IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 5 Ver. V (Sep. - Oct. 2016), PP 74-83
www.iosrjournals.org

Investigation of Strength and Durability Parameters for Metakaolin and GGBS Based Geoplolymer Concrete

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Abstract: *The increasing emphasis on energy conservation and environmental protection has led to investigation of alternatives to customary building material. Effort are urgently underway all over the world to develop environment friendly construction materials which makes minimum utility of natural resources and helps to reduce green house gas emission Geopolymer concrete (GPC) is one of the most recently developed structural concretes, where industrial wastes like fly ash, rice husk, ground granulated blast furnace slag (GGBS) are utilized for complete replacement of ordinary Portland cement in concrete. A major contribution to structural concrete in the form of Geopolymer concrete was developed by many investigators with lesser grade of concrete. The contribution of green house gas emission due to ordinary Portland cement production worldwide is approximately 7%. For each ton of Portland cement manufactures, it is estimated that one ton of* CO_2 *is released into the environment. In this connection, Geopolymer are showing great potential and does not need the presence of Portland cement as binder. Geopolymer concrete is prepared by using alkaline solution of suitable chemical composition. The ratio of mixture is 2.5 and the concentration of sodium hydroxide is 10M. The geo polymer concrete specimens are casted and tested for different types of strengths for 3, 7, and 28 days and cured at ambient temperature.*

Keywords: *Geo-polymer, Metakaolin, Ground Granulated Blast Furnace Slag, Alkali Activator.*

I. Introduction

Geopolymer Concrete (GPC) is an efficient binder in the manufacturing of concrete technology. The source materials such as Metakaolin are treated with alkaline liquid to obtain the binder/adhesive agent. Geopolymer concrete will be introduced as an alternative concrete which did not use any cement in its mixture and used GGBS and Metakaolin as alternative cement. NaOH and Na_2SiO_3 were used as activator solution. Geopolymer cement is a state of art novelity and tend to create a platform for substitution with conventional manufacturing materials for architectural and construction industry. The concrete technology should tune on the lines of sustainability where the materials utilized in construction sector should be eco-friendly as well as facilitate the process of reuse if necessary. The integrated ecological based waste utilization finds its application ranging from small scale industries to large Power plants, etc. As a part of this novel idea, materials such as slag can be transformed in to geoploymer concrete or nowadays called as green concrete. Concrete is predominantly used material in architectural and construction industry[1] The overall global production of cement is 2.8 billion tones according.[2] A recent report to the United Nations Industrial Development Organization highlighted that as of 2005, 60% of China's cement production was from Vertical Shaft Kilns (VSKs); characterized by low production efficiency[3].The VSKs generally produced low quality cement unsuitable for large structures, infrastructure, or export. The emission of CO_2 in the production of cement is due to clinker production, combustion of fuels in the cement kilns, and the use of energy for grinding raw material and clinker[4-13]. Abundant research has been conducted on newer concrete technologies and their use is seen in many construction solutions as they provide viable means of reducing the carbon footprint of concrete.[5] the use of greener concrete is increasing day by day. A recent post-tensioned structure had concrete with 50% replacement of cement by slag for the slabs, columns, and walls; and 70% replacement in the mat foundation, resulting in an estimated reduction on carbon dioxide emissions for the project of 4500 tones (4400 tons). The latest research into the green concrete properties and it is extensive. Researchers have examined the durability and mechanical properties of concrete with fully replacement of cement by pozzolanic material.[7, 8] High volume substitutions for cement replacement results high strength and high durability concrete.[9-18] the covalent bond between the oligomers tends to form a network and this process of combination results in what is known as geopolymerization. Refer Figure 1 shows the mixture of new product.

II. Materials Used

2.1 Met kaolin

Metakaolin is one of the Pozzolanic materials used in concrete as a binder replaced by cement. It is suggested that firing kaolinite at lower temperatures (< 500 ^{O}C) does not give sufficient energy to break the crystalline structure of kaolinite. Refer Figure 2, 3, 4 and Table 1, 2

Table-1: Properties of Metakaolin

Property	Value
Specific Surface	9-16 m²/g
Physical Form	Powder
Specific Gravity	2.50
Color	Baby Pink

Table-2: Chemical Composition of metakaolin

Oxide	%
Al_2O_3	42-44%
SiO_2	51-53%
TiO_2	<3.01%
Fe_2O_3	<2.21%
SO_4	<0.51%
CaO	<0.22%
MgO	<0.11%
K_2O	<0.43%
L.O.I	<0.51%
Na_2O	<0.053%

Figure 4: Metakaolin

2.2 Ground Granulated Blast Funrace Slag:

Ground Granulated Blast Furnace Slag (GGBS) is synthesized through the process of quenching. It is amorphous in nature and formed as a result of slag quenching from blast furnace. It can be seen as auxillary product during production of steel which can aid in concrete technology. Refer Figure 5, 6 and Table 3, 4

Table 3: Properties of Ground Granulated Blast Furnace Slag

Property	Value
Relative density	2.85–2.95
Bulk density (loose)	1.0–1.1 tonnes/m^3
Surface area	400–600 m^2/kg Blaine
Bulk density (vibrated)	1.2–1.3 tonnes/m^3
Colour	Off-white powder

Table-4: Chemical Composition of Ground Granulated Blast Furnace Slag

Oxide	%
CaO	36.77
SiO_2	30.97
$Al2O_3$	17.41
MgO	9.01
SO_3	1.82
Fe_2O_3	1.03
Na_2O	0.69
K_2O	0.46

Figure 6: Ground Granulated Blast Furnace Slag

2.3 Coarse Aggregate:

Coarse aggregates of sizes 10mm and 20mm are taken. Refer Figure 7 and Table 5.

Table-5: I.S. Sieve specifications of Coarse Aggregate

IS Sieve No (mm)	20 mm		10mm	
	Requirement as per IS: 383-1970	Percentage passing	Requirement as per IS: 383-1970	Percentage passing
80	-	-	-	-
40	100 %	100 %	-	-
20	95 – 100 %	96.52 %	95-100%	95.6%
16	-	-	100 %	100 %
10	0 – 20 %	13.72 %	0-45 %	41.52 %
Water absorption (%)	0.35 %		0.41 %	
Specific gravity	2.80		2.80	
Bulk Density (kg/m^3)	1680		1513	
Fineness modulus	7.32		7.32	

Figure 7: Coarse Aggregate

2.4 Fine Aggregate:

Fine Aggregate is generally sand whose properties are given in Refer Figure 8 and Table 6.

Table-6: I.S. sieve Specifications of Fine Aggregate

Sieve Size (mm)	Cumulative Passing (%)	IS: 383-1970 – Zone II
	F.A.	
10	100	100
4.75	98.5	90-100
2.36	95.3	75-100
1.18	70.8	55-90
600 (μm)	46.5	35-59
300 (μm)	17.6	8-30
150 (μm)	3.21	0-10
Fineness modulus	3.12	
Specific Gravity	2.78	
Bulk Density	1375 Kg/m³	

Figure 8: Fine Aggregate

2.5 Sodium Hydroxide:

Sodium Hydroxide is the alkaline activator used in the process of geopolymerisation whose chemical properties are given in Refer Figure 9, 10 and Table 7.

Table 7: Properties of Sodium Hydroxide

Property	Value
Appearance	White
Boiling point	1,389°C
Chemical formula	NaOH
Solubility in water	419 g/L (0°C) 1111 g/L (20°C) 3371 g/L (100°C)
Molar mass	40 g mol^{-1}
Odor	Odorless
Melting point	318°C
Density	2.14 g/cm^3

Figure 9: Sodium Hydroxide Flakes

Figure 10: Sodium Hydroxide Solution

2.6 SODIUM SILICATE (Na_2Sio_3):

Sodium Silicate is the common name for compounds with the formula $Na_2(SiO_2)_nO$. Refer Figure 11, 12, 13 and Table 8.

Figure 11: Solution of Sodium Silicate

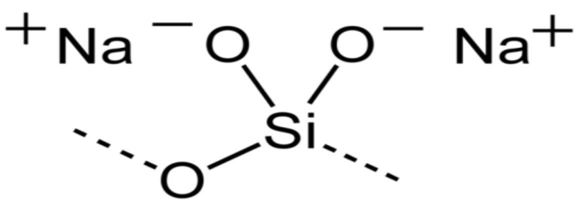


Figure 12: Sodium Silicate Structure

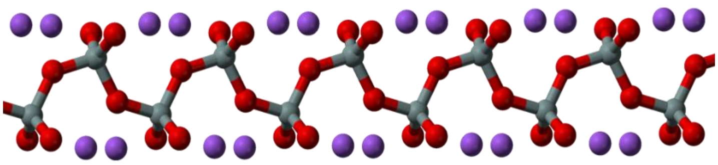


Figure 13: 3-D Structure of sodium silicate

Table-8: Properties of Sodium Silicate

Property	Value
Solubility in water	22.2 g/100 ml (25°C) 160.6 g/100 ml (80°C)
Refractive index (n_D)	1.52
Appearance	White to greenish
Chemical formula	Na_2SiO_3
Density	2.62 g cm^{-3}
Melting point	1,089 °C
Solubility	insoluble in alcohol

2.7 Sodium Sulfate (Na_2So_4):

Sodium sulfate is the inorganic compound with formula Na_2SO_4 is used in the process of green concrete technology. Refer Figure 13, 14 and Table 9.

Figure 14: Sodium sulfate

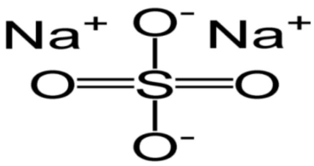


Figure 15: Sodium Sulphate structure

Table-9: Durability Parameters

S. no	Parameters to study	Volume of Specimen in mm	Chemical for curing	No of specimens
1	Chang in compressive strength	150X150X150	Sodium Sulphate	9
2	Change in mass	150X150X150	Sodium Sulphate	9

III. Methodology

3.1 Geopolymer Concrete MIX:

Initially dry mix, fine as well as coarse aggregate, alkaline solution and Pozzolanic material (Metakaolin + GGBS) are combined. About 6 to 8 minutes spent for mixing of concrete to achieve proper bonding of materials. Later, mixing Cubes, beams, cylinders with sizes 150mm X 150mm X 150mm, 500mm X 100mm X 100mm, and 150mm dia 300mm height are casted and compacted properly. In this project ambient curing is chosen for curing of geo-polymer concrete. For ambient curing, cubes are un-moulded after 24 hours of casting and they are placed in the direct sunlight for 72 hours. Refer Table 10, 11, 12.

Table 10: Mixing Proportion of Geopolymer concrete

Ingredients in (kg/m³)		Different mixes					
		C_1	C_2	C_3	C_4	C_5	C_6
Pozzolanic Material		414	414	414	414	414	414
Metakaolin		207	248	290	331	373	414
Ground Granulated Blast Furnace Slag		207	166	124	83	41	0
Coarse Aggregate	**10 mm**	467	467	467	467	467	466
	20 mm	699	699	699	699	699	699
Fine Aggregate		660	660	660	660	660	660
Sodium Hydroxide Solution		53	53	53	53	53	53
Sodium Silicate Solution		133	133	133	133	133	133

STRENGTH:

The experimental investigation processed by taking six pozzolanic Proportions pictured in above table in the aspects of Compressive, Split Tensile, and Flexural strengths where proportions starts from 50% Metakaolin + 50% GGBS to 100% Metakaolin.

Table-11: Mix ID of Pozzolanic Material Proportions for Strength properties

Mix ID	Metakaolin (%)	Ground Granulated Blast Furnace Slag (%)
C_1	50	50
C_2	60	40
C_3	70	30
C_4	80	20
C_5	90	10
C_6	100	0

Durability:

The experimental investigation Processed by taking 3 Pozzolanic Proportions C1, C3, C6 pictured in above table in the aspects of Durability

Table-12: Mix ID of Pozzolanic Material Proportions for Durability Properties

Mix ID	Metakaolin (%)	Ground Granulated Blast Furnace Slag (%)
C_1	50	50
C_3	70	30
C_6	100	0

IV. Results & Discussions

The cubes, beams, cylinder specimens have undergone the process of testing using standard equipment to determine compressive , flexural and split tensile strengths at the age of 3, 7, and 28 days. The figures 5, 6 and 7 are showing the graphical and table 13, 15, 16 shows tabular representation of various strengths with 10 Molarity alkali activator for the specimens which were cured in sunlight.

4.1 Compressive Strength:

The compressive strength of concrete with different proportions are casted of age 3, 7 and 28 days and a graph is plotted between pozzolanic material proportion(x-axis) Vs compressive strength (y-axis).From the figure we can say, as the age of concrete increases compressive strength increases. 100% Metakaolin gives compressive strength of 60.03 N/mm² which is the maximum strength obtained than other proportions. The strength variation between one proportion to other and one age to other is in slight manner. Refer Figure 16, 17 and Table 13

Figure 16: Compression test of Geopolymer concrete

Table-13: Compressive Strength of Geopolymer cocnrete

Mix ID	POZZOLANIC MATERIAL PROPORTION		COMPRESSIVE STRENGTH (N/mm²)		
	Metakaolin (%)	GGBS (%)	3 DAYS	7 DAYS	28 DAYS
C1	50	50	31.23	34.12	35.23
C2	60	40	34.20	35.72	39.29
C3	70	30	42.14	44.32	48.13
C4	80	20	44.91	46.94	50.28
C5	90	10	51.3	53.91	56.71
C6	100	0	53.62	54.64	61.03

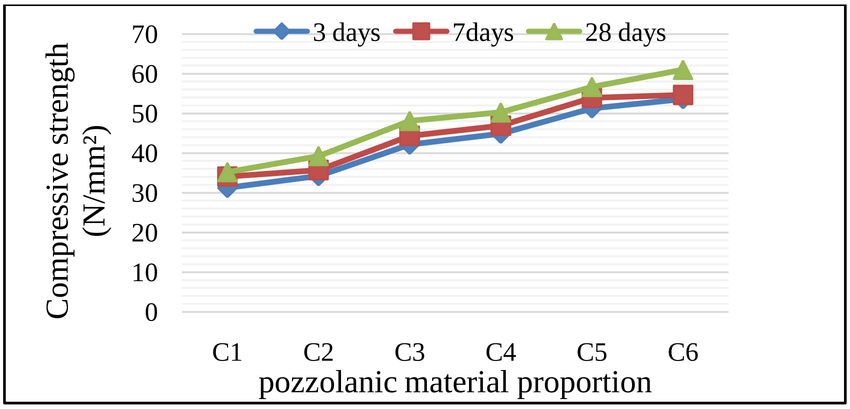


Figure 17: Graph between Compressive Strength and Pozzolanic Material Proportions

4.2 Split Tensile Strength:

The Split Tensile Strength of GPC with different proportions are obtained of age 3, 7 and 28 and a graph is plotted between pozzolanic material proportion (x-axis) vs split tensile strength (y-axis). From the figure we can say, as the age of concrete increases tensile strength increases. 100% Metakaolin gives strength of 6.73 N/mm² which is the maximum strength obtained than other proportions. The strength variation between one proportion to other and one age to other is in slight manner. Refer Figure 18, 19 and Table 14

Table-14: Split Tensile Strength of Geopolymer Concrete

Proportion	POZZOLANIC MATERIAL		SPLIT TENSILE STRENGTH (N/mm²)		
	Metakaolin (%)	GGBS (%)	3 DAYS	7 DAYS	28 DAYS
C1	50	50	3.12	3.72	3.9
C2	60	40	3.70	3.81	4.14
C3	70	30	3.92	3.98	4.23
C4	80	20	4.21	4.65	4.71
C5	90	10	5.26	5.87	5.81
C6	100	0	6.22	6.53	6.73

Figure 18: Split Tensile Test of Geopolymer concrete

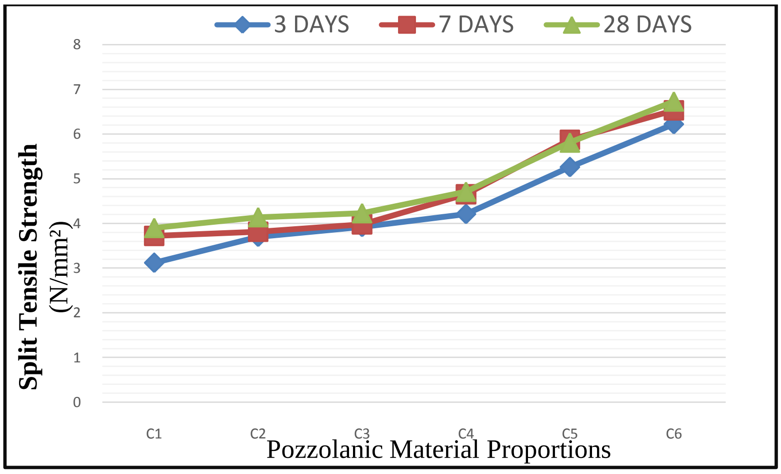


Figure 19: Graph between Split tensile Strength and Pozzolanic Material Proportions

4.3 Flexural Strength:

The Flexural strength of concrete with different proportions are evaluated of age 3, 7 and 28 days and a graph is plotted between pozzolanic material proportion (x-axis) vsFlexural strength (y-axis).A two point load is applied on the beams of size 50mm in length, 10mm in width and 10mm in depth. From the figure we can say, as the age of concrete increases Flexural strength increases. 100% Metakaolin gives Flexural strength of 3.54 N/mm² which is the maximum strength obtained than other proportions. The strength variation of C1, C2, C3 and C4 are slight but C5, C6 has vast variation. Refer Figure 20 and Table 15

Table-15: Flexural Strength of Geopolymer concrete

Proportion	POZZOLANIC MATERIAL		FLEXURAL STRENGTH (N/mm²)		
	Metakaolin (%)	GGBS (%)	3 DAYS	7 DAYS	28 DAYS
C1	50	50	0.75	0.822	0.87
C2	60	40	0.85	0.9	1.2
C3	70	30	1.11	1.58	1.75
C4	80	20	1.63	1.67	1.71
C5	90	10	1.96	2.57	2.81
C6	100	0	3.2	3.41	3.54

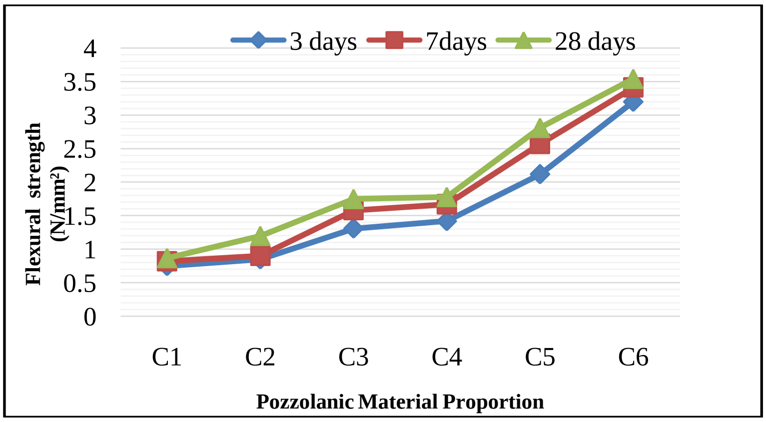


Figure 20: Graph between Flexural Strength and Pozzolanic Material Proportions

Durability:

Durability is a major factor to be considered for the structure to with stand for a long period i.e. the age of the structure should be more durable. So my experimental investigation take me to identify the structural behavior on different environmental like Chloride attack, Acid attack and Sulphate attack. But in this report work is concentrated on sulphate attack. Therefore the results and discussions are processed as follows. Refer Figure 21, 22, 23 and Table 16, 17

- The **initial** compressive strengths are obtained from the proportions C1, C3, C6 which are in ambient curing for **28** days.
- The **final** compressive strengths are obtained from the proportions C1, C3, C6 which are in chemical curing for 30 days and dried for 15 day

Table-16: Percentage Reduction in weight

S.no	Mix ID	Weight of Specimens (grams)		Reduction in weight (grams)	% Reduction in weight	No. of days
		Initial	Final			
1	C_1	8193	8133	60	0.73	20
2	C_3	8856	8795	61	0.68	20
3	C_6	8543	8486	57	0.66	20

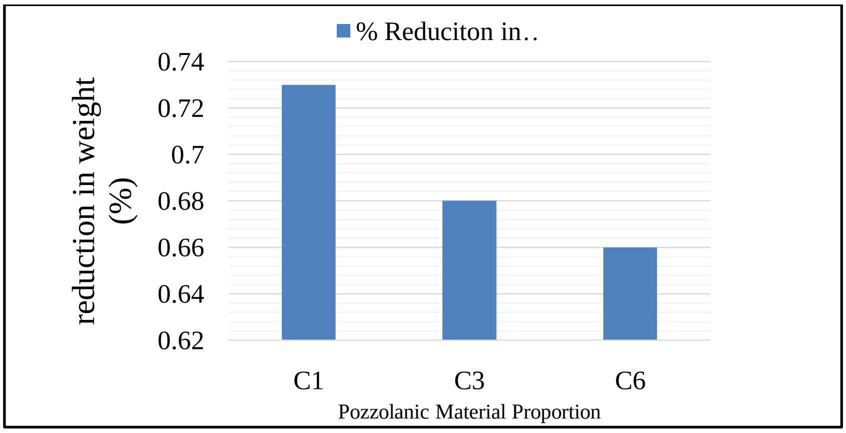
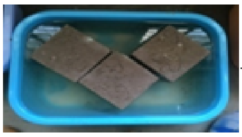


Figure 21: Graph between Pozzolanic Material and % Weight Reduction

Specimens under chemical curing in Na_2So_4



Proportion: 50(MK) + 50(GGBS)
Solution: sodium sulfate
Action: Under chemical curing for 20 days

Proportion: 70(MK) + 30(GGBS)
Solution: sodium sulfate
Action: Under chemical curing for 20 days

Proportion: 100(MK) + 0(GGBS)
Solution: sodium sulfate
Action: Under chemical curing for 20 days

Table-17: Compressive strength of Geopolymer Concrete after exposure to sulfate solution

S.no	MIX ID	Compressive strength (N/mm^2)		% Reduction in C.S	No. of days for chemical curing
		Initial	Final		
1	C_1	35.23	31.09	11.75	20
2	C_3	48.13	43.88	8.83	20
3	C_6	61.03	51.70	15.28	20

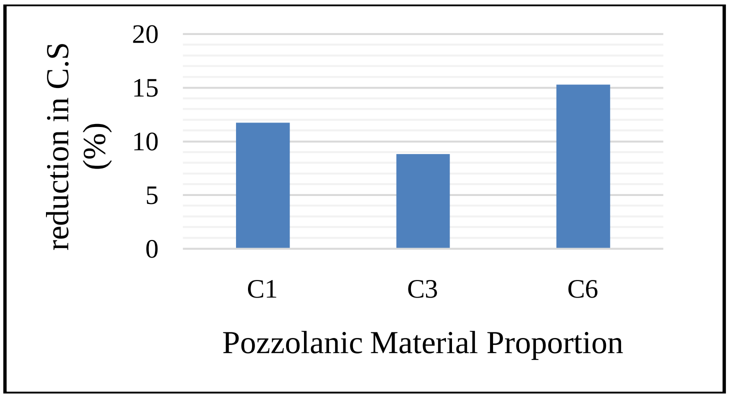


Figure 23: Graph between Pozzolanic proportion and % Reduction in Compressive strength.

V. Conclusion

- From the above results it is apparent that Geopolymer concrete based on GGBS and metakaolin has got more compressive strength than conventional concrete.
- It is observed that the Compressive, Flexural and Split Tensile strengths of Geopolymer Concrete are increased with increase in percentage of Metakaolin quantity i.e GGBS 0%-MK 100% and decreased with increase in GGBS irrespective of curing period.
- The green concrete resists the attack of various chemicals and therefore, it is durable for the given mix proportion.
- Compressive, Flexural and split tensile strengths vary in direct relation to age for a given proportion of a mix.
- Proportion C_1obtained the maximum in percentage reduction of 0.73 in weight for 30 days of chemical curing (Na_2SO_4).
- Proportion C_6 obtained the maximum in percentage reduction of 15.28 in Compressive strength for 30 days of chemical curing (Na_2SO_4).

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