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INFLUENCE OF ALKALINE ACTIVATORS AND TEMPERATURE ON STRENGTH PROPERTIES OF GGBS BASED GEOPOLYMER CONCRETE

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ABSTRACT

Since last few years, Concrete Technologists are putting in continuous efforts to minimize the consumption of Portland cement in concrete. Cement concrete offering architectural freedom is second highest consumed material on earth. Portland cement production is one of the major causes of CO_2 emission in atmosphere. With limited natural resources and durability issues, a need is felt to lessen or curtail the use of cement in concrete and replace the same with immensely available industrial by-products. Partial replacement of Portland cement has been successful but research is still going on for its complete replacement by materials that are rich in Silica and Alumina. These materials, when activated by an alkaline solution exhibit similar strength and durability properties of that of conventional cement concrete. Present study emphasizes on studying potential application of GGBS, in presence of Sodium based alkaline activators, for developing Geopolymer concrete. Compressive strength development up to 90 days is studied for different molarities (2M-8M) of NaOH solution and varying temperature conditions (ambient and oven). Split tensile strength tests were done on cylinders on 28th day of casting. From this study it is revealed that with the similarity in structural behaviour with conventional concrete, Geopolymer Concrete from GGBS can be a potential material for the construction industry in future.

KEYWORDS: Alkaline Activators, Compressive Strength, GGBS, Geopolymer Concrete, Molarity, Split Tensile Strength, Temperature

INTRODUCTION

Portland cement concrete is considered an "artificial stone", which is made by mixing Portland cement, water, sand and crushed stone aggregate. Cement concrete is used more than any other man-made material in the world, making it the second most widely consumed substance on the earth after water [1]. The environmental and sustainability problems that have arisen with the extensive use of Portland cement have led to the need to develop strategies to minimize these problems. There are various studies now that aim at developing alternate pozzolanic material such as fly ash, slag, rice husk ash, metakolinite etc. that can partially or wholly replace cement in the production of concrete [1]. India with annual production of 390 million tons, ranks second in the world as producer and consumer of cement [2][3][4].

Cement less alkali activated of binders that are produced by activating aluminate and silicate bearing materials with a caustic activator are the being studied extensively across the world. These binders are referred as **Geopolymer binders**[5].GGBS had been used to make durable concrete structures in combination with OPC and/or other pozzolanic materials in Europe, United States, Japan and Singapore because of its contribution to durability of concrete, which extends the life of buildings from fifty years to hundred years[6].In 1978, Prof. Joseph Davidovits developed a technology for alkali activated binder material by subjecting the mixture to high temperatures. He gave it the name '**Geo-Polymer**'; geo referring to products related to earth and polymerization being the action due to which, the material gains strength. According to Davidovits, any material that contains mostly silicon (Si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer [7]. Geopolymers consist of a polymeric silicon-oxygen-aluminium framework, with alternating silicon and aluminium tetrahedron joined together in three directions by sharing of the oxygen atoms [8].

The foundations of modern research on concrete structures dates back to early 1940-1950. This technology of alkali activated cement or alkali activated material was first developed in Eastern Europe, in the 1940s. This technology has been developed post-World War 2 era, in Ukraine, France, Spain, Germany and other European countries. Important structures such as civil water works, railway sleepers, pipes, pavement, roads, fire resistance coatings, conventional precast products and few buildings such as 20 storey building in Lipestsk and 9 storey building in Ukraine were constructed using this technology [9] [6]. In the 1950s, due to a shortage of OPC in Eastern Europe, researchers conducted extensive work on the activation of GGBS with reactive alkalis to form cement applicable to concrete construction [10].When the work was completed, many structures were built using this type of cement. Duxson and Deventer claim that these structures have shown outstanding durability over the years. However, when OPC production was restored, these cements were once again side-lined and the technology lay dormant for the next 20 years till in 1979, Professor Joseph Davidovits, brought back the idea of alkali activated cements [11].Thus, although geopolymer based concretes have been known for a long time, their application has been sporadic over the years.

EXPERIMENTAL PROGRAMME

For this work **GGBS** was used as a source material for binder. It was obtained from a single source from a manufacturing company. It was very fine light brown coloured powder. The physical properties and chemical composition were within the limits given in IS 12089 and are given in Table 1 [12].

Table 1: Physical and Chemical Properties of GGBS

Oxides and Other Properties	Proportion
SiO_2	35.2%
Al_2O_3	21.4%
Fe_2O_3	1.8%
CaO	31.2%
MgO	8.4%
SO_3	0.15%
Colour	Light brown
Fineness (m^2/kg)	400
Specific gravity	2.9

The alkaline liquid was a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. Water, fine aggregates and coarse aggregates were also used. NaOH flakes and Na_2SiO_3 solution were procured from a local distributor.The ratio of Na_2SiO_3 solution to NaOH solution was kept as 1.5. The following table shows the mixture proportion adopted for experimental work.

Table 2: Mixture Proportion for Concrete

Materials	Quantity	Units
GGBS	425	kg/m^3
Coarse aggregates	1105	kg/m^3
Fine aggregates	505	kg/m^3
Alkaline liquid / GGBS	0.55	
Alkaline liquid (Na_2SiO_3 solution + NaOH solution)	233.75	kg/m^3

Mixing, Compacting and Curing of Concrete

For mixing, a rotating drum mixer of 80 litres capacity was used. Aggregates were prepared in saturated-surface-dry condition, and were kept in a plastic container. The mixing and compacting procedures were as per relevant Indian standard as code for geopolymer concrete has not been formulated [13]. The samples were cured at ambient temperature and at 50^{o}C in oven for 24 hours.The cubes and cylinders were tested to obtain the mechanical strength parameters for each mixture. For all of these tests, Indian standard testing methods and specifications for concrete were followed as testing standards for geopolymer concrete are not yet available. Compressive tests were conducted on 150 mm cubes in 2000 kN capacity Compression Testing Machine (CTM) available in the laboratory. Split tensile strength tests were conducted on cylinders of size 150mm diameter and 300mm length, in 2000kN capacity of the CTM. The testing procedures were according to the Indian Standard Code IS: 516 – 1959.

RESULTS AND DISCUSSIONS OF GEOPOLYMER CONCRETE FROM GGBS

Compressive Strength

The mean compressive strengths of the samples are shown below.

Table 3: Mean Compressive Strength (N/mm^2) of Concrete

Mix	Curing Condition	3 Days	7 Days	14 Days	28 Days	56 Days	90 Days
2M	Open air	28.91	40.20	48.53	52.29	53.61	54.09
	50^{o}C oven	40.90	45.33	52.01	54.81	54.80	56.01
4M	Open air	33.56	41.74	51.30	54.33	54.87	54.90
	50^{o}C oven	44.77	50.05	53.75	57.06	58.28	58.46
6M	Open air	37.81	48.48	55.69	59.53	59.47	59.55
	50^{o}C oven	49.50	53.90	57.43	62.08	62.21	64.27
8M	Open air	42.63	51.62	56.93	61.65	61.81	62.57
	50^{o}C oven	53.34	57.65	62.43	65.55	65.69	66.31

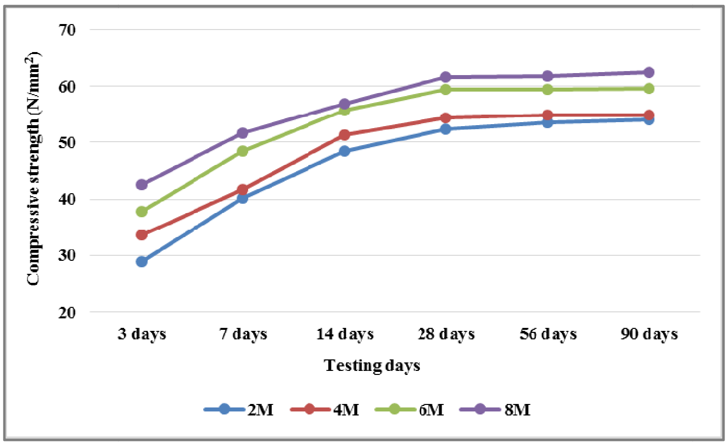

Figure 1: Compressive Strength of Concrete Cured at Ambient Temperature

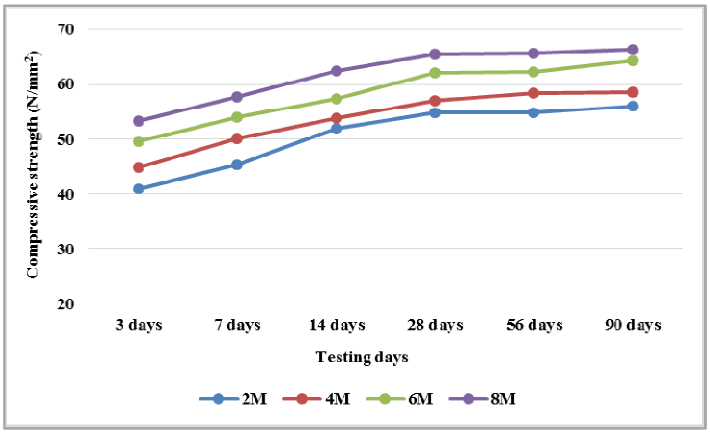

Figure 2: Compressive Strength of Concrete Cured at 50°c

Effect of Temperature Curing

The graphs for compressive strength for all days for all mixture proportions adopted and cured at varying temperature are shown below.

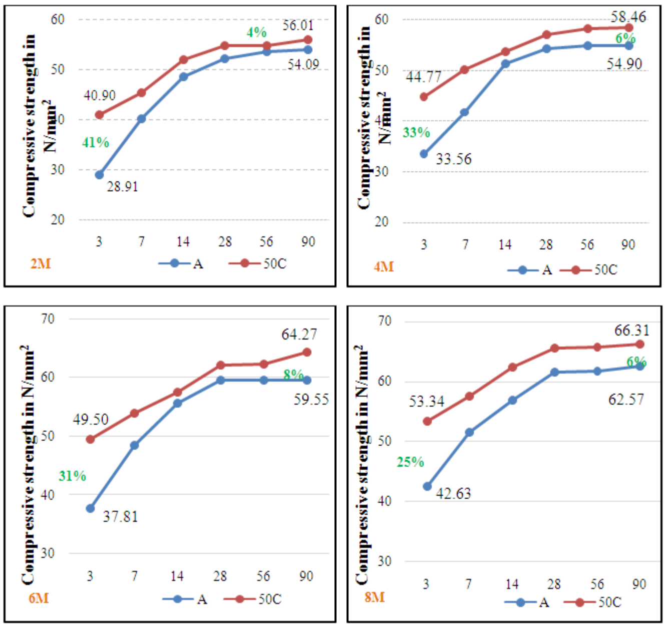

Figure 3: Effect of Temperature on Compressive Strength of Concrete with Varying Molarity

The following figure shows the effect of molarity and temperature on 28 days strength for different mixtures.

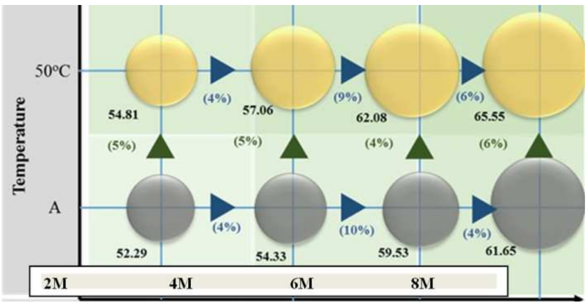

Figure 4: Effect of Molarity and Temperature on Compressive Strength on 28th Day

Split Tensile Strength

The mean split tensile strength values of geopolymer concrete with GGBS as source material are tabulated below in table 4. The figure 5 shows the relationship between compressive strength and split tensile strength of GGBS based Geopolymer concrete.

Table 4: Mean Split Tensile Strength of Concrete

Mix	Curing Condition	Split Tensile Strength in N/mm^2
2M	Open air	1.85
	50^{o}C oven	1.97
4M	Open air	1.86
	50^{o}C oven	1.98
6M	Open air	2.17
	50^{o}C oven	2.38
8M	Open air	2.64
	50^{o}C oven	2.67

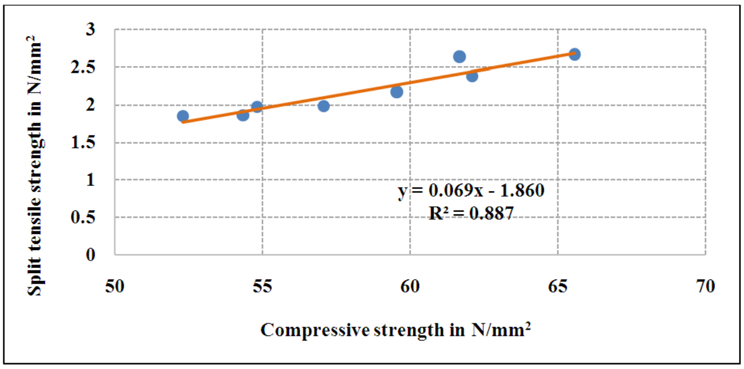

Figure 5: Relationship of Compressive Strength and Split Tensile Strength for GGBS based Geopolymer Concrete

OBSERVATIONS OF RESULTS

The main observations are listed as under:

- The cubes cured at oven temperature had higher strength than those cured in open air ambient conditions. The compressive strength was observed in the range of 52 N/mm^2 to 65 N/mm^2.
- About 95%-98% of the 90 days strength was achieved within 14 days of casting of cubes. The compressive strength for ambient curing may vary with the actual temperature at the time of casting and curing. These variations are to be considered accordingly.
- Overall difference in compressive strength due to increase in molarity from 4M to 8M of NaOH solution was consistently about 5-10%. With increase in molarity, about 10% of difference in compressive strength was seen in during the first few days and this difference decreased to 6% by 14 days. This change is lower in samples having 2M concentration.
- The split tensile strength was of about 3-4% of the corresponding compressive strength of the sample.

DISCUSSION AND CONCLUSIONS

- The compressive strength gain was higher during initial days and about 90 % of strength of 90 days was gained within the first 14 days of casting. The strength development for this type of mixture proportion showed that due to elevated temperature, there is initial strength gain.
- The source materials having this type of chemical components, when heated resulted in a very small increase (about 5%) in compressive strength after 28 days. The strength gain mechanism could be a result of hydration, because of the presence of substantial amounts of calcium and silica, and it is small due to polymerization. This might be due to polymerization of Si and Al in presence of Na^{++} ions. There was strength gain subsequently, which may be attributed to the presence of Ca ions in GGBS, which also combines with Si ions in presence of water. Here, water is already present in form of alkaline solution and also due to geopolymerization, water molecules are liberated, which combine with Ca and Si ions.
- Geopolymer concrete with GGBS as source material may have the combination of S-A-H gel along with C-S-H and this may contribute towards early and rapid strength gain. It is also mentioned in the literature that activation of materials with SiO_2+CaO resulted in 70% formulates [$(Na, K)_2O$-CaO-Al_2O_3-SiO_2-H_2O] system. This requires relatively low alkaline concentration. In this work, the main reaction product is a C-S-Hgel, similar to the gel obtained during Portland cement hydration, which takes up a small percentage of Al in its structure (C-(A)-S-H gel).[6]

With the benefits such as strong, durable and economical product, there is a need for awareness in the construction industry to start implementing this technology. It will be difficult as still research is ongoing in some areas and the codal regulations and specifications are yet to be drafted. A lot of confidence is also needed for the material to replace cement that has been ruling construction industry since more than 150 years. Although its applications have already commenced in some parts of world, it will take time to fully understand the material and its technology.

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