Mathematical Prediction on the strength and behaviour of structural member by incorporating Incinerated Bio-Medical Waste Ash in Ground Granulated Blast Furnace Slag based Geopolymer Concrete

Suresh Kumar A[a], Muthukannan M[b], Arun Kumar K[c], Chithambar Ganesh A[d], and Kanniga Devi R[e]

[a,c]
Research Scholar, Department of Civil Engineering, Kalasalingam Academy of
Research and Education, Virudhunagar, India. Email: sureshalmighty@gmail.com
arunapcivil@gmail.com
[b]Professor, Department of Civil Engineering,
Kalasalingam Academy of Research and Education, Virudhunagar, India.
Email: civilkannan@gmail.com
[d]Assistant Professor, Department of Civil Engineering, SreeVidyanikethan Engineering College, Tripati, India.
Email: chithambarmailid@gmail.com
[e]Professor, Department of Civil Engineering, Kalasalingam Academy of Research and Education, Virudhunagar, India.
Email: civilkannan@gmail.com

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Abstract: Concrete seems to be the more commonly used construction substance throughout the entire globe as well as its usage have been expanded over the last decade because the demand for building works has increased. Geopolymer concrete (GPC) is one of the technologies that may be used to replace traditional concrete. Geopolymer concrete is an inorganic alumino-silicate polymer made mostly of silicon, aluminum, and by-product materials such as Fly Ash (FA), Ground Granulated Blast Slag (GGBS), and other by-product materials. While the key motives for utilizing GPC is technical and economic advantages, the avoidance of environmental pollution by appropriate waste management has become a concern. The primary goal of this research is to see how Incinerated Bio-Medical Waste Ash (IBWA) affects the mechanical and flexural activity of GPC. In this report, IBWA is substituted for GGBS in various percentages (0, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%). The inclusion of IBWA converts the substance from brittle to ductile, resulting in substantial improvements in tensile stress, tensile strain, toughness, and energy absorption capacities. The samples was held constant at ambient temperature throughout the curing phase. On concrete specimens, the mechanical properties of concrete, including the compressive strength of the cube, the split tensile strength and the bending strength were inspected. The experimental findings indicate that introducing IBWA to GPC enhances the mechanical behaviour of the material as well as the load carrying capability of the beams.

Keywords: Incinerated Bio-Medical Waste Ash, Geopolymer Concrete, GGBS, Mechanical Properties, Flexural behaviour, Load carrying Capacity

1. Introduction

Concrete perhaps the most frequently utilized construction substance throughout the planet due to its mouldability, reliability, fire and energy efficiency resistance. The demand for concrete as a construction material increases, as does the production of cement [1,2]. One ton of cement produced releases nearly one ton of Carbon dioxide into the ecosystem [3,4]. There is a need to create alternate binders for concrete in attempt to address the impact on the environment of Portland cement [5,6]. Alternative binders are being used to partially or fully substitute cement as a result of increased environmental consciousness in the building sector.

Almost at the same time, waste management has been facing an enormous problem in recent decades, including the waste disposal of hazardous wastes from hospitals. Hospital waste or bio-medical waste is an unusual source of waste [7,8]. According to the 1998 Indian rules on bio-medical waste (Management and Handling) "Bio medical waste refers to any waste that is generated when people or animals are diagnosed, treated or immunized or during study activities related to it or during the processing or testing of biological waste, even in different types". Because of its poisonous and harmful elements, it is more dangerous. Management, storage and disposal of this waste in most of the developed world have become a growing environmental concern.

Every day, India produces approximately 517 tonnes of hazardous waste. Biomedical waste has been subjected to various of treatment and disposal methods. However, the safest way of mitigating toxic waste has been identified as incineration [9-11]. Nevertheless, that would result in a further waste in terms of ash, which would be enriched with heavy metals that will leach into the soil and groundwater. In India, 3.28 lakh (metric tons per year) of hazardous waste is incinerated to create around 0.82 lakh MTA ash [12]. Since incineration ash is expensive to handle and dispose of, landfill capacity is limited, and environmental consciousness is growing, there is a need to find an alternate application for Incinerated Bio-Medical Waste Ash (IBWA) apart from disposal [13-21].

The development of an inorganic alumina-silicate polymer, classified as Geopolymer, made from volcanic products or by-product materials enriched in silicon and aluminum, such as fly ash, is the strongest option for reducing the problems caused by Hazardous Incinerated Bio-Medical Waste Ash and Cement [1-6, 22-31].

The aim of this research is to look at a new form of geopolymer concrete that uses GGBS as a source material and IBWA as a partial substitute. The impact of adding IBWA on compressive strength, split tensile strength, and flexural strength, as well as structural behavior of beams, is investigated for up to 28 days. The Incinerated Bio-Medical Waste Ash Geopolymer Concrete would be a sustainable concrete.

2. Experimental investigation

2.1.1 Mix design and specimen details

The source material used for GPC was ground granulated blast furnace slag (GGBS). In Geopolymer Concrete, Incinerated Bio-Medical Waste Ash is partly substituted for GGBS. A combined effect of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions makes up the alkaline activator. The sodium silicate solution was made with a silicon dioxide (SiO_2) to sodium oxide (Na_2O) mass ratio of 2 (Na_2O=147%, SiO_2=294%) and 55.9 percent water.

The 97–98 percent pure sodium hydroxide pellets were combined with water to make a 13M concentration solution. The coarse aggregate (nominal scale 10 mm) and fine aggregate (M-Sand) used in this project met the requirements of IS 383-1970 (BIS, 2002). Reinforcement was given by high-yield-strength deformed (HYSD) bars with nominal diameters of 12 mm, 8 mm, and 6 mm, with yield strengths of 450 N/mm^2, 430 N/mm^2, and 412 N/mm^2, respectively.

According to Rangan's guidelines, a GPC mix of grade M30 was developed (2006) [32-34]. The mix ratio for Geopolymer concrete is 1:1.36:2.36 and binder-solution ratio is 0.61. Variations in the percentage of IBWA replacing GGBS in the GPC mix were used to develop Reinforced Geopolymer Concrete (RGPC) mixes. Table 1 indicates the blend proportions chosen for GPC.

In this analysis, 150mm x 150mm x 1500mm beams were evaluated. In the mould, there was a separate provision for inserting plates for mounting linear variable differential transformers (LVDTs) to calculate the deformation [35,36]. This structure was rendered such that the main strains could be determined right after the peak stress had occurred. As longitudinal bars, four 12mm dia. bars were used, and ties were supported as 6mm dia. bars with a 100mm core to centre spacing. GRGPC (without IBWA) and IGRGPC (with 30 percent IBWA (which is optimal)) beams were prepared.

Table 1: Mix Proportion for IBWA mix

Mix	% of GGBS	% of IBWA	Mix proportion (kg/m^3)			
			GGBS	IBWA	M-Sand	Coarse aggregate
IBWA 0	100	0	450	0	615.67	1064.44
IBWA 5	95	5	427.5	22.5	614.88	1063.08
IBWA 10	90	10	405	45	614.1	1061.72
IBWA 15	85	15	382.5	67.5	613.31	1060.36
IBWA 20	80	20	360	90	612.53	1058.99
IBWA 25	75	25	337.5	112.5	611.74	1057.64
IBWA 30	70	30	315	135	610.96	1056.28
IBWA 35	65	35	292.5	157.5	610.17	1054.92
IBWA 40	60	40	270	180	609.38	1053.56
IBWA 45	55	45	247.5	202.5	608.60	1052.20
IBWA 50	50	50	225	225	607.81	1050.84

2.1.2 Preparation of test specimens

The aggregates were combined for 5 minutes in a pan mixer with GGBS and IBWA in a saturated surface dry state. The alkaline solutions and additional water were then applied to the dry products, and the mixture was blended for 4 minutes. Normal cubes of 150 mm x150 mm x 150mm, cylinders of 100 mm dia. and 200 mm long, and prisms of 100 mm x 100 mm x 500 mm were also prepared to assess the hardened properties. Both of the specimens were stored at room temperature for 28 days after casting The research specimens were then left in the laboratory atmospheric conditions for 28 days after curing [37]. All of the specimens' hardened properties were assessed, and the results are described in Table 2.

Table 2: Mechanical Properties of IBWA incorporated in GGBS based Geopolymer concrete

Mix	Compressive Strength N/mm^2		Split Tensile Strength N/mm^2		Flexural Strength N/mm^2	
	7 days	28 days	7 days	28 days	7 days	28 days
IBWA 0	24	35.2	2.45	2.97	3.14	3.8
IBWA 5	24.8	36.2	2.49	3.01	3.19	3.85
IBWA 10	25.6	37.4	2.53	3.06	3.24	3.91
IBWA 15	26.8	38.2	2.59	3.09	3.31	3.96
IBWA 20	28.5	39.8	2.62	3.15	3.36	4.04
IBWA 25	30.3	41.4	2.68	3.22	3.44	4.12
IBWA 30	32.5	43.3	2.74	3.29	3.51	4.21

IBWA 35	29.3	40.2	2.66	3.17	3.41	4.06
IBWA 40	26.2	37.8	2.56	3.07	3.28	3.93
IBWA 45	24.4	35.6	2.47	2.98	3.16	3.82
IBWA 50	22	33.5	2.35	2.89	3	3.7

The reinforced geopolymer concrete beams were put through their paces using a four-point flexure mechanism, as per ASTM C1161 [38]. The beam specimens were 1.50 m x 0.15 m x 0.15 m in size and were simply supported over a 1200 mm effective span. All beams were strengthened with two 12 mm dia. tension bars and two 8 mm dia. hanger bars with 6 mm dia. shear reinforcement mounted at 100 mm c/c. The beams were monotonically checked before failure in a universal testing machine with a 1000 kN capability and a four-point loading setup as seen in Fig. 1. At 400 mm on each side of the midspan, the loads were applied symmetrically.

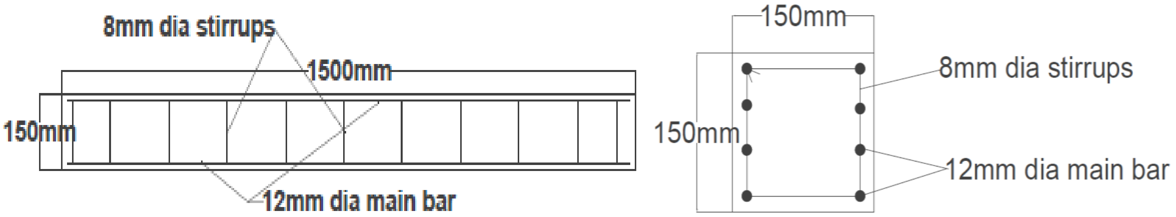

Figure 1 beam's cross-section and reinforcement details

3. Result and Discussion

3.1. Mechanical properties

3.1.1. Compressive strength

As shown in the Fig. 2, the compressive strength values are recorded as the mean of 3 samples for every combination at 7 and 28 days. The strength increasing trend of IBWA Geopolymer concrete with GGBS substitution can be seen in the compressive strength test performance. The compressive strength of IBWA0 was observed to be 24 MPa at 7 days of age, while that of other mixes IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA30, IBWA35, IBWA40, IBWA45, and IBWA50 was 24.8, 25.6, 26.8, 28.5, 30.3, 32.5, 29.3, 26.2, 24.4, and 22 MPa, with an increase in 3.33%, 6.66%, 11.67%, 18.75%, 26.25%, 35.41%, 22.08%, 9.16%, 1.67% and decrease by 8.33% respectively. Likewise, the compressive strength of IBWA0 was 35.2 MPa at 28 days, while the compressive strengths of other mixes IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA30, IBWA35, IBWA40, IBWA45, and IBWA50 were 36.2, 37.4, 38.2, 39.8, 41.4, 43.3, 40.2, 37.8, 35.6, and 33.5 MPa, with an increase in 2.84%, 6.25%, 8.52%, 13.07%, 17.61%, 23.01%, 14.20%, 7.38%, 1.13% and decrease by 4.83% respectively. As a result, strength improved at all ages as the IBWA material increased by up to 45 percent. Over all ages, it was revealed that the mixing ratio comprising 30% IBWA showed the highest compressive strength (Fig. 2). The IBWA30 concrete mix has the highest compressive strength (43.3 MPa), which was 23.01 percent higher than the IBWA0 concrete mix.

The micro filler effect of IBWA concrete is the main reason for a strength improvement of up to 45 percent in IBWA concrete. The existence of calcium and silica is the second possible cause for the rise in strength. The existence of calcium and silica in IBWA improved the compressive strength by inducing pozzolanic action between IBWA and an alkaline solution. Both the geopolymerisation phase and the pozzolanic reaction between the IBWA and GGBS in the Geopolymer matrix are responsible for the compressive nature of these blends. Tzanakos et al. [10] found similar findings. Experiments conducted by other scientists [11,12, 39-45] show that as the amount of IBWA increases, water absorption increases, lowering the unit weight of concrete and explicitly correlating with strength effects.

The regression analysis was carried out under atmospheric conditions for 7 and 28 days of GPC compressive pressure. $y = -0.0358x^3 + 0.347x^2 + 0.3328x + 22.983$ and $y = -0.0294x^3 + 0.2417x^2 + 0.7741x + 33.921$, respectively, are the relationships between compressive force (y) and percentage of IBWA (x) for 7 and 28 days under ambient curing. The R^2 values are 0.87 and 0.89 for 7 and 28 days, respectively. The 28-day regression analysis has a high correlation of outcomes as compared to the 7-day regression study.

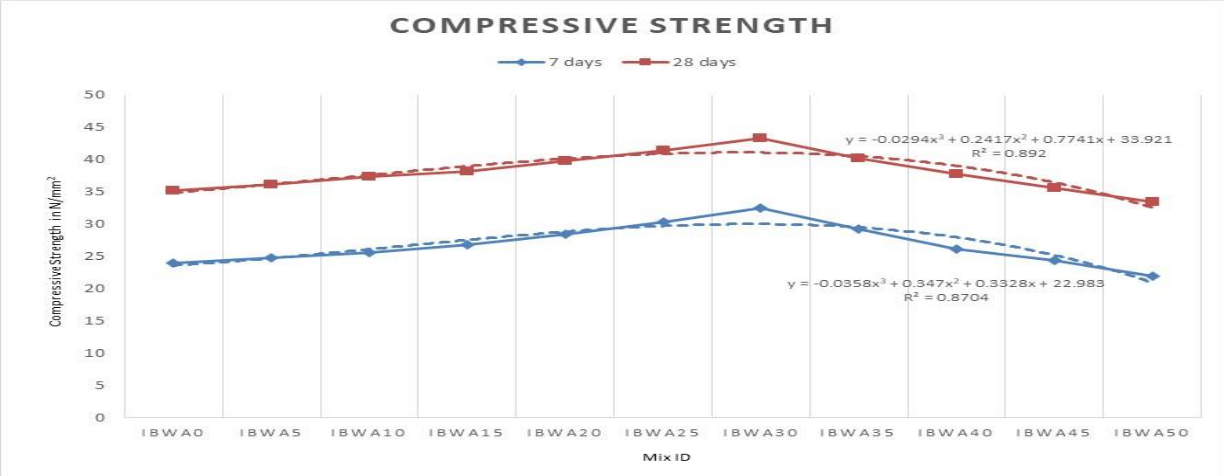

Figure 2 Effect of IBWA on Compressive strength for 7 and 28 days

3.1.2. Splitting tensile strength

At 7 and 28 days after curing, the impact of GGBS replacement with differing percentages of IBWA on split tensile strength is shown in Figure 3. It was discovered that the split tensile strength of IBWA5 to IBWA45 Geopolymer concrete mixes improved. According to the findings of the analysis, adding IBWA in Geopolymer concrete improved the split tensile strength by 30% when GGBS was substituted with IBWA, as shown in Fig. 3. The Geopolymer concrete strength obtained in IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA35, IBWA40, and IBWA45 was less than IBWA30. IBWA50 is the only blend that has a split tensile strength less than IBWA0. IBWA30 recorded the largest improvement in split tensile strength over all curing days. The design of the paste is becoming more essential than compressive strength in determining the splitting tensile strength of concrete. The structure of the paste and an interfacial transition zone (ITZ) are both affected by the properties of IBWA, which impact the tensile strength [46-55]. The split tensile strength of IBWA0 was 2.45 MPa at 7 days, while that of other mixes IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA30, IBWA35, IBWA40, IBWA45, and IBWA50 was 2.49, 2.53, 2.59, 2.62, 2.68, 2.74, 2.66, 2.56, 2.47, and 2.35 MPa, with a rise of 1.63%, 3.26%, 5.71%, 6.94%, 9.39%, 11.84%, 8.57%, 4.49%, 0.82% and decrease by 4.08% respectively. Similarly, the split tensile strength of IBWA0 was 2.97 MPa after 28 days, while that of other mixes IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA30, IBWA35, IBWA40, IBWA45, and IBWA50 was 3.01, 3.06, 3.09, 3.15, 3.22, 3.29, 3.17, 3.07, 2.98 and 2.89 MPa, with rises of 1.35%, 3.03%, 4.04%, 6.06%, 8.41%, 10.77%, 6.73%, 3.37%, 0.34% and decrease by 2.70% respectively.

The 7 and 28 day split tensile strength of GPC under atmospheric cured conditions is analyzed using regression analysis. As seen in Fig. 3, the relationship between split tensile strength (y) and percentage of IBWA (x) after 7 and 28 days of ambient curing is $y = -0.0013x^3 + 0.0124x^2 + 0.0163x + 2.4165$ and $y = -0.0012x^3 + 0.0102x^2 + 0.0289x + 2.9212$, respectively. The R^2 values for seven and twenty-eight days are 0.95 and 0.9, respectively. In comparison to the 28-day regression analysis, the findings of the 7-day regression analysis are highly correlated.

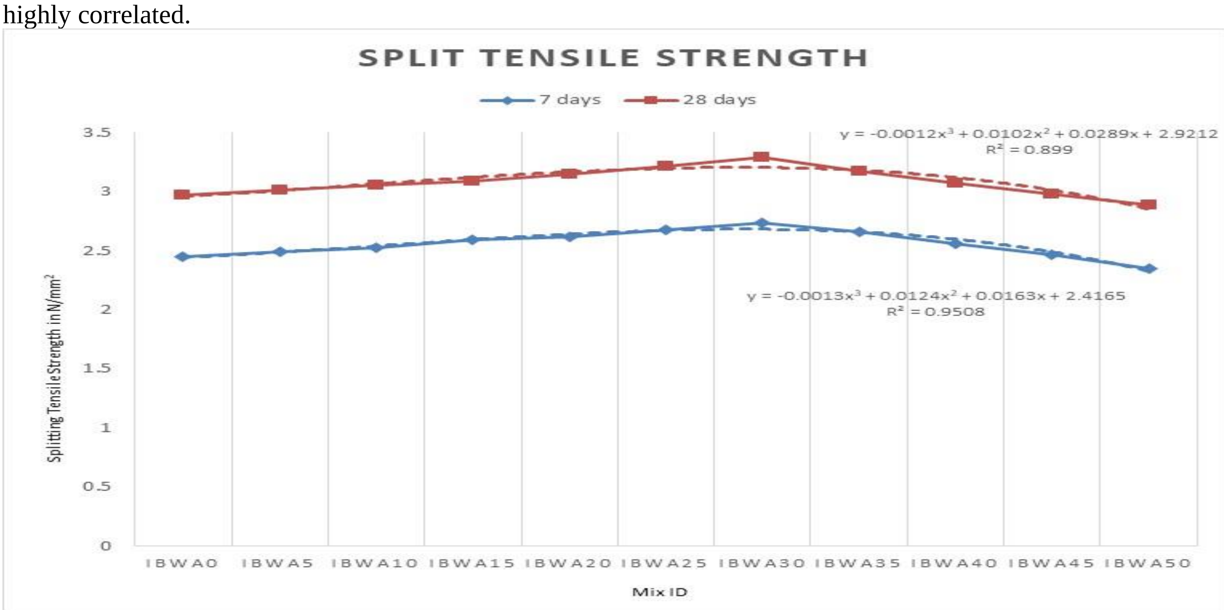

Figure 3 Effect of IBWA on Split Tensile strength for 7 and 28 days

3.1.3 Flexural Strength

Figure 4 depicts the impact of replacing GGBS with differing percentages of IBWA on flexural strength at 7 and 28 days after curing. The flexural strength of geopolymer concrete mixes ranging from IBWA5 to IBWA45 was found to increase. The test results show that integrating IBWA into Geopolymer concrete improved Flexural strength when 30% of GGBS was replaced with IBWA (see Fig. 4). The Geopolymer concrete flexural strength obtained in IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA35, IBWA40, and IBWA45 was less than IBWA30. IBWA50 is the only blend that has a flexural strength lower than IBWA0. IBWA30 recorded the largest improvement in flexural strength over all curing days. Concrete's flexural strength, rather than compressive strength, is becoming largely dependent on the composition of the paste. The properties of IBWA also have an effect on the nature of paste and an interfacial transition zone (ITZ), all of which have an impact on flexural strength [46-55]. The flexural strength of IBWA0 was 3.14 MPa at 7 days, while that of other mixes IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA30, IBWA35, IBWA40, IBWA45, and IBWA50 was 3.19, 3.24, 3.31, 3.36, 3.44, 3.51, 3.41, 3.28, 3.16 and 3 MPa, with a rise of 1.60%, 3.18%, 5.41%, 7.0%, 9.55%, 11.78%, 8.60%, 4.46%, 0.64% and decrease by 4.46% respectively. Similarly, the flexural strength of IBWA0 was 3.8 MPa after 28 days, while that of other mixes IBWA5, IBWA10, IBWA15, IBWA20, IBWA25, IBWA30, IBWA35, IBWA40, IBWA45, and IBWA50 was 3.85, 3.91, 3.96, 4.04, 4.12, 4.21, 4.06, 3.93, 3.82, and 3.7 MPa, with raises of 1.32%, 2.89%, 4.21%, 6.31%, 8.42%, 10.79%, 6.84%, 3.42%, 0.53% and decrease by 2.63% respectively.

For the 7 and 28 day Flexural strength of GPC under atmospheric cured conditions, regression analysis was carried out. As seen in Fig. 4, the relationship between flexural strength (y) and percentage of IBWA (x) after 7 and 28 days of ambient curing is $y = -0.0018x^3 + 0.0175x^2 + 0.0139x + 3.1027$ and $y = -0.0015x^3 + 0.0127x^2 + 0.0394x + 3.7336$, respectively. The R^2 values for seven and twenty-eight days are 0.95 and 0.91, respectively. In comparison to the 28-day regression analysis, the findings of the 7-day regression analysis are highly correlated.

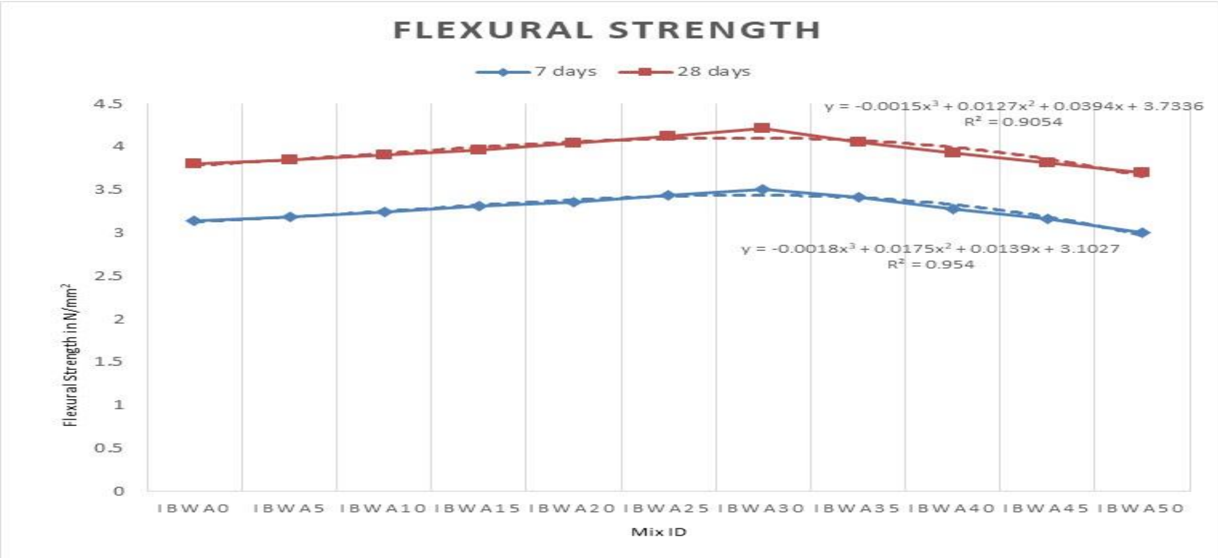

Figure 4 Effect of IBWA on Flexural strength for 7 and 28 days

3.2. Flexural behavior of geopolymer specimens with IBWA

3.2.1. Load-carrying ability

Figure 5 depicts the loads performed by the beams at different periods. With increasing IBWA material, the loads carried by the beams increase, resulting in increased flexural strength. Despite the differing ultimate load, the load at the first crack stage was observed to be identical for all of the evaluated beams. Almost all of the measured beams had an ultimate load in the region of 78-87 kN. At 30 percent replacement stage, there was a rise in strength of 11.54 percent, followed by a decrease in the strength increment. A slight slump in the load just after maximum load was reached in almost all of the beams, demonstrating the destruction of compression concrete due to compression steel bulging.

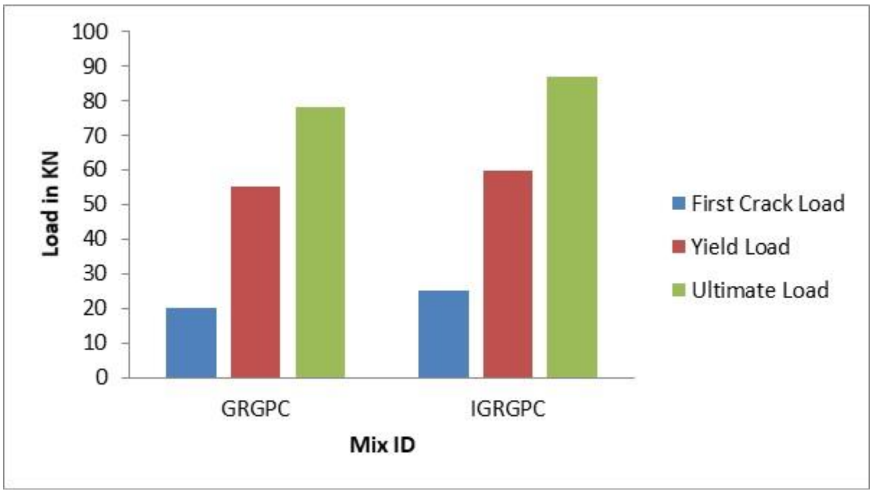

Figure 5 Load carrying capacity of beams

3.2.2. Deflection behaviour of beams

Until the reinforced steel begins to yield, the load–deflection properties of the measured beams display a linear variance. The curves display a polynomial variance as the load rises, all the way up to the maximum load. It was discovered that using IBWA does not result in an apparent change in the series of nonlinear efficiency and performance (see Fig. 6). As compared to concrete without IBWA, the deformation of beams with IBWA has superior values and rises as the IBWA material increases. Table 3 compares the Analytical midspan deflections at the ultimate moment to the expected value according to ACI 318-11 [56]. The Analytical values are greater than the expected values and enhances with the increase in IBWA material. The determined beams' span-deflection ratio was determined to be below the ACI-recommended permissible limit of span/250.

Table 3: Comparison between analytical and empirical loads and deflections for all beams.

Mix	Analytical		Empirical		Analytical/Empirical	
	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
GRGPC	78	14.4	72	12.8	1.08	1.13
IGRGPC	87	16.8	83	14.8	1.05	1.14

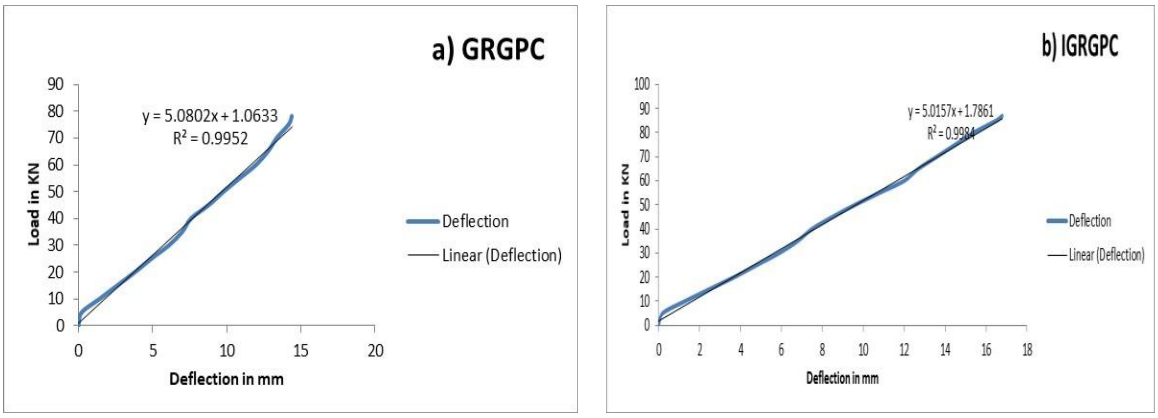

Figure 6 Load-Deflection curve for beams

For the 28 day, the load-deflection of RGPC beams under atmospheric cured conditions, regression analysis was carried out. As seen in Fig. 6, the relationship between load (y) and delection (x) after 28 days of ambient curing for GRGPC and IGRGPC is y = 5.0802x + 1.0633 and y = 5.0157x + 1.7861, respectively. The R^2 values for twenty-eight days GRGPC and IGRGPC are 0.9952 and 0.9964, respectively. In comparison to the GRGPC regression analysis, the findings of the IGRGPC regression analysis are highly correlated.

3.2.3. Ductility behaviour of beams

The ductility results of the evaluated beams are shown in Fig. 7, which seems to be the proportion of deformation at maximum level to deformation when steel yields, and is explicitly proportional to the curvature of the employees. The ductility of the beams reduces as the load rises because of the unexpected reduction in stiffness induced by the development of flexural cracks. The ductility ratios improve as the IBWA content increases, implying that adding IBWA to the geopolymer concrete beams enhances their ductility. Increased ductility increases the member's capacity to consume energy without increasing the crucial rate of failure.

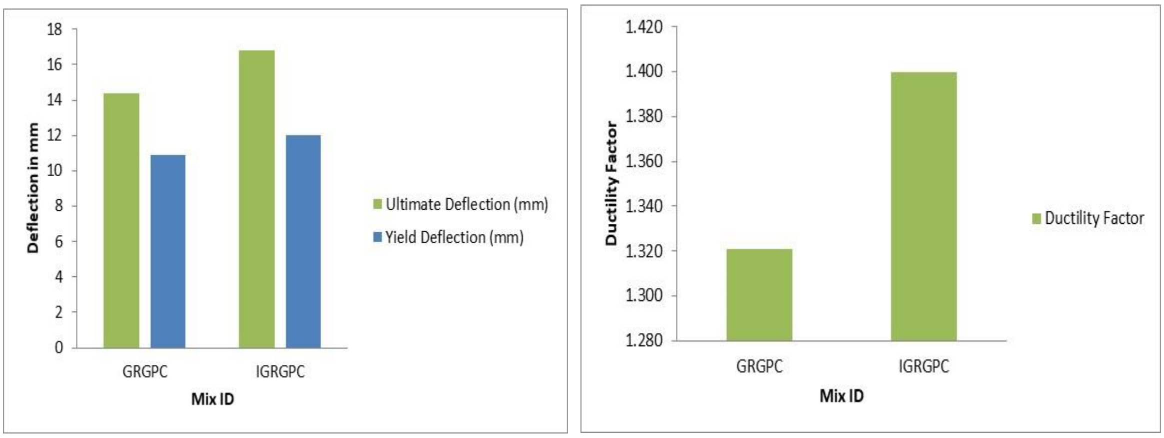

Figure 7 Effect of IBWA on Ductility of beams

3.2.4 Toughness Index of beams

The energy - absorbing capability of reinforced geopolymer concrete samples is measured by toughness. The samples' hardness is assessed according to ASTM C1018-1997. The toughness indices of the different beam samples are shown in Table 4, and Fig. 8 shows the difference in toughness indices.

Table 4: Toughness Index for all Beams

Mix ID	Area under Load Deflection Curve		Toughness Index
	First Crack (A1) mm^2	At three times the Cracking Deflection (A2) mm^2	
GRGPC	52.25	345.5	6.61
IGRGPC	77.25	577.2	7.47

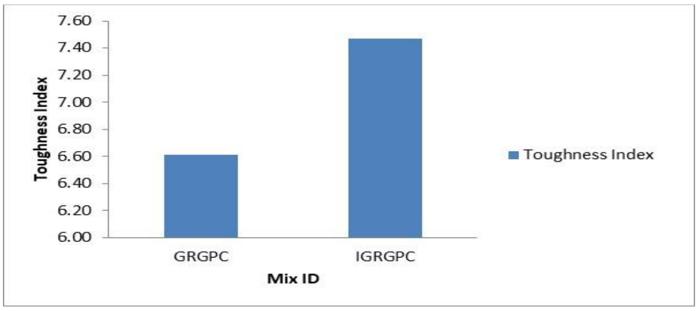

Figure 8 Effect of IBWA on Toughness Index

4. Conclusions

The effect of Incinerated Bio-Medical Waste Ash for partially substitute of Ground Granulated Blast Furnace Slag on mechanical behaviour of geopolymer concrete and flexural behavior of reinforced geopolymer concrete beams is studied in this paper. The following assumptions may be made based on the experimental findings collected and the discussions:

- The inclusion of IBWA enhances the compressive strength of GGBS-based Geopolymer concrete. The strengthened and dense structure of GGBS-based Geopolymer concrete contributes to its increased compressive strength.
- Compressive strength was improved by up to 30% by raising the volume of IBWA content in Geopolymer concrete. However, compressive strength was reduced by more than 30% by increasing the volume of IBWA content in Geopolymer concrete.
- Split tensile and flexural strength trended in the same trend as compressive strength for 7 and 28 days.
- Improving the IBWA content, performance of initial stiffness have been enhanced slightly and ultimate flexural deflections are increased in high level. Moreover, the influence of IBWA inclusion seems to have a massive effect on the flexural strength of GGBS-based Geopolymer concrete beams.
- The load-carrying ability of the GPC beams improves as the IBWA concentration increase. With a rise in loading of 11.54 percent, the increase was found to be optimal at 30 percent replacement stage.

- As the IBWA content of the geopolymer beams increases, the deflection and ductility properties of the beams enhance. Many of the mixes' span/deflection ratios were considered to be inside the ACI allowable maximum.

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