Effect of Temperature Curing on Bond Strength of Geopolymer Concrete

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Abstract –

Geopolymer concrete is being seen as replacement of conventional concrete because of better mechanical and durability characteristics than conventional cement concrete. If geopolymer concrete will be utilized in large scale it will use the industrial waste like fly ash, GGBS, silica fume and metakaoline. This will lead to environment friendly and sustainable development. To use geopolymer concrete as reinforced concrete it should have good bond strength with rebar. In this research effect of temperature curing on compressive strength and bond strength was studied. Seven type of mix were prepared by varying the binder content. From each mix 6 cube were prepared for compressive strength and 6 bond strength specimen were prepared. Half specimen were provided temperature curing and half were provided ambient curing. Compressive strength test and bond strength test was done. It was found that compressive strength and bond strength both were affected by binder content. If effect of curing is considered then it was observed that temperature curing cause increase in compressive strength but does not affect the bond strength. Bond strength of geopolymer concrete was found better than OPC concrete of similar compressive strength.

Keywords *- Bond strength, Compressive strength, Fly ash, Geopolymer concrete, GGBS, Silica fume.*
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1 INTRODUCTION

Cement concrete is significant factor for emission of greenhouse gases. Cement industry is the second largest contributor of greenhouse gases [1]. Due to increasing infrastructure development production of cement is increasing day by day. Production of cement in 2016 was 4.13 Gt and is expected to grow 4.68 Gt/year by 2050 [2]. Increasing consumption of cement is big concern because one ton of CO_2 is being produced in production of one ton of cement [3]. Cement industry is responsible for (5-9) % of CO_2 emission [6-10]. Reliance on cement will continuously increase the emission of CO_2 into the atmosphere. On the other hand limestone is being harvested for cement production which is non reversible resource [11-14]. Harvesting activities are also causing pollution problem for environment [4]. Production of cement is also energy consuming. Around 110 kWh electrical energy is consumed for 1 ton of cement production [5] which makes this industry as 3rd largest energy consumer [2].

Considering all these challenges it is necessary to find some other alternate material of cement concrete without compromising the properties of cement concrete. Geopolymer concrete is alternate material of cement concrete which is environment friendly and it can provide comparable strength properties of geopolymer concrete. Geopolymer concrete is made of binding material, fine aggregate, coarse aggregate and alkaline activator. Binding material may consist of fly ash, GGBS, silica fume and metakaoline. Alkaline activator is a mixture of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution. Geopolymerization is responsible for bond and strength in geopolymer concrete. Previous research has confirmed that mechanical properties of geopolymer concrete is affected by types and source of binding material (aluminosilicates), curing time, curing temperature, type and concentration of alkaline solution [15-17]. Previous study shows that temperature cured geopolymer concrete has high strength and low drying shrinkage [18], good fire resistance [19- 20] and durability [21-22]. Nano silica and fly ash based geopolymer concrete can give good strength even at ambient curing [23].

To use geopolymer concrete in reinforced concrete there should be good bond between geopolymer concrete and reinforcement. Many literature are available on bond strength of geopolymer concrete [24-28] but the experimental data on effect of temperature curing on bond strength of geopolymer concrete is not established. In this research effect of temperature curing on bond strength is studied. Compressive strength was also studied for temperature cured concrete. Geopolymer concrete was prepared with fly ash, GGBS and silica fume. Results of temperature cured GPC and ambient cured concrete are compared.

2 MATERIALS

2.1 Fly ash

Fly ash is a fine, granular byproduct of coal-fired power plants. Exhaust gases from burning coal carry this leftover mineral and metal oxide out from the combustion chamber which forms fly ash. Due to its adaptability and environmental advantage, fly ash has found significant usage across a variety of industries, notably in the building and infrastructure development sectors. Construction projects and other uses for fly ash divert it from landfills, where it can cause environmental damage. As a result, it lessens the need for cement manufacture and the accompanying emissions of greenhouse gases. Fly ash used in this research was obtained from Kanti thermal power plant, Muzaffarpur, Bihar, India.

2.2. GGBS

The cooling of molten iron slag yields GGBS, a waste product of the steel and iron industries. Powder is made from the glassy granules that develop during this quick cooling process. As a type of additional cementitious material, GGBS finds widespread usage in the construction sector. In addition to lowering the environmental effect of cement manufacturing, GGBS also boosts the durability and performance of the final product. As a means of improving concrete's qualities while decreasing the carbon footprint caused by conventional cement production, its application has spread rapidly around the globe.

2.3. Silica fume

The synthesis of silicon and ferrosilicon alloys in an electric arc furnace produces silica fume, also known as microsilica or condensed silica fume, a highly reactive, amorphous, and fine-grained substance. It's made up of little bits of silicon dioxide (SiO2) and other oxides. Because of its special qualities, silica fume is frequently utilised as an addition in concrete and other building materials. Construction projects that need for high-performance, long-lasting concrete often include silica fume as a key ingredient. By enhancing the characteristics of concrete and decreasing the environmental effect of construction, its use contributes to the creation of long-lasting and sustainable infrastructure.

2.4. Aggregate and plasticizer

Fine aggregate used was natural available river sand satisfying criteria of zone II. 40% coarse aggregate was of 10 mm nominal size and 60% was made of 20 mm nominal size. Plasticizer was also used to improve the workability of geopolymer concrete.

2.5. Alkaline activator

For preparation of alkaline activator first of all sodium hydroxide (NaOH) solution was prepared of 12M concentration. Once NaOH solution is cooled down it is uniformly mixed with sodium silicate solution in specified ratio (1:2.5). This mixed solution is kept for 24 hours before using.

3. EXPERIMENTAL PROGRAM

3.1. Mix proportion and specimen preparation

Geopolymer concrete mix was prepared with fly ash, GGBS and silica fume. Different types of mix were prepared by varying the percentage of fly ash, GGBS and silica fume. Different ID was assigned to different types of mix. For example FA70G10SF20 means fly ash 70%, GGBS 10% and silica fume 20% of total binder content. Fine aggregate, coarse aggregate and alkaline activator was also used. Different types of mix details are shown in **Table 1**.

Once the mix was prepared (**Figure 1**) it was transferred to cube mould in three layers. Each layers were provided tamping and then also vibrated using cube mould vibrator. A total of 12 cubes were prepared for each mix out of which 6 cubes for compression strength test and 6 cubes including rebar for bond strength test. As the vibration was over 16 mm bar was inserted to 6 cube specimen for 150 mm inserted length at centre (**Figure 2**). Out of 6 compressive strength test specimens 3 were provided ambient curing and 3 were provided temperature curing. Similarly out of 6 bond strength specimen 3 were provided temperature curing and 3 were provided ambient curing.

3.2 Curing of GPC specimen

After 24 hours of casting of samples cubes were demoulded and 3 compressive strength specimen and 3 bond strength specimens were provided temperature curing (**Figure 4)** at 150^{o}C for 4 hours then it was also kept at ambient temperature. Other 3 compressive strength specimen and 3 bond strength specimens were provided ambient curing (**Figure 3**). Samples were kept for 28 days.

Fig. 1 Geopolymer concrete mix

Table 1. Mix proportions of GPC

Sample ID	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Binder (kg/m^3)			Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	
			FA	GGBS	SF		20 mm	10 mm
FA100G0SF0	84.66	211.64	539	-	-	808	970	646
FA90G10SF0	84.66	211.64	485.1	53.9	-	808	970	646
FA80G20SF0	84.66	211.64	431.2	107.8	-	808	970	646
FA70G30SF0	84.66	211.64	377.3	161.7	-	808	970	646
FA70G0SF30	84.66	211.64	377.3	-	161.7	808	970	646
FA70G10SF20	84.66	211.64	377.3	53.9	107.8	808	970	646
FA70G20SF10	84.66	211.64	377.3	107.8	53.9	808	970	646

Fig 2. Bond strength test specimen

Fig 3. Ambient curing of specimen

Fig 4. Temperature curing of specimen

3.3 Testing procedure

After curing was over compressive strength specimens were taken for compression strength test in digital compression testing machine. Samples were kept at centre and loading was applied at rate of 140 kg/cm^2/min (**Figure 5**). As the sample failed the strength of samples was noted down for ambient cured cube specimen and temperature cured cube specimen.

For obtaining the bond strength pull out test of specimen was done in universal testing machine (UTM). Reinforcement bar was gripped in UTM and load was applied. Maximum load resisted by bond between GPC and reinforcement was taken and maximum bond strength was calculated.

4. RESULTS AND DISCUSSION

As the curing period was over. Samples were tested for compressive strength test and bond strength test of both types of specimen i.e. temperature cured and ambient cured. Results obtained from test are as in table 2 and table 3. Graphical representation of results is shown in figure 7, 8 and 9.

Fig 5. Compressive strength test of specimen

Figure 6: Bond strength test of GPC

Table 2. Compressive strength of cube specimen after 28 days

Sample ID	Compressive strength (Mpa) of temperature cured (CSTC) cube	Compressive strength (Mpa) of ambient cured (CSAC) cube
FA90G10SF0	20.85	18.21
FA80G20SF0	32.91	20.92
FA70G30SF0	35.62	22.43
FA70G0SF30	10.67	12.92
FA70G10SF20	14.4	20.42
FA70G20SF10	18.3	24.3
FA100G0SF0	5.41	6.2

Table 3. Bond strength of GPC specimen after 28 days

Sample ID	Bond strength (Mpa) of temperature cured (BSTC) cube	Bond strength (Mpa) of ambient cured (BSAC) cube
FA90G10SF0	4.3	4.1
FA80G20SF0	4.42	3.61
FA70G30SF0	5.53	5.27
FA70G0SF30	2.46	2.63
FA70G10SF20	3.32	2.83
FA70G20SF10	4.9	4.21
FA100G0SF0	3.2	3.12

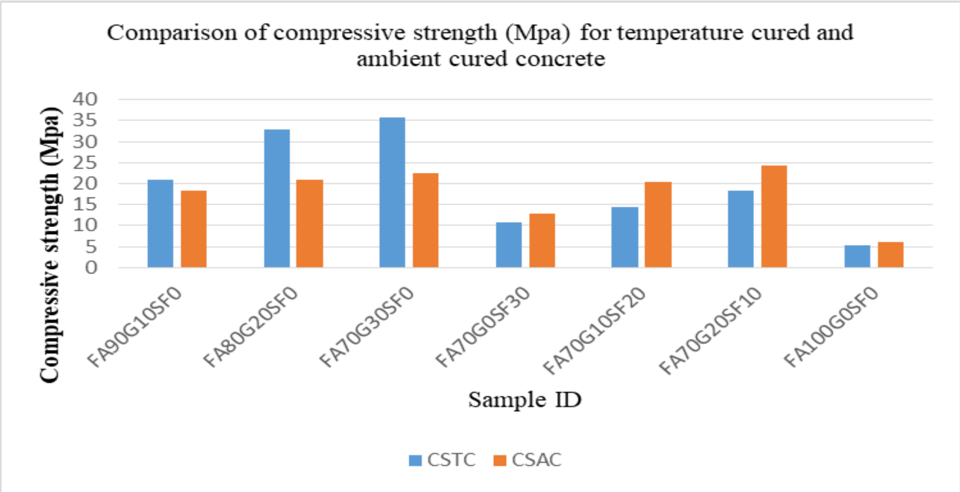

Fig 7. Graphical comparison of compressive strength for temperature cured and ambient cured GPC

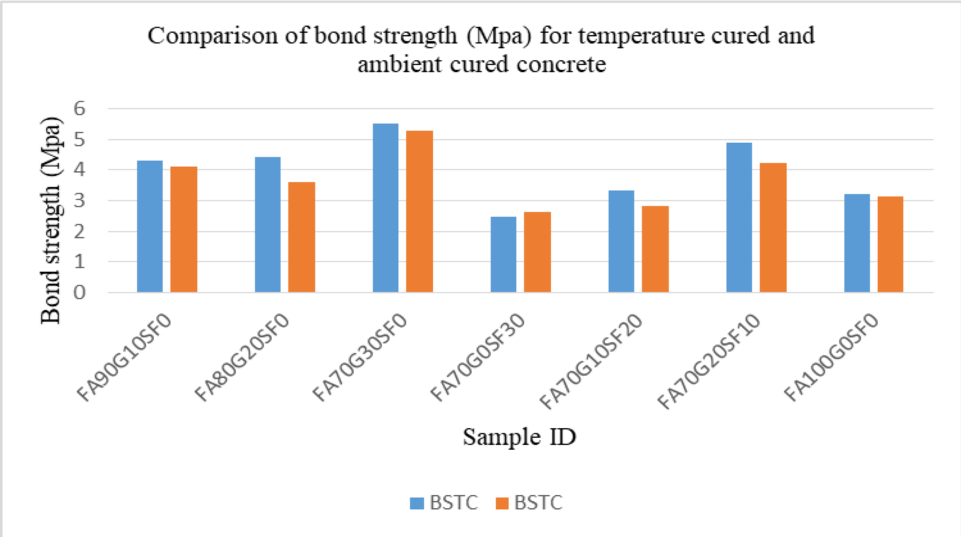

Fig 8. Graphical comparison of compressive strength for temperature cured and ambient cured GPC

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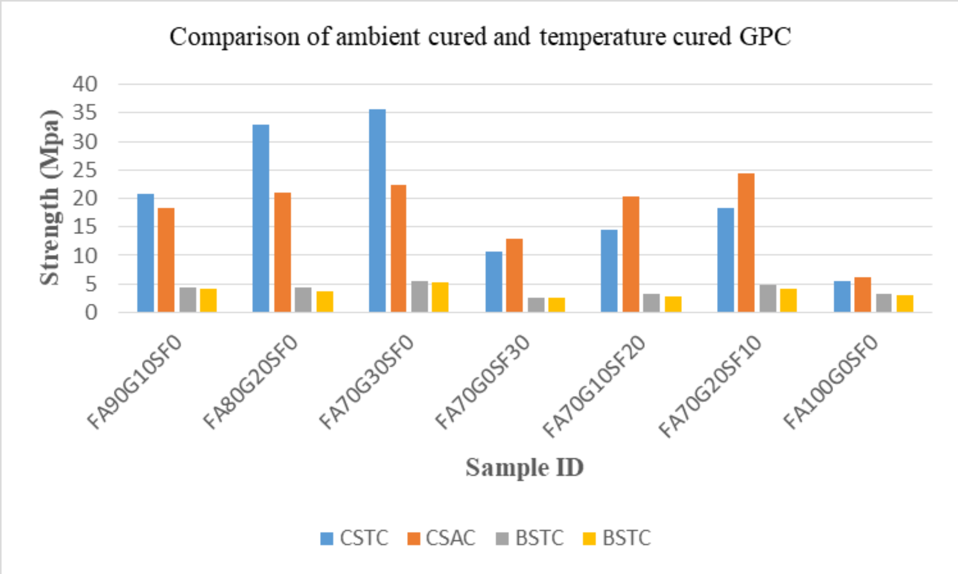

Fig 9. Graphical comparison of compressive strength and bond strength for temperature cured and ambient cured GPC

As shown in table 2, compressive strength of GPC where only fly ash was used as binder was very less. If fly ash, GGBS and silica fume were used as binder in which fly ash was kept 70% and %age of silica fume and GGBS were varied then as the %age of silica fume increased as replacement of GGBS, compressive strength decreased for both ambient cured GPC and temperature cured GPC. It was also found that silica fume cannot be used more than 20% for temperature cured GPC because it changed the volume of specimen if utilized more than 20%. If fly ash and GGBS were used as binder and fly ash is replaced with GGBS in different %age then as the percentage of GGBS increases compressive strength for both ambient cured sample and temperature curded sample increases.

In all mix temperature cured specimen had better results than ambient cured specimen for compressive strength which was also observed in literature.

In case of bond strength, bond strength of GPC specimens if effect of binder content is observed all specimen showed similar trend as in case of compressive strength test however if effect of curing is considered there was not much difference in specimen obtained from both type of curing. This may be due to reason that temperature curing increases geopolymerization process which develop faster bond between GPC constituents and bond between GPC constituent and rebar is not affected by geopolymerization process.

5. CONCLUSION

Based on the experimental results following conclusions can be drawn.

1. Temperature curing increases the compressive strength of GPC but there is very little effect of temperature curing on bond strength of GPC.
2. If GGBS and fly ash are used as binding materials and if fly ash is replaced with GGBS then compressive strength and bond strength increase with increase in GGBS content.
3. If silica fume is also used along fly ash and GGBS as binding material then as the percentage of silica fume increases it reduces the compressive strength and bond strength.
4. Silica fume if used more than 20% of total binder then volume of specimen is affected by temperature curing.
5. GPC has higher bond strength than OPC concrete of similar compressive strength.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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