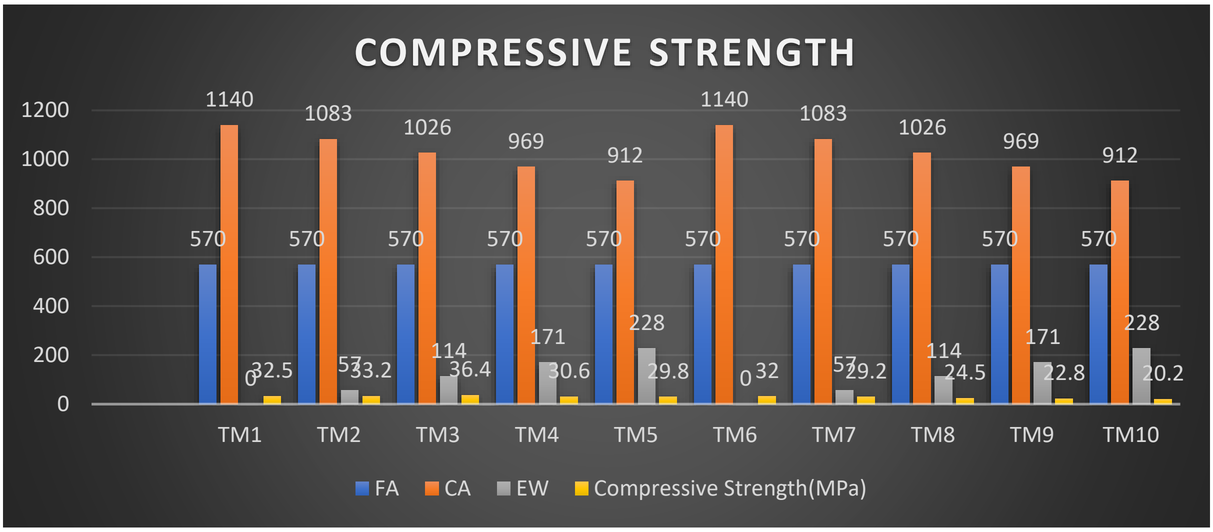
Table 8 shows the compressive strength of a mixture containing more than 15% E trash as the coarse aggregate declines after 28 days. To that end, E-waste may be substituted for conventional coarse aggregate in building projects, contributing to more effective E trash management. Compressive strength tests were conducted over 28 days, and the results were represented in graphs 1, 2, and 3.

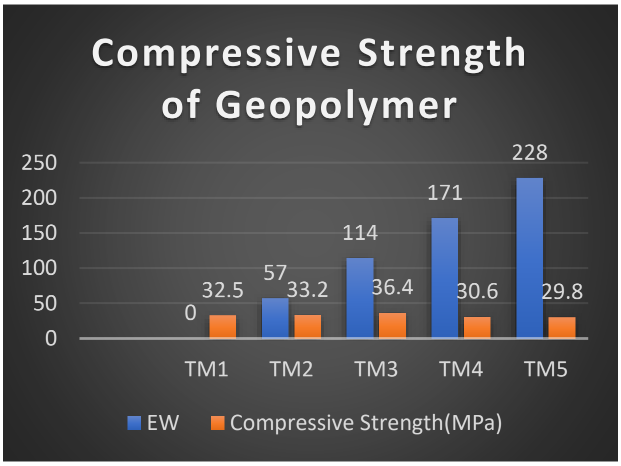
Compressive strength is calculated using the following equation

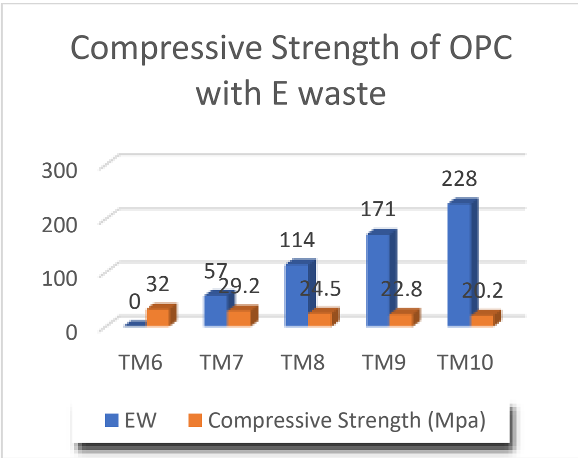
FCS = Load at Failure/ Area of cross-section

Table 8: Compressive strength of trial mixes

Mix	Aggregates			Compressive Strength (MPa)
	FA	CA	EW	
TM1	570	1140	0	32.5
TM2	570	1083	57	33.2
TM3	570	1026	114	36.4
TM4	570	969	171	30.6
TM5	570	912	228	29.8
TM6	570	1140	0	32
TM7	570	1083	57	29.2
TM8	570	1026	114	24.5
TM9	570	969	171	22.8
TM10	570	912	228	20.2







Graph a, b, c: Compressive strength of OPC and geopolymer mix with various proportions of E wastes.

IV. CONCLUSION

- Up to 15 percent E-Waste replacement in concrete and geopolymer was proven effective. Twenty percent E trash as coarse aggregate in concrete is suitable for usage in low-weight concrete. In this research, E trash may be utilized with or without cement. However, waste segregation is a crucial obstacle to the bulk manufacture of concrete from E wastes.
- Compressive strength is increased in geopolymer concrete that incorporates e-waste. When E-Waste is added to a mixture, it becomes more manageable. Concrete and geopolymer

concrete made from e-waste is more lightweight. Furthermore, pollution from E wastes and industrial by-products may be reduced in addition to these measures.

- The collection of E garbage, or the separation of E-waste from solid wastes, is going to be the main problem. Second, the investigation into E-waste leaking. Since aggregates are expected to be non-reactive.

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