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Effect of Kaolin Content and Alkaline Concentration on the Strength Development of Geopolymer Concrete

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Abstract: Cement concrete is used as an important material in the construction industry. Cement industry is one of the largest producer of greenhouse gases, chiefly CO_2. Hence to reduce the impact of global warming, an alternative material is required. Geopolymer is such a material which produces less CO_2 than ordinary Portland cement. Geopolymer concrete consists of an alumino-silicate source material treated to an alkali activated solution consists of sodium hydroxide and sodium silicate at desired concentration levels. This paper deals with the strength characteristics of slag based geopolymer at different replacement levels of slag with metakaolin, sodium hydroxide concentration, maintaining the alkaline ratio constant at 2.5. The tests includes cube compressive strength at the age of 7 & 28 days and split tensile strength at 28 days of ambient curing conditions.
Keywords: Kaolin Content and Alkaline Concentration, Strength Development,Geopolymer Concrete.

Introduction

Concrete, basically consists of cement is widely used as a material for construction[1]. The production of cement results in releasing 7% of CO_2 into the atmosphere[2]. Due to this, attempts have been made to reduce the usage of cement in concrete[3] and thereby reducing CO_2 emission. Hence an alternate for cementitious binder with low CO_2 emission and less energy consumption was required. Geopolymer is such a reliable material which has very low CO_2 emission compared to Ordinary Portland Cement (OPC)[4]. Industrial by-products such as Flyash[5], Ground Granulated Blast Furnace Slag (GGBFS)[6], Rice Husk Ash (RHA)[7], Metakaolin[8], Palm Oil Fuel Ash (POFA)[9] etc. are used as source material in geopolymer concrete. The most commonly used alkaline solution for the polymerization to take place are sodium hydroxide with sodium silicate solution[10-11] or potassium hydroxide with potassium silicate solution[11]. This solution is termed as activator solution and the mechanical property of concrete was found to be increased with increase in the concentration of activator solution[3,12]. Addition of metakaolin as partial replacement of cement causes increase in mechanical property and decrease in workability of concrete[8]. On the other hand, complete replacement of cement by slag also gives a good compressive strength[13].There were few papers put on the basis of slag/metakaolin blends. They show early strength development and higher compressive strength after 90-180 days[14-15].

Materials and Methodology

Materials

Ground Granulated Blast Furnace Slag (GGBFS) and Metakaolin

Ground Granulated Blast Furnace Slag (GGBFS) obtained from JSW limited, Salem was used as a primary raw material. Metakaolin obtained by calcination in laboratory was mixed at different ratios with GGBFS to get a cementitious material. The specific gravity and specific surface area of former is 2.6 and

20(m^2/g), and for later is 2.9 and 438(m^2/g). The chemical composition of the binders use were obtained by XRF and are detailed in table 1.

Table 1. Chemical composition of GGBFS and Metakaolin

Oxide	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3	Na_2O	K_2O
GGBFS	36.77	30.97	17.41	9.01	1.82	1.03	0.69	0.46
Metakaolin	0.09	52.0	46.0	0.03	-	0.60	0.10	0.03

Aggregates

Coarse aggregate of 12mm maximum size having fineness modulus of 6.48 and specific gravity 2.85 were taken in surface dry condition. Natural River sand of specific gravity 2.63 and fineness modulus of 2.79 were used as fine aggregate.

Alkaline Activated Solution

Alkaline activator solution was achieved by blending of sodium silicate solution[15] having 28 wt.% SiO_2, 35 to 40 wt.% solid and 9 wt.% Mg_2O, together with sodium hydroxide solution (99.51% purity) to get a desired modulus of 2.5.

Experimental Investigation

The NaOH flakes were dissolved in water to make the solution with requiredMolarity[16].Sodium hydroxide solution release large amount of heat during preparation and hence the solution is prepared a day before the process of casting. Sodium silicate solution are then added to it and left undisturbed for few hours for alkaline reaction to take place.

Table 2. Variation of parameters

Mix No.	GGBFS Content (%)	Metakaolin Content (%)	NaOH concentration (moles)
M01	100	0	10
M02	100	0	12
M03	100	0	14
M04	90	10	10
M05	90	10	12
M06	90	10	14
M07	80	20	10
M08	80	20	12
M09	80	20	14
M10	70	30	10
M11	70	30	12
M12	70	30	14

Proportioning of geopolymer concrete was made to analyze the effect of mix variables which include the replacement of GGBFS by metakaolin and amount of alkaline solution. The total binder content was kept constant as 400 kg/m^3. Table 2 shows the variation of parameters in the mix and the mix proportioning of the geopolymer concrete is shown in table 3.

Table 3. Mix proportioning of the geopolymer concrete

Mix No.	GGBFS (kg/m^3)	Metakaolin (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Sodium hydroxide solution (kg/m^3)	Sodium silicate solution (kg/m^3)
M01	400	0	524	1024	62.86	156.25
M02	400	0	524	1024	62.86	156.25
M03	400	0	524	1024	62.86	156.25
M04	360	40	524	1024	62.86	156.25
M05	360	40	524	1024	62.86	156.25
M06	360	40	524	1024	62.86	156.25
M07	320	80	524	1024	62.86	156.25
M08	320	80	524	1024	62.86	156.25
M09	320	80	524	1024	62.86	156.25
M10	280	120	524	1024	62.86	156.25
M11	280	120	524	1024	62.86	156.25
M12	280	120	524	1024	62.86	156.25

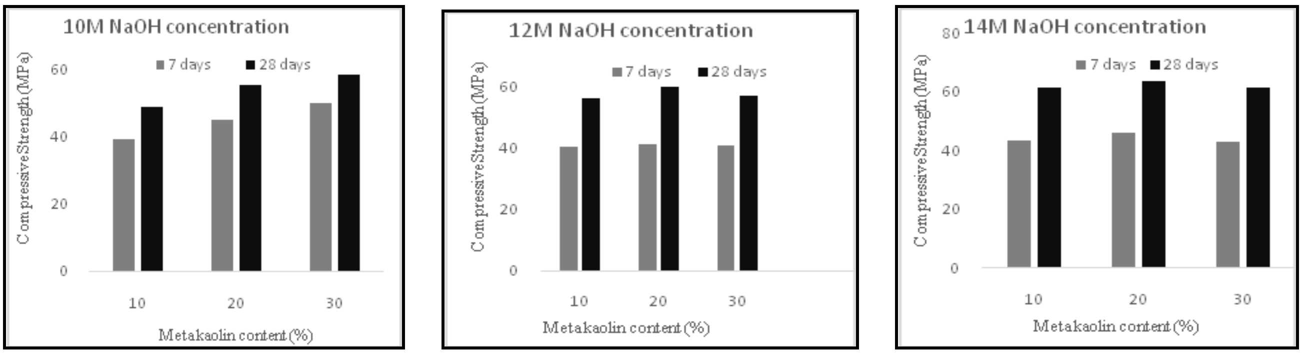
Sample Preparation and Curing

By varying the amount of slag content with metakaolin and at different NaOH concentration, keeping the alkaline ratio constant at 2.5, the mixes were prepared. 100mm cubes were casted for determining the compressive strength at the age of 7 days & 28 days curing while 100mm diameter and 200mm height cylinders were casted to determine the split tensile strength at 28 days curing. Ambient curing was followed as it was found to be optimum for geopolymer mixes as the elevated temperature curing results in high early age strength and no such appreciable improvement in the strength at the age of 28 days.

Results and Discussion

Effect of age of curing

The compressive strength of the geopolymer mixes were determined at the age of 7 and 28 days in order to determine the effect of age of curing on the strength development. The strength characteristics due to age of curing with varying NaOH concentration and Metakaolin content are shown in figure 1(a, b, c).



(a) **(b)** **(c)**

Figure 1. Effect of age of curing on Compressive strength

It was observed that the strength at 7 days curing attains more than 70% of strength obtained at the age of 28 days and this was found to increases with the increase in NaOH concentration. This may be due to the increase in the alkaline nature of the geopolymer mixes thereby improved polymerization reaction.

Effect of Metakaolin content on strength properties of geopolymer concrete

Compressive strengths of cement free binder concretes were found to increasewith increase in activator concentration[17]. The geopolymer concrete having slag alone as binder exhibits low strength when compared to concrete mixture consisting of 10%, 20% and 30% of Metakaolin content. From figure 2, it was observed that among the replaced geopolymer concrete, mixes containing 20% replaced metakaolin content exhibits high compressive strength when compared to 10% and 30% replacement.

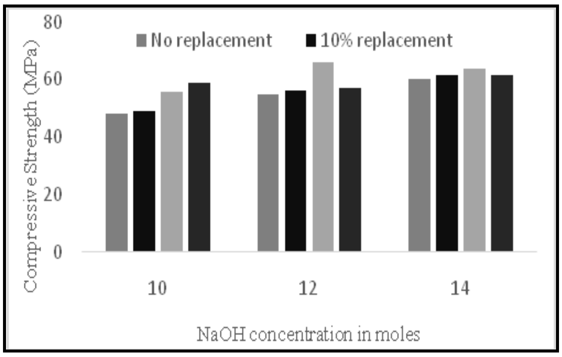


Figure 2.Effect of Metakaolin content and NaOH concentration on 28 days compressive strength

A diametrical compressive force is applied along the length of the cylinder at gradually increasing rate till the specimen gets failed. Tensile stress and high compressive stress are induced on the plane where the load is applied. Similar to compressive strength, from figure 3, it was found that the concrete containing 20% replaced metakaolin content exhibits high split tensile strength when compared to 10% and 30 % replacement.

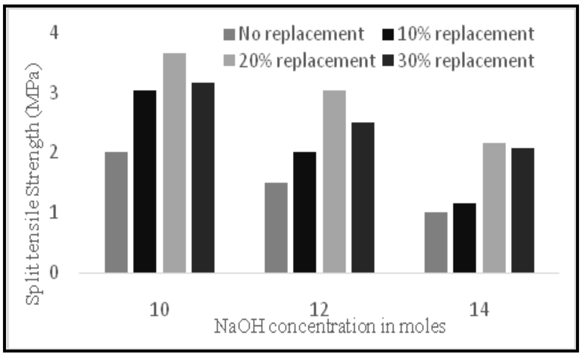


Figure 3. Effect of Metakaolin content and NaOH concentration on Split Tensile strength

Effect of NaOH concentration on strength properties of geopolymer concrete

The compressive strength of the geopolymer mixes increases with the increase in the NaOH concentration without metakaolin. There is no such appreciable change in the compressive strength of the geopolymer mixes with the inclusion of metakaolin content under high concentration of sodium hydroxide. The split tensile strength of the mixes reduces with the increase in the NaOH concentration. It was also observed that the strength was found to be optimum with 20% replacement level of slag with metakaolin.

Conclusion

The following statements were concluded from the results obtained:

1. Geopolymer concrete can be used as an effective replacement for cement concrete thereby reduces environmental pollution as in case of cement concrete.
2. The high alkaline nature of the geopolymer concrete increases the polymerization reaction, thereby increase in the strength of the concrete mixes.
3. The 7 days compressive strength attains more than 70% of the corresponding 28 days compressive strength and thus the early age strength is attained at faster rate due to high alkaline nature of geopolymer concrete.
4. The 28 days compressive strength of geopolymer concrete increases with the increase in the metakaolin content and sodium hydroxide concentration. The mix with 12M NaOH concentration and 20% metakaolin replacement shows optimum mix proportioning of the geopolymer concrete.
5. The split tensile strength results shows that the increase in the metakaolin content with 20% as the

optimum replacement level, whereas the strength decreases gradually with the increase in the NaOH concentration.

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