

Impact and Compressive Strength Performance of Fibre Reinforced Geopolymer Concrete

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Abstract - This paper presents an experimental study on the impact and compressive strength performance of fibre reinforced Geopolymer concrete, prepared using Ground Granulated Blast Furnace Slag (GGBFS) and Black Rice Husk Ash (BRHA). The Fibre reinforced Geopolymer concrete was prepared with GGBFS as the primary binder instead of BRHA and cement was replaced with GGBS at various proportions such as 10%, 20% and 30%. The compressive strength of Geopolymer concrete for various replacement of BRHA was studied in addition to the impact study. The test results showed that the strength of Geopolymer concrete with 10% replacement of BRHA was high compared to 20% and 30% replacement levels. The Addition of crimped fibers in the geopolymer concrete was used for studying the impact strength of concrete. Crimped fiber was added at 0.5%, 0.75% and 1% by volume of concrete. Energy absorption of geopolymer concrete with 0.5% addition of crimped fibers is found in the higher compared to other percentages of fibers.

Key Words: Impact study, Geopolymer concrete, Compressive strength, Crimped fibers, Replacement level.

1. INTRODUCTION

Concrete is the most predominantly used construction material in the world. The basic ingredient of concrete is Ordinary Portland Cement (OPC) which is a major contributor to global warming. The yearly global cement production of 1.6 billion tons is responsible for about 7% of the total CO₂ emission into the atmosphere (Mehta, 2001). The raw materials required for cement production are non-renewable and depleting at a rapid rate. At the same time, a lot of industrial and agro wastes with inherent cementation properties are produced abundantly but mostly dumped into landfills. Employing such byproducts as alternates for cement has multiple benefits including conservation of environment, sustainability of resources and solving the disposal problem of byproducts. Extensive researches are being carried out to assess the feasibility of utilizing industrial wastes as a complete replacement for OPC and generating superior binders from the same. One such successful attempt is Geopolymer concrete, which entirely eliminates the use of OPC in concrete production. Davidovits coined the term 'geo-polymer' in 1978 to describe a family of mineral binders that can be produced from the polymerization reaction between an alkaline liquid and a

source material containing silicon (Si) and aluminum (Al), which possess a chemical composition similar to zeolites but exhibiting an amorphous microstructure (Davidovits, 2011). These zeolitic polymers possess high strength in comparison to OPC concrete (Jun and Oh, 2015). The polymerization process is a relatively quick chemical reaction involving alkaline liquids and Si-Al minerals. The end product is a three-dimensional polymeric ring structure comprising of Si-O-Al-O bonds, termed as 'silicon Oxo aluminates' or 'silicates' in short. The general formula describing the chemical composition of the geopolymer is given by, $Mn[-(SiO_2)_z-AlO_2]_n \cdot wH_2O$, where, M is the alkaline component (like potassium or sodium), the symbol represents the presence of a bond, n is the degree of polymerization and z is a number 1, 2, 3 etc. up to 32 (Davidovits, 1999). The properties of Geopolymers are mainly dependent on the source materials used. Contrasting to OPC, the principal binders in Geopolymer concrete are not calcium-silicate-hydrates. Instead, an aluminosilicate polymeric gel formed by tetrahedrally-bonded silicon and aluminium with oxygen atoms shared in between acts the binder. However, several studies have revealed that, when sources like GGBS or Metakaolin containing high amounts of soluble calcium silicates are added, calcium dissolution occurs at low alkalinity resulting in the formation of a C-S-H gel in conjunction with the geopolymeric gel (Ismail et al., 2014). The geopolymeric gel remains the principal binder phase with small calcium precipitates scattered inside. This co-existence of two binder phases enhances the mechanical strength of the geopolymer concrete. Black Rice Husk Ash (BRHA) is an agro-industrial waste generated from rice milling industry. It is obtained by burning rice husk in the incinerator. The ash obtained as a result of this combustion process has a high content of unburnt carbon. Hence the use of BRHA as a construction material is very limited, even though it has high silica content about 90%. But several researchers reported that the addition of BRHA in concrete has improved its durability property.

In Geopolymer concrete, most of the research works have been made in Fly ash based geopolymers and in this present study, industrial waste which is Ground Granulated Blast Furnace Slag (GGBS) and the agro waste which is Black Rice Husk Ash (BRHA) are used as source materials for Geopolymer concrete. GGBS was kept as the base material in which BRHA was replaced at different

percentages and its effect on the compressive, Impact Strength of Geopolymer Concrete were studied.

2. MATERIAL AND METHODOLOGY

A) Black Rice Husk Ash (BRHA)

BRHA was obtained from a Kodhari Bio Fuels at Purasaivakkam. It was finely ground in a ball – mill for a 30 minutes and passed through 75 microns sieve before using in GPC production.



Figure1 Black Rice Husk Ash

Table 1 Chemical Properties of Black Rice Husk Ash

S.NO	PROPERTY	VALUE
1	Silicon- di- oxide(SiO_2)	93.96 %
2	Aluminium tri oxide (Al_2O_3)	0.56 %
3	Ferric Oxide (Fe_2O_3)	0.43 %
4	Calcium Oxide (CaO)	0.55 %
5	Magnesium Oxide (MgO)	0.40 %
6	Loss On Ignition	9.79 %
7	Specific Gravity	2.41
8	Blaine Fineness	5673 cm^2/g

B) Ground Granulated Blast Furnace Slag (GGBS)

GGBS is obtained from JSW Cement Godown.

It is stored in tight bags.



Figure 2 GGBS

Table2 Chemical properties of GGBS

S.NO	PROPERTY	VALUE
1	Silicon-oxide(SiO_2) di-	31.25 %
2	Aluminium oxide (Al_2O_3) tri	14.06 %
3	Ferric Oxide (Fe_2O_3)	2.80 %
4	Calcium Oxide (CaO)	33.75 %
5	Magnesium Oxide (MgO)	7.03 %
6	Loss On Ignition	1.52 %
7	Specific Gravity	2.61
8	Blaine Fineness	4550 cm^2/g

C) Fine aggregate

Locally available river sand having a bulk density of 1693 kg/m^3 , fineness modulus of 2.75, specific gravity of 2.61 and conforming to grading zone-III as per IS: 383 - 1970 was used.



Figure 3 Fine Aggregate

D) Coarse aggregate

Crushed granite coarse aggregates of 12.5 mm maximum size having a specific gravity of 2.73 were used. Bulk Density of the coarse aggregate used is 1527 kg/m³



Figure 4 Coarse Aggregate

E) Crimped steel fibre

Crimped steel fiber of 30mm length, 0.4mm diameter and aspect ratio of 60 is used. These fibers have a density of 7850 kg/m³, modulus of elasticity of 2x10⁵ MPa and yield strength of 650 MPa .



Figure 5 Crimped Steel

F) Alkaline liquid

Preparation of Alkaline Activator Solution

A combination of sodium hydroxide solution of 8 molarities and sodium silicate solution was used as alkaline an activator solution for geopolymerisation. To prepare sodium hydroxide solution of molarity (8M), 320 g [8molarity x 40(molecular weight of NaOH)] of sodium hydroxide flakes was dissolved in one litre of distilled water.

DEVELOPMENT OF GEOPOLYMER CONCRETE

Table 3 Mixing quantities

S.NO	MATERIALS	QUANTITIES (Kg/m ³)			
		GP	GPR1	GPR2	GPR3
1	GGBS	394	355	315	276
2	BRHA	0	39	79	118
3	Fine aggregates	554	554	554	554
4	Coarse Aggregates	1294	1294	1294	1294
5	Sodium hydroxide	45	45	45	45
6	Sodium Silicate	113	113	113	113

Note: GP-Geopolymer, GPR1-90% of GGBS+10% of BRHA, GPR2-80% of GGBS+20% of BRHA, GPR3-70% of GGBS+30% of BRHA.

3. PREPARATION OF TEST SPECIMEN

The materials GGBS were weighed and first mixed in dry condition for 3-4 minutes. Sodium hydroxide of 8M was added with sodium silicate solution which was added to the dry mix. The mixing was continued for about 6-8 minutes. After the mixing, the concrete was placed in steel mould by giving proper compaction. Precautions were taken to ensure uniform mixing of the ingredients.

For the ambient curing, the cubes were kept in room temperature after casting and de-molded after 1 day and further cured in the room temperature till the day of testing. The cubes were then tested at 7 and 28 days from the day of casting. Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the Black rice husk ash, GGBFS and the aggregates were first mixed together in dry condition.



Figure 6 - 10%BRHA replacement



Figure7- 20%BRHA Replacement



Figure 8- 30%BRHA Replacement



Figure 9 Compressive Strength Testing

Table4- Compressive Strength

MIX	COMPRESSIVE STRENGTH (N/mm ²)	
	7 DAYS	28 DAYS
GPR1	44.72	52.46
GPR2	40.75	47.32
GPR3	20.8	27.24

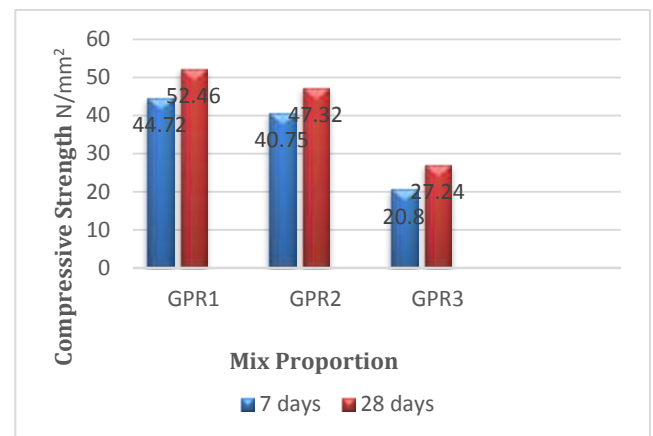


Figure 10 Compressive Strength

4. RESULT AND DISCUSSION

A) Compressive strength:- In accordance to IS 10080-1982, each layer was well compacted by a tamping rod of 12mm diameter. After compaction, the top surface was leveled using a trowel and left for 24 hours to dry in room temperature. The Geopolymer concrete cubes, prepared using different combination of GGBFS and BRHA with sodium silicate and sodium hydroxide solution. The specimens are tested in a 2000 kN capacity hydraulic compression testing machine, as per IS: 4031-1982 (Part 6). Totally eighteen numbers of geopolymer concrete cubes, six each for the various combinations were cast and tested. The testing of Geopolymer concrete cubes on the compression testing machine is shown in fig.

B) IMPACT TEST

In this study Geo-polymer concrete specimens were casted with replacement of BRHA with 10% and 90% of GGBS by volume of concrete. Specimens were prepared by addition of crimped steel fibers of 0.5%, 0.75% and 1% by volume of concrete. The size of the specimen is as per ACI standards. Diameter is 152 mm and thickness of the specimen is 63.5mm. Geo polymer concrete is cured at ambient conditions. The specimens are placed on the Impact testing equipment. Weight by dropping hammer is 45N and the drop height is 457mm. These specimens are placed on the base plate with finished face up and

positioned within four legs of the Impact testing equipment. The bracket with cylindrical sleeve is fixed in place and the hardened steel ball is placed on the top of the specimen within the bracket.

The drop hammer is then placed with its base upon the steel ball and held vertically. The hammer is dropped repeatedly. The number of blows required for the first visible crack to form on the top surface of the specimen is recorded and also for the ultimate failure. Formation of first crack was found by visual observation and the corresponding number of blows noted (N1) is recorded. The number of blows required to open the cracks in the specimen and the fractured pieces touching the positioning legs (N2) is also recorded. The impact strength in number of blows is shown in the table. The Impact energy delivered to the specimen is calculated as



Figure13 Test Specimen in impact mould



Figure 11 Impact Test Apparatus



Figure14 Test Specimen with 0.5% of Crimped Fiber



Figure12 Mixing concrete with Fibre



Figure15 Test Specimen with 0.75% of Crimped Fibre



Figure 16 Test Specimen with 1 % of Crimped Fiber



Figure 20 Final Crack of 0.5% Crimped Fibre @ 28 Days



Figure 17 Final Crack of 0.5% Crimped Fibre @ 7 Days



Figure 21 Final Crack of 0.75% Crimped Fibre @ 28 Days



Figure 18 Final Crack of 0.75% Crimped Fibre @ 7 Days



Figure 22 Final Crack of 1% Crimped Fibre @ 28 Days



Figure 19 Final Crack of 1% Crimped Fibre @ 7 Days

DROP WEIGHT OF IMPACT TEST RESULT

Table 5 Drop Weight Impact Test Result

No. of Blows Recorded	% of Fiber					
	0.5 %		0.75 %		1.0 %	
	7days	28days	7days	28days	7days	28days
No. of Drops for First Crack N1	330	351	222	239	171	197
No. of Drops for Failure N2	354	392	273	292	203	227

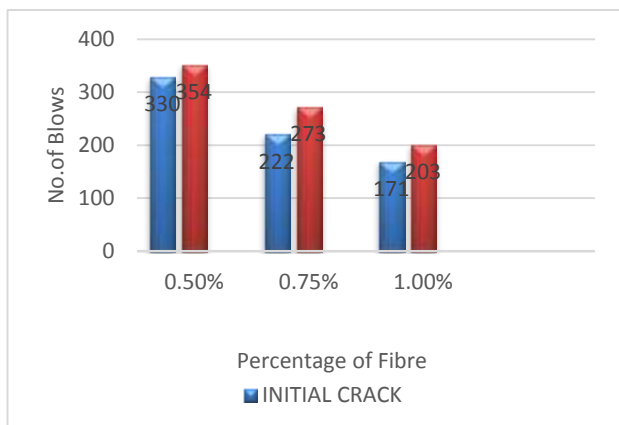


Figure 23 Impact Value for Various % of Crimped Fibre-7 Days

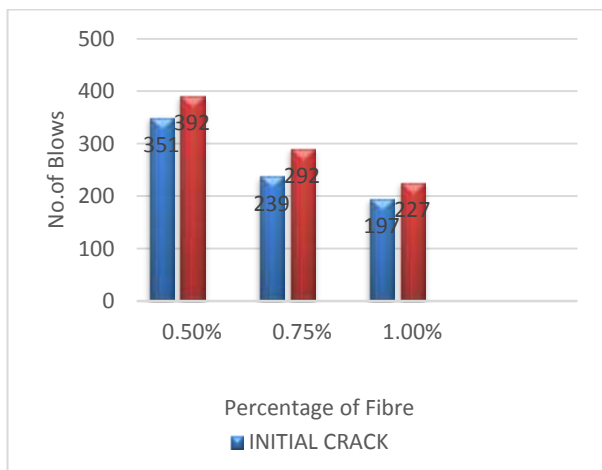


Figure 24 Impact Value for Various % of Crimped Fibre-28 Days

ENERGY ABSORPTION OF FIBER REINFORCED GEOPOLYMER CONCRETE

Table 6 Energy Absorption of Fiber Reinforced Geopolymer Concrete (N-m)

Energy Absorption N-m	% of Fiber					
	0.5 %		0.75 %		1.0 %	
	7days	28days	7days	28days	7days	28days
Impact Energy at First Crack E1 N-m	6742	7171	4536	4883	3494	4025
Impact Energy at Failure crack E2	7233	8009	5578	5966	4148	4644

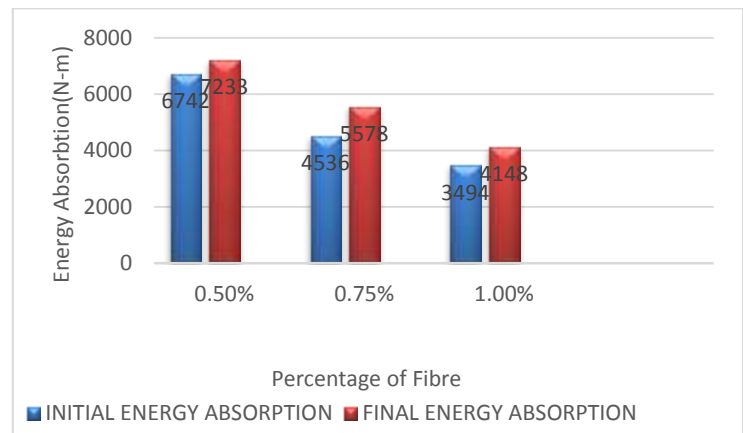


Figure 25 Energy Absorption for Various % of Crimped Fibre-7 Days

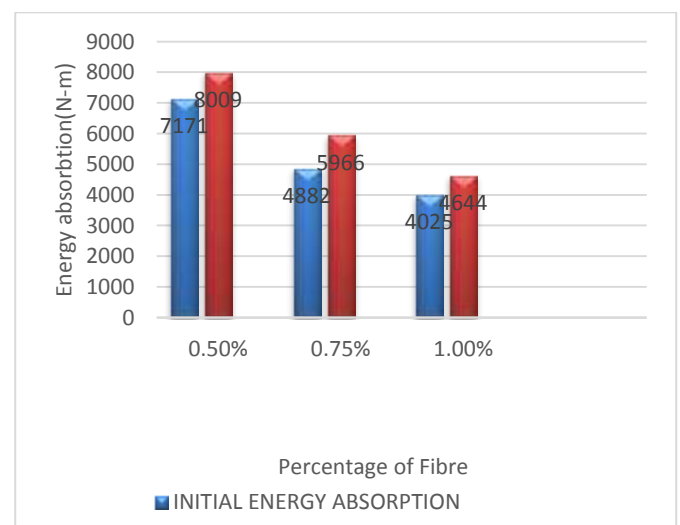


Figure 26 Energy Absorption for Various % of Crimped Fibre-28 Days

CONCLUSIONS

- The compressive strength of specimen with 10% BRHA replacement was found to be higher than other replacement percentage.
- The compressive strength with 10% BRHA replacement is 10% higher than 20% replacement and 115% higher than 30% replacement at 7 days.
- The compressive strength with 10% BRHA replacement is 11% higher than 20% replacement and 92% higher than 30% replacement at 28 days.
- Impact specimens with 0.5% of crimped fiber were found to absorb higher energy compared to the other 0.75% and 1% of fibers.
- The energy absorption of specimen with 0.5% crimped fiber is 47% higher than the 0.75% and 78% higher than the 1% during the initial crack.
- The energy absorption of specimen with 0.5% crimped fiber is 34% higher than the 0.75% and 72% higher than the 1% of the ultimate failure.

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