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EFFECT OF SODIUM HYDROXIDE MOLARITY AND FINE AGGREGATE TO COARSE AGGREGATE RATIO ON GGBS BASED GEOPOLYMER CONCRETE

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ABSTRACT

The concentration of sodium hydroxide solution increased the reaction rate during the geopolymerization process and thus enhanced the development of the early strength of concrete. The percentage volume of aggregates played a vital role in the strength development due to the better durability than paste alone and also filling and packing ability. The present study aims to determine the optimum molarity of sodium hydroxide and the aggregate ratio of geopolymer concrete towards high-strength performance concrete based on compressive strength and split tensile strength by conducting destructive and non-destructive tests. The variable samples investigated include the sodium hydroxide (NaOH) concentration and aggregate ratio to ambient temperature curing; the ratio of alkali activator solution and solid-to-liquid ratio remained constant. This is the result of the present work on the development of GGBS based geopolymer concrete having increment in the rate of strength development.

Keywords: GGBS, sodium hydroxide, sodium silicate, geopolymer concrete, alkali activator solutions, coarse aggregate.

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INTRODUCTION

Cement is used excessively as a construction material throughout the world ranking only second after water. Ordinary Portland Cement (OPC) is used as a binding material to produce concrete; hence it plays an important role in construction industries. Considering the rapid construction development all over the world it is for sure the demand for concrete will rise significantly [1]. But at the same time, it is much known that the production of OPC not only utilizes a lot of natural resources but also solely accounts for about 7% of the global carbon dioxide ($_{CO2)}$ emission i.e. around 2.7 billion tons of greenhouse gas emissions yearly [1, 4]. It is estimated that manufacturing of 1 tons of (ordinary Portland cement) OPC releases 1 tons of carbon dioxide. Considering these serious threats which are sure to grow in the coming future with the advancement of construction industries, the need for an alternative binder with less carbon footprint to replace environmentally harassing cement is of prime importance.

In 1998, Davidovits proposed a geopolymer technology as a replacement for the Ordinary Portland Cement binder traditionally being used in the construction industry [4]. Geopolymers are chains or networks of mineral molecules which are connected by covalent bonds. In this technology, the original material is rich in Silicon (Si) and Aluminum (Al) it reacts with high alkali solutions to produce binder material through the process of geopolymerisation. The alkaline solution acts as an activator for the polymerization process under high alkali conditions on the Si-Al mineral resulting in a complex polymeric chain of Si-O-Al-O bonds [8]. The main significance of geopolymer technology is its ability to produce high-performance binders from materials such as fly ash or GGBS.

Geopolymer concrete is the ultimate of the reaction of aluminosilicate-containing materials with concentrated alkali solutions it produces an inorganic polymer binder. Though it has a history starting in the 1940s and has attracted a significant number of researchers, it has not yet been used significantly in mainstream concrete construction. However, in the case of ready mixed applications usage of Geopolymer concrete is increasing, also its application in the field of precast industry using accelerated curing is noticeable.

Geopolymer Concrete, in today's world, emerges as a new environmentally friendly construction material for sustainable development as there are several benefits associated with it. Geopolymer concrete not only reduces the CO_2 released from the production of OPC but also effectively utilizes industrial wastage by-products such as fly ash, blast furnace slag, etc. as an original material which is activated by alkali solutions to act as a binder. CO_2 emissions to the atmosphere caused by the cement and aggregates industry can be reducing about 79.95% with the help of geopolymer technology [5]. Hence it can be said that the geopolymer concrete show considers promises to the applications in the concrete industry as an alternative binder to OPC and is a relatively new area for research that can lead us to mainstream use of geopolymer, environmentally friendly concrete eventually.

State of Art

B. Sarath Chandra Kumar and D. Sravanthi (2019) mentioned that in India approximately 120 million

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tonnes of GGBS is produced every year from thermal power stations. Usage or disposal of this by-product within the framework of its economic structure becomes a challenging problem for every country because of increasing interest in the conservation of energy and resources and growing concern with environmental issues. GGBS is used as ingredients in mortar which enhance the properties of mortar and utilization of M-sand is helpful for consumption. To study the alkaline solution of NaOH and Na_2SiO_3 is mixed with processed fly ash to become a geopolymer mortar.

Mr. Bennet Jose Mathew *et al*. (2013) mentioned that the need to reduce global anthropogenic carbon dioxide has encouraged researchers to search for sustainable building materials. Cement, the second most consumed product in the world, contributes nearly 7% of global carbon dioxide emissions. Geopolymer concrete (GPC) is manufactured using industrial waste like fly ash GGBS is considered as a more eco-friendly alternative to Ordinary Portland Cement (OPC) based concrete. The feasibility of the production of geo-polymer concrete using coarser bottom ash is evaluated in this study.

Aissa Bouaissi *et al*. (2019) conducted research on this paper which presents an experimental investigation of the mechanical properties and microstructure of geo-polymer concrete mixed using ground granulated blast furnace slag (GGBS). An optimal combination of FA, GGBS, and HMNS was determined using the compressive strength tests of geo-polymer (GP) pastes mixed with various replacements of FA with GGBS. It was found that the replacement of FA with 20% of GGBS and 10% of HMNS in GP concrete increases the 28-day compressive strength by 100% and the 28-day splitting tensile strength by 58%.

B. Rajini and A. V. Narasimha Rao (2014) conducted research on the effect of ground granulated blast furnace slag (GGBS) on the mechanical properties of geo-polymer concrete (GPC) at different replacement levels (FA0-GGBS100, FA25-GGBS75, FA50-GGBS50; FA75-GGBS25, FA100, GGBS0). Sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solutions have been used as alkaline activators. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength, and split tensile strength of GGBS based geo-polymer concrete. These properties have been determined at different curing periods like 3, 7, and 28 days and ambient room temperature.

The Objective of the Present Work

To study the strength of GGBS based geopolymer concrete by varying sodium hydroxide molarity and aggregate ratio.

MATERIALS USED

The materials used are GGBS, coarse aggregate, fine aggregate, alkali solutions like sodium silicate, sodium hydroxide, and 10 % water. The alkali solutions (NaOH and Na_2SiO_3) have a ratio of 1:2.5.

GGBS

The ground granulated impact heater slag is a result of iron assembling which when added to concrete improves its properties, for example, usefulness, quality, and sturdiness.

Advantages of GGBS

GGBS gives a useful blend. It has greater siphon capability and compaction qualities. The infiltration of chloride can be diminished. Lower odd of blossoming gives greater surface completion and improves style. The structure made of GGBS constituents helps in expanding sulphate assault opposition. The warmth of hydration is less contrasted with customary blend hydration. The shading is more even and light. The salt silica response is opposed exceptionally. Unlike bonds, GGBS does not create carbon dioxide, sulphur dioxide, or nitrogen oxide.

Figure-1. GGBS.

Sodium Hydroxide (NaOH)

It is also known as caustic soda and is an inorganic compound with the formula NaOH. It is a highly caustic base and alkali that decays at ambient temperature and causes chemical burns. It is available in the form of solids, flakes, granules, and solutions. This is highly soluble in water but is insoluble in ether and other non-polar solvents. The molarities used in this experiment are 8M and 10 M. The solution is prepared 24 hours before the casting.

Figure-2. Sodium hydroxide flakes.

Sodium Silicate (Na_2SiO_3)

It is also known as water glass or liquid glass. It is in gel form. The solution is prepared 24 hours before the casting. The alkali solutions are combined and used in a ratio of 1:2.5.

Figure-3. Sodium silicate.

Fine Aggregate

Fine aggregate is the essential ingredient in concrete that consists of natural sand or crushed stone. The quality and fine aggregate density strongly influence the hardened properties of the concrete. The concrete or mortar mixture can be made more durable, stronger, and cheaper if you make the selection of fine aggregate based on grading zone, particle shape and surface texture, abrasion and skid resistance absorption, and surface moisture.

Coarse Aggregate

Aggregates are irregular broken stones or naturally occurring round gravels that are used to make concrete, coarse aggregates for structural concrete consist of broken stones of hard rock like granite and limestone (angular aggregates) or river gravels (round aggregates Coarse).

Aggregates larger than 4.75 mm in size are termed coarse aggregates. These aggregates are obtained from stone quarries and stone crushers, the sizes between 4.75 mm to 80 mm.

Figure-4. Coarse aggregate.

EXPERIMENTAL PROCEDURE

Destructive Testing

The destructive testing method is suitable and economically beneficial for the concrete specimens that are produced on a large scale. The crushing of the samples is the usual destructive test to determine the concrete strength. By using a compressive testing machine we can determine the strength of concrete.

The destructive testing method is suitable and economically beneficial for the concrete specimens that are produced on a large scale. The main aim is to investigate the service life and detect the weakness of design which might not show under normal working conditions. It includes methods where the concrete specimen is broken to determine mechanical properties i.e. hardness and strength. This type of testing is very easy to carry out, easier to interpret, and yields more information. Some popular destructive test methods are as follows Shankar and Joshi [5].

Non-Destructive Testing

Non-destructive testing (NDT) is mainly concerned with the evaluation of flaws in materials which are in the form of cracks and which might lead to loss of strength in a concrete structure (Samson *et al.* [7]. NDT is a method for the testing of existing concrete structures to determine their durability and strength. In the modern construction world, it has become a vital part of the quality control process. NDT also helps in investigating the crack depth, deterioration, and micro-cracks present in concrete. Large no of parameters like density, strength, and surface hardness can be determined by using NDT methods. It is also possible to check the integrity of structure and quality of workmanship by detecting cracks and voids Kumavat *et al.* [6]. It applies to both new as well as existing structures.

Regression Analysis

Regression analysis is a powerful statistical method that allows you to examine the relationship between two or more variables of interest. While there are many types of regression analysis, at their core they all examine the influence of one or more independent variables on a dependent variable. Regression models predict a value of the Y variable given known values of the X variables. Prediction within the range of values in the dataset used for model-fitting is known informally as interpolation. Prediction outside this range of the data is known as extrapolation. Performing extrapolation relies

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strongly on the regression assumptions. The further the extrapolation goes outside the data, the more room there is for the model to fail due to differences between the assumptions and the sample data or the true values.

The regression analysis is carried out to predict compressive strength according to the water-cement ratio or cement-water ratio, cement contents, and cement-aggregate ratio.

Linear Regression Analysis

Linear regression is a linear approach for modelling the relationship between a scalar response and one or more explanatory variables (also known as dependent and independent variables). The case of one explanatory variable is called simple linear regression; for more than one, the process is called multiple linear regressions. This term is distinct from multivariate linear regression, where multiple correlated dependent variables are predicted, rather than a single scalar variable.

In linear regression, the relationships are modelled using linear predictor functions whose unknown model parameters are estimated from the data. Such models are called linear models. Most commonly, the conditional mean of the response given the values of the explanatory variables (or predictors) is assumed to be an affine function of those values; less commonly, the conditional median or some other quintile is used. Like all forms of regression analysis, linear regression focuses on the conditional probability distribution of the response given the values of the predictors, rather than on the joint probability distribution of all of these variables, which is the domain of multivariate analysis.

Linear regression analysis is used to predict the value of a variable based on the value of another variable. The variable you want to predict is called the dependent variable. The variable you are using to predict the other variable's value is called the independent variable.
Linear regression: $y=Ax+B$

Quadratic Regression Analysis

Quadratic regression is an extension of simple linear regression. While linear regression can be performed with as few as two points (i.e. enough points to draw a straight line), quadratic regression comes with the disadvantage that it requires more data points to be certain your data falls into the "U" shape. It can technically be performed with three data points that fit a "V" shape, but more points are desirable. As more data points are required, it's also more costly than simple linear regression.

Quadratic Regression Equation

Quadratic regression is a way to model a relationship between two sets of variables. The result is a regression equation that can be used to make predictions about the data. The equation has the form.
$y = ax^2 + bx + c$ where $a \neq 0$

Casting of Cube Specimens

The cubes of dimensions 150mmX150mmX150mm were prepared, and the specimens cast for geopolymer concrete were GGBS, fine aggregate, coarse aggregate, and alkali *activators (*NaOH and Na_2SiO_3) were mixed and tested for 3 days, 7 days, and 28 days respectively.

Table-1. Mix proportions of geopolymer concrete.

MIX ID	Molarity (M)	Aggregate ratio (FA: CA)	GGBS (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Sodium hydroxide (kg/m^3)	Sodium silicate (kg/m^3)
M1	8 M & 10 M	40:60	414	718	1078	53	133
M2	8 M & 10 M	35:65	414	629	1167	53	133
M3	8 M & 10 M	30:70	414	539	1257	53	133

Mix Identification

Table-2 gives the utilization of different percentages of fine aggregate and coarse aggregate in the GPC mix.

Table-2. Mix Identification.

Mix ID	Fine Aggregate (%)	Coarse Aggregate (%)
M_1	40	60
M_2	35	65
M_3	30	70

Figure-5. GPC cubes.

TEST CONDUCTED

Compressive Strength Test

The test was conducted according to IS 515-1959. The compressive strength test measures the maximum amount of compressive load of a specimen to find the specified compressive force at a period. The working procedure of the compression testing machine is, that it contains two plates, one is fixed and the other is movable. The cube is placed on the fixed plate, with the help of the movable plate the specimen is tightened, and the load is applied. The readings are taken which are shown in the dial gauge which is fixed to the testing machine.

The compressive strength test was performed on 3, 7, and 28 days on GGBS concrete as shown in Table-3 they listed all the mixes. The results of the experiments increased geopolymer concrete compressive strength and for 3, 7, and 28 days.

Table-3. Average compressive strength test results.

MIX ID	MOLARITY OF NaOH	3 DAYS (MPa)	7 DAYS (MPa)	28 DAYS (MPa)
M1	8 M	58.98	60.98	71.36
	10 M	60.52	63.52	73.04
M2	8 M	65.64	67.57	79.73
	10 M	67.67	69.67	83.57
M3	8 M	70.97	72.97	84.51
	10 M	74.64	75.64	89.99

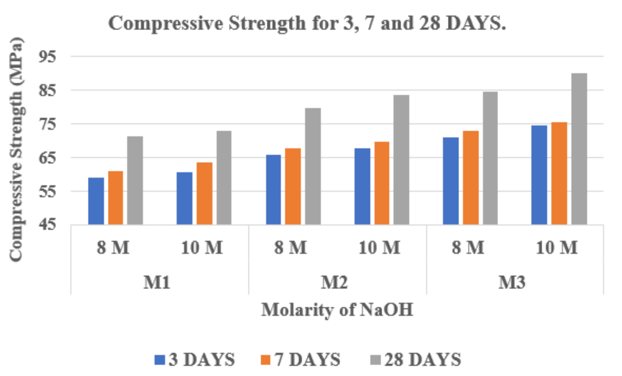

Figure-6. Comparison of 3, 7, and 28 days Compressive Strength.

For geopolymer concrete with 8M NaOH, as the % of coarse aggregates increases from 60 to 70 the compressive strength is increased by 12%. For geopolymer concrete with 10M NaOH, as the % of coarse aggregates increases from 60 to 70 the compressive strength is increased by 18%. For a given % of coarse aggregate when molarity is increased from 8M to 10M, the compressive strength of concrete is increased by 6%.

The larger coarse aggregate leads to a less specific surface area, so it is surrounded by a thicker geopolymer paste. Consequently, the paste between the larger coarse aggregate would have better quality and fewer microcracks, which yielded a higher compressive strength.

Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity was performed on 3, 7, and 28 days on GGBS based geopolymer concrete as shown in Table-4. The method adopted is the direct method.

Table-4. Ultrasonic pulse velocity test results.

MIX ID	MOLARITY OF NaOH	3 Days Pulse Velocity (km/Sec)	7 DaysPulse Velocity	28 Days Pulse Velocity
M1	8 M	4.39	4.59	4.69
	10 M	4.40	4.60	4.70
M2	8 M	4.42	4.61	4.71
	10 M	4.47	4.66	4.75
M3	8 M	4.52	4.71	4.82
	10 M	4.54	4.74	4.85

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The strength and quality of concrete or rock are assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure or natural rock formation above 4.5km/sec so, the quality of concrete is excellent according to IS-13311.

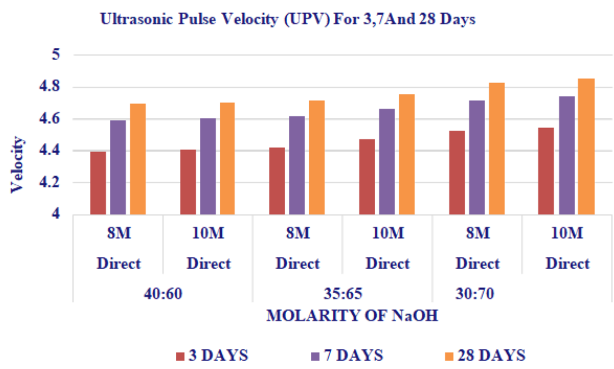

Figure-7. Ultrasonic pulse velocity for 3, 7, and 28 days.

For geopolymer concrete with 8M NaOH, as the % of coarse aggregates increases from 60 to 70 the ultrasonic pulse velocity is increased by 10%. For geopolymer concrete with 10M NaOH, as the % of coarse aggregates increases from 60 to 70 the ultrasonic pulse velocity is increased by 8%. For a given % of coarse aggregate when molarity is increased from 8M to 10M, the ultrasonic pulse velocity of concrete is increased by 3%.

Rebound hammer test

The rebound hammer test was performed on 3, 7, and 28 days on GGBS concrete as shown in Table-5 they listed all the mixes.

Table-5. Rebound value test results.

MIX ID	MOLARITY OF NaOH	3 DAYS (MPa)	7 DAYS (MPa)	28 DAYS (MPa)
M1	8 M	41	44	46
	10 M	42	47	52
M2	8 M	43	48	56
	10 M	44	49	57
M3	8 M	45	50	59
	10 M	46	52	60

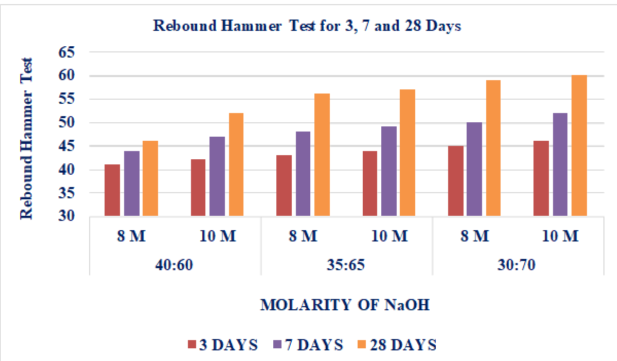

Figure-8. Rebound hammer values for 3, 7, and 28 days.

For geopolymer concrete with 8M NaOH, as the % of coarse aggregates increases from 60 to 70 the rebound hammer values are increased by 7%. For geopolymer concrete with 10M NaOH, as the % of coarse aggregates increases from 60 to 70 the rebound hammer values are increased by 3%. For a given % of coarse aggregate when molarity is increased from 8M to 10M, the rebound hammer values of concrete are increased by 3%. The larger coarse aggregate leads to a less specific surface area, so it is surrounded by a thicker geopolymer paste. Consequently, the paste between the larger coarse aggregate would have better quality and fewer microcracks, which yielded a higher rebounded value and higher ultrasonic pulse velocity.

Split Tensile Test

It is finding a concrete strength to subject into the cylinder of a lateral compressive force. There was no direct method for knowing the Concrete tensile strength, for determining the tensile strength of geopolymer and normal concrete cylinders. The test specimens in a horizontal direction they were placed in the compressive force machine. The size of 0.15m diameter and 0.30m large cylinders were cast with different molarity at 28 Days.

Split tensile strength was done on the cylinders of 0.30m height and 0.15m diameter. On 3, 7, and 28 days on geopolymer concrete cubes of different molarities, the tensile strength was executed. And they listed all the mixes as shown in Table-4.

Table-6. Split tensile strength test results.

MIX ID	MOLARITY OF NaOH	3 DAYS (MPa)	7 DAYS (MPa)	28 DAYS (MPa)
M1	8 M	2.45	2.64	2.69
	10 M	2.47	2.68	2.72
M2	8 M	2.90	3.05	3.23
	10 M	2.93	3.10	3.32
M3	8 M	3.10	3.32	3.46
	10 M	3.14	3.36	3.49

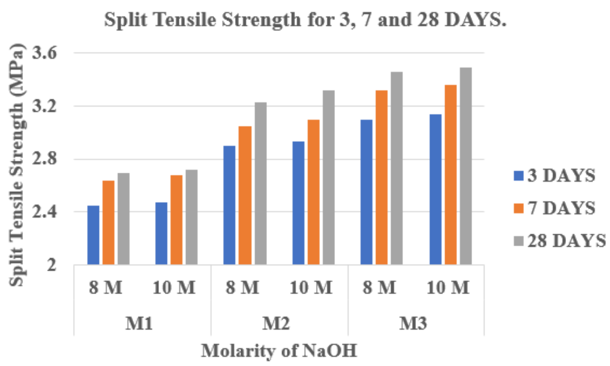

Figure-9. Comparison of 3, 7, and 28 days split tensile strength.

CONCLUSIONS

The conclusions based on the limited observations from the present investigation on properties of fresh GGBS based geopolymer concrete are:

a) The workability of geopolymer concrete decreases as the coarse aggregate content increases.

b) Mechanical properties such as compressive strength show an increasing trend with the increase of coarse aggregate.

c) Nearly 90% of the total strength of GPC is achieved within the age of 7 days.

d) The results showed that the NaOH molarity and aggregate ratio an important factors in a mix design for developing and producing high compressive strength geopolymer concrete.

e) Then increase in strength of GPC between 7 days and 28 days appeared to be high when compared with 3 days and 28 days. It shows that even after 7 days Geopolymer reaction is taking place but at a higher rate.

f) The compressive strength up to 89.99 MPa with 10 M sodium hydroxide concentration and 70/30 aggregate ratio at 28 days was achieved at normal ambient curing.

g) The ultrasonic pulse velocity is more than 4km/s and the average rebound number is greater than 40 so the quality of concrete is very good according to code IS-13311:1992.

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