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Experimental investigation on geopolymer concrete subjected to elevated temperature

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ABSTRACT

Geopolymer concrete can be expressed as "concrete without cement". Geopolymer concrete is environmentally friendly and an inventive way to replace the conservative concrete which contributes 7-8% of total CO_2 production in the world. "The concrete which entails of the source materials and the alkaline solution". The source material can be from agricultural wastes such as Bagasse ash, Rice husk ash, Palm fuel ash, etc and the industrial by-products such as Fly ash, Ground Granulated Blast Furnace Slag, Copper Slag, etc. The alkaline solutions can be either sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicate. In the present study, an effort has been made to check the likelihood of reuse of bagasse ash in Geopolymer Concrete by probing mechanical properties of M30 grade concrete for 0, 25, 50, 75 and 100 percent replacement by bagasse ash. The behavior of 100% GGBS replaced concrete under elevated temperature by weight loss, residual strength, cracking pattern and spalling pattern.

Keywords— *Geopolymer concrete, Sunlight curing, GGBS, Bagasse-ash, Weight loss, Residual strength*

1. INTRODUCTION

What is the most frequently used material on our sphere? some of you would perhaps think water and you would be right but if I were to ask you what you alleged was the second most commonly used material in our earth you might think timber or plastic or even steel so you most likely be surprised when I tell you that it is in fact concrete.

This year alone the Portland cement association estimates that we will yield over 4 billion tonnes of cement worldwide for the manufacture of concrete. So, what's the problem? The problem is finite natural resources the problem is acidification of our oceans the problem is the type of weather change. For every tonne of cement, we produce through the crushing, heating and grinding of the limestone over three-quarters of the tonne of carbon dioxide is released into our planet's atmosphere. This will equivalent over 3.2 billion tonnes of carbon dioxide this year alone the compatible with the emissions of 581 million cars that's all of the car wholes in Europe and America and China.

Conservative concrete is made using cement and water to impasse virgin aggregate materials such as gravel and sand taken from quarries, riverbeds, and beaches not only this material relies on finite natural resources but it also yields large volumes of carbon-di-oxide. The geopolymer concrete customs the by-products materials of industrial processes such as water purification, waste incineration and the production of steel. This is united with waste materials such as GGBS, Bagasse Ash, quarry dust, agricultural waste and recycle construction aggregates to yield high-performance low influence concrete. We must move from our current model of taking, make and dispose of a more sustainable circular model to make, use and recycle. The high-performance low influence geopolymer concrete is one of the methods in which we can do this.

Geopolymer concrete is a creative and ecosystem friendly building material and it's one of the customs to replace to the normal Portland cement concrete. The employment of geopolymer concrete diminishes the mandate of the OPC which is accountable for "global warming".

Geopolymer was the name given way back in 1978 by the investigator J Davidovits to the material which is made by the chains or ring structure or inorganic molecules or three-dimensional structure. Geopolymer concrete can be expressed as "A concrete without cement" which is defined as "The concrete which consists of the source materials and the alkaline solution". The source material can be from agricultural wastes such as Bagasse ash, Rice husk ash, Palm fuel ash, etc and the industrial by-products such as Fly ash, Ground Granulated Blast Furnace Slag, Copper Slag, etc. The alkaline solutions can be either sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicate.

2. LITERATURE REVIEW
Jeetendra Ahirwar et al explains the waste generated from the demolition in India is about 530 million tonnes every year, which causes a serious problem of disposing of it. Based on study 3 different mix proportion of geopolymer concrete are considered which yields better results. The impact value of the demolition aggregates was 12.26%, after the casting, the test specimens are heat cured at 80 degrees for 24 hours. From the three different mix proportions, this mix proportion 1:1.5:3 yields the best than the other two mix proportions which are 1:1.75:3.25 and 1:1:1.85. The fly ash-based concrete with 100% replacement decreases the strength of about 5 to 10%, even the split tensile strength also decreases. The fly ash based geopolymer concrete solves the problem of disposal in India and also helps to overcome the environmental pollution.

Dilip Srinivas et al explains to understand the utility of bagasse ash in geopolymer concrete. Production of one tonne of cement emits the hazardous pollutants of 0.8 tonnes which cause environmental pollution. The bagasse ash passing through 150 microns sieve with the specific gravity of 0.32 was taken for the study. The experimental program was carried out for two different replacement viz 25% and 30% of SCBA. The test specimens cast are the cubes of 150mmx150mmx 150mm and the RC beams of 150mmx150mmx1100mm to study the compressive strength and the flexural strength, density check, slump. The geopolymer concrete shows good results with a low concentration of NaOH viz 5M concentration of NaOH, GPC achieves the early strength of about 95% at 7 days. The density of the geopolymer mix i.e, 2276 kg/cum which is less than the normal concrete i.e, 2400 kg/cum. The workability the mixes of 25 and 30% were good viz 150mm and 170mm respectively. The bagasse based geopolymer concrete solves the problem of an unnecessary landfill and also helps in reducing pollution.

Mr Bennet Jose Mathew et al explains the impact of cement production on the environment in fact 7% of total carbon emission in the world is due to the cement manufacture. Geopolymer concrete is produced using fly ash and GGBS which are industrial waste that can reduce the carbon emission to the atmosphere. The materials physical properties and chemical properties are discussed fly ash, bottom ash, sand, coarse aggregates, and cement with specific gravity 2.05, 2.63, 2.88 and 3.13 respectively, the silica content in fly ash and bottom ash are 53.3 and 57.6% respectively. The parameters controlled are the 15M concentration of NaOH, sodium silicate in the ratio of 2.33, the sodium hydroxide of 97% purity, water is used for mixing the proportion, naphthalene sulphonate is the superplasticizers used and the heat curing at 60 degrees for 24 hours. Different methods of curing like heat and ambient curing will produce fly ash GGBS concrete with comparative strength, this concrete showed a lower strength due to the large particle distribution in the source materials, geopolymer concrete is 7% higher than the OPC concrete, the embodied energy is 40 percent lesser than the OPC concrete. Hence this method helps to reduce pollution and can lead to an eco-friendly environment.

Omar A. Abdulkareem et al explain the mechanical properties of lightweight geopolymer concrete subjected to the elevated temperature from 100 degrees to 800 degrees. The mechanical properties of the unexposed lightweight geopolymer concrete show better results in strength to weight ratio than the lightweight geopolymer concrete which is published in other research. The mechanical property of the specimens proves its reliability use in the industry due to its pozzolanic activity of strength which increases at the age of 365 days. The lightweight geopolymer concrete which is exposed to an elevated temperature for 100, 200, 300 degree has a better thermal resistance whereas the specimens which are exposed after 400 degree insists the decrease in residual strength due to vapour effect in the geopolymer concrete. It's preferable to use this geopolymer concrete for a design of fire-resistant structure because the rate of degradation increases with the increase in time and temperature. The unexposed geopolymer concrete bonding between the paste and aggregates is impressive than other concrete which is analyzed in the ITZ transition zone.

3. MATERIALS
The properties of the following materials are enumerated further down:

3.1 Ground Granulated Blast Furnace Slag (GGBS)
Ground Granulated Blast Furnace Slag (GGBS) is a by-product from the blast furnace which is used to manufacture iron. The physical property of the GGBS determined such as specific gravity and fineness of the material. The specific gravity of GGBS is 2.92 and the percentage of passing through 90 microns IS sieve is 94%.

3.2 Bagasse Ash (BA)
The end product from the sugarcane industry which is commonly known as Sugar Cane Bagasse Ash (SCBA). The physical property of the Baggase Ash determined such as specific gravity and fineness of the material. The specific gravity of Bagasse ash is 0.32 and the percentage of passing through 90 microns IS sieve is 38%.

3.3 Sodium Hydroxide (NaOH)
Sodium hydroxide flakes used in this research are of commercial grade with 97% purity. The physical properties such as molecular weight are 40 grams, density is 1470 kg/m^3 and specific gravity is 1.47.

3.4 Sodium Silicate (Na_2Sio_3)
Sodium silicate solution flakes used in this study are of commercial grade with 97% purity. The physical properties such as molecular weight are 122.062 grams, density is 1600 kg/m^3 and specific gravity is 1.6.

3.5 Fine Aggregate (FA)
Manufactured Sand (M-sand) confirms to zone-IV from sieve analysis. Its specific gravity is found to be 2.51 and water absorption of 1.25%. Its loose density and compacted densities are 1317 kg/m^3 and 1572 kg/m^3 respectively.

3.6 Coarse Aggregate (CA)

10mm aggregates confirm to IS 383-1970 from sieve analysis. Its specific gravity is found to be 2.62 and water absorption of 1.4%. Its loose density and compacted densities are 1353.31 kg/m^3 and 1534.16 kg/m^3 respectively.

20mm aggregates confirm to IS;383-1970 from sieve analysis. Its specific gravity is found to be 2.6 and water absorption of 1.6%. Its loose density and compacted densities are 1264 kg/m^3 and 1479 kg/m^3 respectively.

3.7 Distilled Water

Water is very essential in concrete which helps in providing the strength in the binder and helps to stimulate the chemical reaction. The pH of distilled water is between 5.6 and 7.

3.8 The physical property of Bagasse Ash:

In geopolymer concrete, silica and aluminum play a very important role in providing strength to the concrete. The minimum criteria for the selection of Bagasse Ash are the combined percentage of Silica, Aluminium and Iron should be greater than 70%.

Table 1: Chemical Composition of Bagasse Ash

S.no.	Test	Unit	Results
1.	Silicon as SiO_2	%	76.062
2.	Iron as Fe_2O_3	%	5.609
3.	Aluminum as Al_2O_3	%	4.948
4.	Calcium as CaO	%	1.860
5.	Magnesium as MgO	%	1.487
6.	Sodium as Na_2O	%	0.552
7.	Potassium as K_2O	%	1.776
8.	Fixed carbon	%	0.71

4. METHODOLOGY

4.1 General

(a) Preliminary tests on aggregates being carried out for manufactured sand, 10 mm aggregates, and 20 mm aggregates
(b) Preliminary tests on source materials [bagasse-ash and GGBS] is being carried out such as specific gravity and fineness of the sample
(c) Design mix for the geopolymer concrete for the grade of M30 mix is done by adopting Rangan method design mix of geopolymer concrete
(d) Preparation of sodium hydroxide solutions for 5M, 10M, 15M concentration, it takes place exothermic reaction for about 24 hours
(e) Preparation of alkaline solution by adding sodium silicate to the sodium hydroxide solutions before 30 minutes of casting
(f) Preparation of test specimens for the requirements mentioned below
(g) The trail mixes are carried out for 100% GGBS replacement with varying concentration 5M,10M,15M NaOH
(h) The test specimens are casted for various mixes (0%, 25%, 50%, 75%, 100% GGBS replaced by Bagasse Ash) which are cubes (150mmx150mmx150 mm), cylinders (height=300mm,diameter=150 mm) and beams (100mm x100mmx500mm) with different molarity (5M,10M,15M)
(i) The test specimens are demoulded and exposed to the sunlight for the sunlight curing
(j) The results such as compressive strength, split tensile strength and flexural strength are tabulated for cubes, cylinders, and beams respectively
(k) The economic replacement is being carried forward for the behavior of concrete under elevated temperature up to 800^o c for a duration of 2 hours
(l) The test specimens are demoulded and exposed to the sunlight for the sunlight curing
(m) The following observations are made such as spalling and cracking patterns on the tested specimens
(n) Further the results such as residual strength and the weight loss for the tested specimens are tabulated

Table 2: Mix design for 1m^3 of concrete

Mix-proportion per cubic meter	
sodium silicate	170.32 kg
Sodium hydroxide solution	68.12 kg
Extra water required	75 kg
Baggase-Ash	346.832 kg
GGBS	86.71 kg
Fine aggregate (M-sand)	760.32 kg
Coarse aggregate	967.68 kg
20 mm downsize aggregates	483.84 kg
10 mm downsize aggregates	483.84 kg

Fig. 1: Batching of materials as per mix design

Fig. 2: Dry mix and Wet mix in the pan mixer

Fig. 3: Compaction by tamping rod

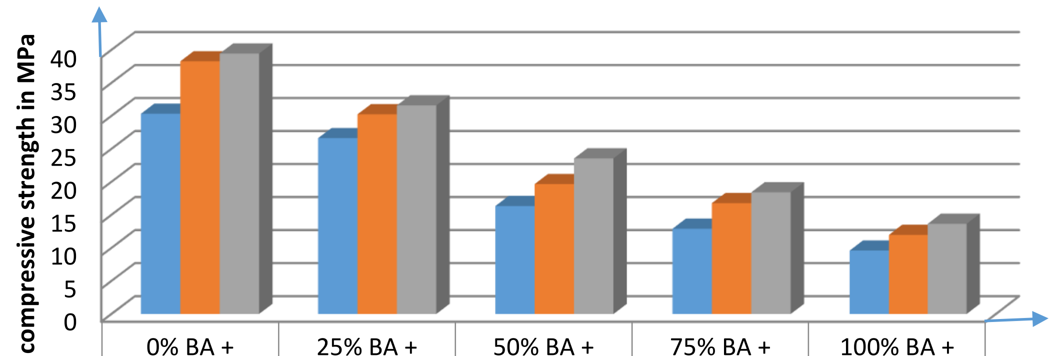
Fig. 4: Casted specimen

4.2 Sunlight curing

For the curing of geopolymer concrete specimens, the specimens are placed in direct sunlight. For the sunlight curing the cubes are demoulded after 24 hours of casting and they are placed in direct sunlight for 28 days.

Fig. 5: Sunlight curing

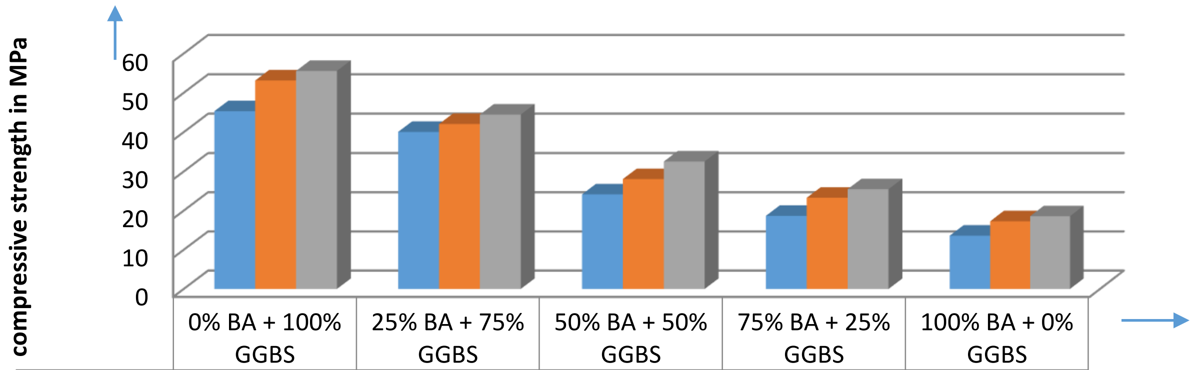
5. EXPERIMENTAL RESULTS



	0% BA + 100% GGBS	25% BA + 75% GGBS	50% BA + 50% GGBS	75% BA + 25% GGBS	100% BA + 0% GGBS
5M NaOH	30.32	26.62	16.34	12.9	9.6
10M NaOH	38.27	30.24	19.66	16.77	11.97
15M NaOH	39.45	31.59	23.55	18.41	13.65

Fig. 6: A comparative study of 7 days compressive strength on molarity of NaOH

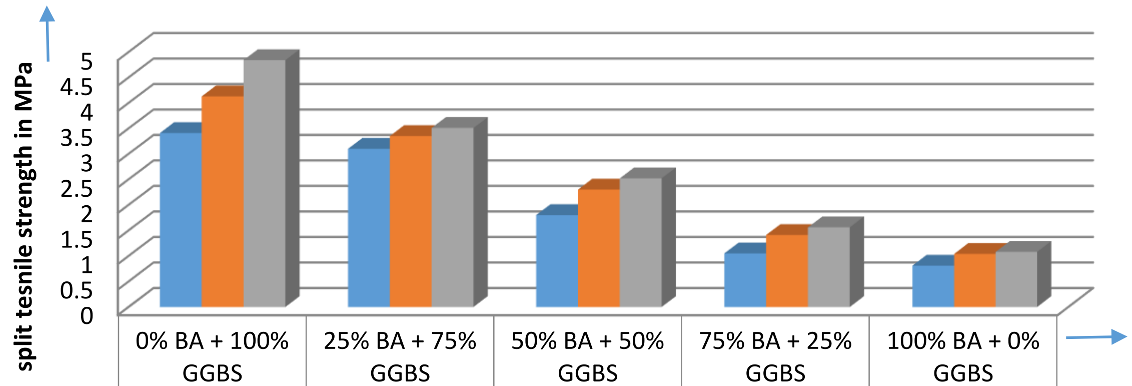
From graph in figure 6, it can be witnessed that the compressive strength of the geopolymer concrete at the 7^{th} day increases as the molarity of NaOH increases. Similar annotations with regard to molarity of NaOH have been prepared by other investigators. For geopolymer concrete with 100% GGBS, the compressive strength with 5M, 10M and 15M NaOH are 30.32 MPa, 38.27 MPa, and 39.45 MPa respectively. Similarly, for 75%, 50%, 25%, and 0% GGBS, the compressive strength increases as the molarity of NaOH increases.



	0% BA + 100% GGBS	25% BA + 75% GGBS	50% BA + 50% GGBS	75% BA + 25% GGBS	100% BA + 0% GGBS
5M NaOH	45.32	40.07	24.15	18.68	13.61
10M NaOH	53.14	42.08	28.06	23.29	17.29
15M NaOH	55.56	44.46	32.54	25.48	18.57

Fig. 7: A comparative study of 7 days compressive strength on molarity of NaOH

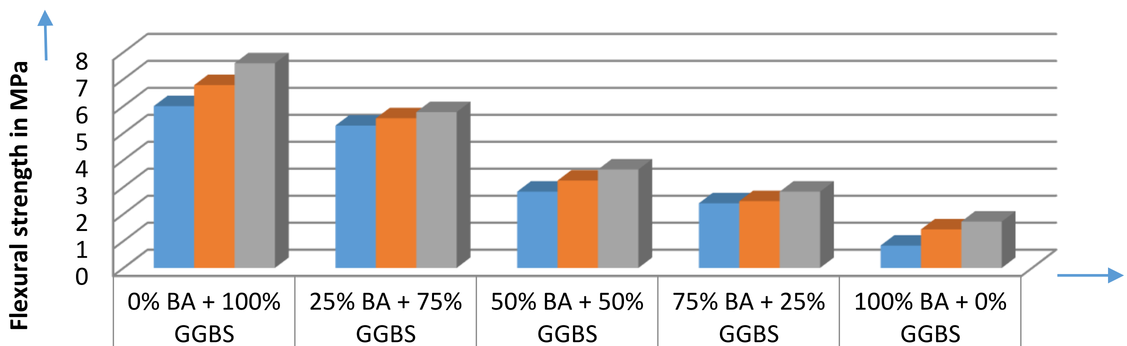
From the graph in figure 7, it can be pragmatic that the compressive strength of the geopolymer concrete at the 28th day increases as the molarity of NaOH increases. Similar annotations with respect to molarity of NaOH have been prepared by other investigators. For geopolymer concrete with 100% GGBS, the compressive strength with 5M, 10M and 15M NaOH are 45.32 MPa, 53.14 MPa, and 55.56 MPa respectively. Similarly, for 75%, 50%, 25%, and 0% GGBS, the compressive strength increases as the molarity of NaOH increases.



	0% BA + 100% GGBS	25% BA + 75% GGBS	50% BA + 50% GGBS	75% BA + 25% GGBS	100% BA + 0% GGBS
5M NaOH	3.41	3.1	1.8	1.05	0.81
10M NaOH	4.13	3.35	2.3	1.41	1.04
15M NaOH	4.84	3.51	2.52	1.56	1.08

Fig. 8: A comparative study of 28 days split tensile strength on molarity of NaOH

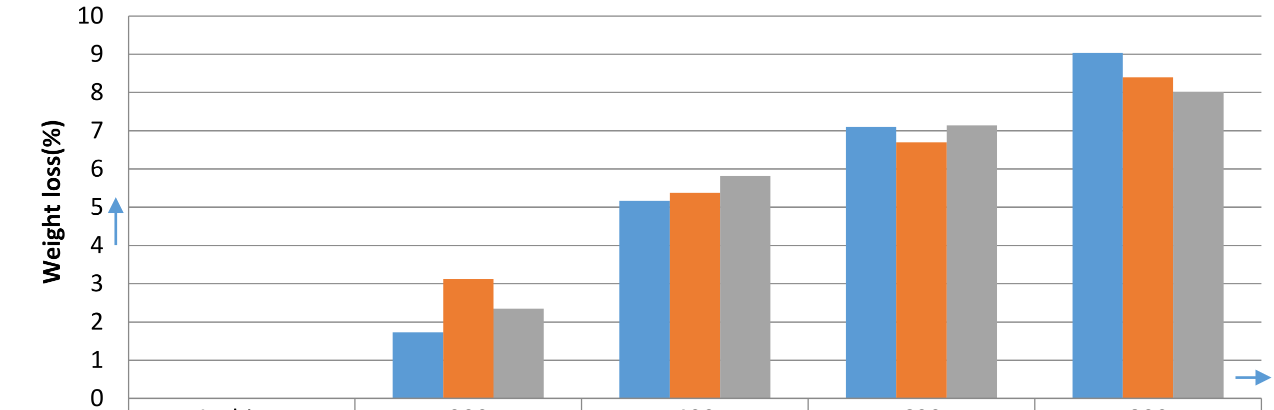
From the graph in figure 8, it can be perceived that the split tensile strength of the geopolymer concrete at the 28th day increases as the molarity of NaOH increases. Similar observations with respect to molarity of NaOH have been made by other investigators. For geopolymer concrete with 100% GGBS, the split tensile strength with 5M, 10M and 15M NaOH are 3.41 MPa, 4.13 MPa, and 4.84 MPa respectively. Similarly, for 75%, 50%, 25%, and 0% GGBS, the split tensile strength increases as the molarity of NaOH increases.



	0% BA + 100% GGBS	25% BA + 75% GGBS	50% BA + 50% GGBS	75% BA + 25% GGBS	100% BA + 0% GGBS
5M NaOH	6	5.28	2.83	2.4	0.83
10M NaOH	6.78	5.55	3.24	2.48	1.43
15M NaOH	7.59	5.78	3.65	2.83	1.72

Fig. 9: A comparative study of 28 days flexural strength on molarity of NaOH

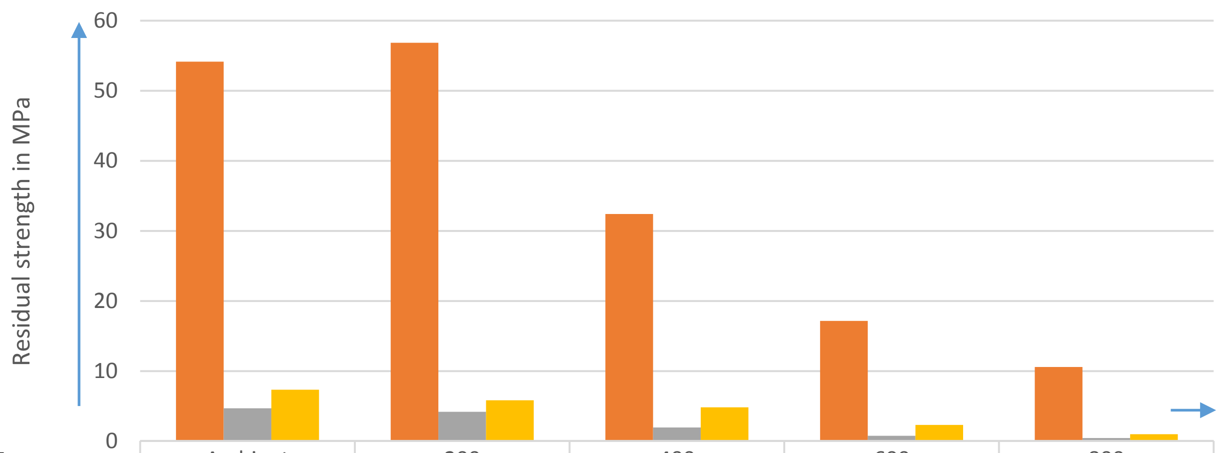
From graph in figure 9, it can be witnessed that the flexural strength of the geopolymer concrete at the 28th day increases as the molarity of NaOH increases. Similar annotations with regard to molarity of NaOH have been through by other investigators. For geopolymer concrete with 100% GGBS, the flexural strength with 5M, 10M and 15M NaOH are 6 MPa, 6.78 MPa, and 7.59 MPa respectively. Similarly, for 75%, 50%, 25%, and 0% GGBS, the flexural strength increases as the molarity of NaOH increases.



Temperature	Ambient	200	400	600	800
Cubes	0	1.73	5.17	7.1	9.03
Cylinders	0	3.13	5.38	6.7	8.4
Beams	0	2.35	5.82	7.14	8.02

Fig. 10: A comparative study of Weight loss w.r.t Elevated temperature

From the graph in figure 10, it can be detected that the average weight loss increases as the temperature increases for an exposure of 2 hours. Similar observations with regard to average weight loss have been made by other investigators. At ambient temperature, there is no change in the mass. At 200ºC sustained elevated temperature it's understood that there is an increase in average weight loss in cubes, cylinders, and beams to 3.13%, 1.73%, 2.35% w.r.t ambient temperature. Likewise, at 400ºC, 600ºC, and 800ºC the average weight loss in geopolymer concrete increases w.r.t ambient temperature respectively. The test specimens are self-governing of each other w.r.t weight loss.



Temperature	Ambient	200	400	600	800
Cubes	54.15	56.84	32.4	17.14	10.56
Cylinders	4.67	4.18	1.95	0.74	0.45
Beams	7.32	5.84	4.8	2.32	0.96

Fig. 11: A comparative study of Residual strength w.r.t Elevated temperature

From the graph in figure 11, it can be pragmatic that the average residual split tensile strength decreases as the temperature increases for an exposure of 2 hours. Parallel observations with respect to average residual strength have been through by other investigators. At ambient temperature, there is no change in the residual strength. At 200ºC sustained elevated temperature it's understood that there is a decrease in average residual strength in cylinders and beams by 10.49% and 20.22% w.r.t ambient temperature but for cubes, the residual strength is increased by 1.05%. Similarly, at 400ºC, 600ºC, and 800ºC the average residual split tensile strength decreases w.r.t ambient temperature respectively.

6. CONCLUSIONS

- The economic replacement level of geopolymer concrete can be carried up to 25% Bagasse ash with 75% GGBS which contributes maximum strength
- The strength in geopolymer concrete increases as the molar concentration of sodium hydroxide increases

- The weight loss in geopolymer concrete increases as the elevated temperature increases
- The residual strength in geopolymer concrete decreases as the elevated temperature increases
- The geopolymer concrete has a better resistance against surface cracking and spalling up to 600ºC

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