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Mechanical and Durability Properties of Geopolymer Concrete using Copper Slag and Metakaolin

Rohith.R, Elavenil, S.

Abstract: ***The common binder which is used in the construction industries all over the world is Ordinary Portland Cement (OPC). OPC gives required strength and durability to the buildings. But during the process of cement manufacturing a large amount of Co_2 is emitted. Since it is the commonly used binder, the emission of Co_2 is significantly greater. To reduce the emission of Co_2 some of the developed countries are focusing on other types of binder which emits less Co_2. In construction industry, river sand are mainly used as the fine aggregates, which has resulted in depletion of few rivers and also lead to saline water intrusion from the nearby seas. So the government has prohibited the sand mining to preserve the natural resource. This increased the demand and cost of sand.***

To overcome the above criteria the river sand is fully replaced with copper slag and the cement is fully replaced with flyash (90% & 80%) and metakaolin (10% & 20%). This paper gives an overlook of mechanical and durability properties of geopolymer concrete using Metakolin and Copper Slag along with activator solutions.

keywords: Geopolymer Concrete, Copper Slag, Metakaolin, Mechanical and durability properties.

I. INTRODUCTION

Concrete is most extensively used construction material in the world. It is made by mixing the aggregates together with cement and water. In developing country like India mostly uses Portland cement. Portland cement is one of the major reasons for emission of CO_2 in the atmosphere. A result showed more than 70% of the total CO_2 emission is due to the construction industry. However, currently we are using OPC as the main binder for constructions and we need to find the alternative ecofriendly materials. One other possible outcome is the use of alkali-activated binder using industrial by-products containing silicate materials. The most common industrial by-products used as binder materials are fly ash (FA).Metakaolin can be used as substitute for cement. Metakaolin can reduce the emission of CO_2 and by reacting with water to form calcium hydroxide.

After lime and cement concrete, Geopolymer is the next generation cement. The term ''geopolymer'' is generically used to describe an amorphous alkali aluminosilicate which is also commonly used for to as ''inorganic polymers'', ''alkali-activated cements, ETC [1].

Compared to other concrete GPC are more durable and stronger which gives them the advantage over other concrete. It has better spalling resistances compared to OPC [1]. Curing temperature and duration are the most essential matter that affects the strength obtained of geopolymer concrete. The presence of Na_2SiO_3 gel delays the setting time of the concrete at room temperature, to avoid this oucome the concrete is cured at 60^oC for 1 to 2 days [3]. Absorption of water is less compared to normal concrete. The strength is achieved is a very short time [10]

Geopolymer uses industrial by-product and various minerals. For binding materials flyash, ggbs, metakaolin,etc… are used. Dibyendu adak, to overcome the limitation activation of heat at various temperature, so he included necessary percentage of nano silica to the mixture. The nano silica changed geopolymer concrete shows increment in the structural behavior without a heat activation [3].

Hamdy k prepared 18 concrete mixtures while varying the percentages of cement and flyash with alkaline solution of NaOH and LSS. And conducted various mechanical test on the concrete and he found that the mechanical property was achieved at 50% replacement [4].

Samira Selmani studied the various effect of geopolymer concrete on addition of geopolymer concrete and found that the concrete forms a homogenous structure if there are less impurity on the metakaolin [6]. Pavel Ronanik conducted an experiment to find the changes in curing temperature of metakaolin based GPC concrete. He found the effect of curing at various temperatures for compressive and flexural strength, and he found that the pore size increases with rise in temperature [7].

Since we are industrial by products as the main binder we will get binding property if we add water, so for that purpose we alkaline activators such as NaOH or KOH and Na_2SiO_3 or K_2O_3Si to the binders. This process is called as geopolymerization.

Thais da silva rocha studied the influence of different alkaline activators on the mechanical, thermal, and microstructural behaviour[2].

Mahindran used the combination of Sodium silicate (Na2SiO3) and Sodium Hydroxide (NaOH) in the ratio of 2.5. The laboratory grade sodium hydroxide was used having 97 % purity and in form of flakes which were bought from local seller. In order to get 10 molarities concentration, 400 grams of sodium hydroxide flakes were dissolved in one litre of distilled water. The sodium silicate solution with a ratio of

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ROHITH R, M.TECH Structural engineering, VIT University/Chennai. India

ELAVENIL S, SMBS, PROFESSOR/ VIT University/Chennai India

SiO2 to Na2O is approximately 2 is used, that is 34.31 %. Tanakorn phooffound the flexural strength of beam filled with alkali activated binders with various alkali solutions. Alkali-activated binders (ABB) were manufactured from low calcium fly ash and GBFS with 11.67% Na_2O, 28.66% SiO_2 and 59.67%H2O were used as alkali activators. 10M SH, sodium hydroxide pellets of 400g was dissolved by distilled water of 1 L and then allowed to cool down for 24hrs [5].

Jaishankar experimented on the strength of concrete using metakolin and M-Sand to find the mechanical property of the concrete [8]. Neethu susan conducted few experiments to find the effects of copper slag as a partial replacements for Fine aggregate in GPC with 40% replacement of copper slag with M-Sand [9].

Brindha studied the durability studies on copper slag admixed concrete with flyash as the main binder [10]. The researchers have studied the effects of GPC with partial replacements of fine aggregates by copper slag in concrete and found the workability, density and strength of concrete [11]

The author have done the experimental study on beams on GPC with copper slag as replacement as fine aggregates [12]. Khalifa conducted a study to find the effect of using copper slag as a fine aggregates on mortar and concrete [13].

Xing li investigated the effects of aggregates on the mechanical properties and microstructure of GPC. The effects of silica sand and steel fibre aggregates on the microstructure and mechanical strength of the geothermal metakaolin based geopolymer. Compressive strength XRD, FTIR, SEM, BET, NMR was found out. The compressive strength was more than 35Mpa with 50% silica sand [14].

II. MATERIALS

A. Flyash

Fly ash is the most commonly used industrial by-product in which it has a high amount of silica and alumina. Fly ash is a by-product of coal based industry. Fly ash can be used as a mineral admixture, filler, synthetic aggregate.

Metakolin

Metakaolin is a chemical phase that forms upon thermal treatment of kaolinite. Metakaolin is white in color and acts as a pozzolanic material. Like other pozzolonas (flyash and silica fumes are two common pozzolans), metakaolin reacts with calcium hydroxide by-product produced during cement hydration.

Copper Slag

Copper slag is an industrial by-product produced during matte smelting and refining of the copper. The copper slag will be a black crystalline structure . The particle sizes are similar to sand. The specific gravity of the slag is 3.9.

B. Alkaline Solution

In Geopolymerisation process the alkaline solution is prepared by mixing the sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) solutions. The vital role of the alkaline solutions is to provide a high alkaline liquid medium for condensation polymerization. The sodium hydroxide solution must be prepared one or two days before the batching as it liberates a huge amount of heat at the time of preparation. The alkaline activator is used in a combination of sodium hydroxide and sodium silicate in the ratio of 1:2.5. In order to get an 8 molarities concentration, 320gram of sodium hydroxide flakes were dissolved in one liter of water to create sodium hydroxide solution.

III. SPECIMEN PREPARATION

The specimens are all casted according to the IS recommendations. The cubes were casted of size 150mm x 150mm x 150mm, and they are tested according to IS codes for both compressive strength and Durability test. Cylinders of size 150mm diameter and 300 mm height are casted for split tensile and durability tests. And for flexural strength beams of size 150mm x 150mm x 700mm is casted

IV. MIX PROPORTIONS

For this study a mix of 8M of NaOH is taken. The ratio between the NaOH and Na_2SiO_3 is 2.5. and the binder to alkaline ratio is 0.45.

Mix Proportions:

Two different mix preparation were made by changing the binder content. M1 mix consists of 90% flyash and 10% metakaolin and copper slag as the fine aggregate. And M2 mix consist of 80% flyash and 20% metakaolin along with copper slag as the fine aggregates. The mix proportion for this study is 1:1.54:2.89

Mix proportion

Materials	**M1 Kg/m^3 (%)**	**M2 Kg/m^3 (%)**
Flyash	387.53 (90)	317.8(80)
Metakaolin	39.725 (10)	79.45 (20)
Copper slag	638.4 (100)	638.4 (100)
12mm CA	711.36 (60)	711.36 (60)
20mm CA	474.24 (40)	474.24 (40)
NaOH	51.07	51.07
Na_2SiO_3	127.68	127.68

V. RESULTS AND DISCUSSIONS

a) Non Destructive tests

a) Rebound hammer test

Rebound Hammer test is a Non-destructive testing method of concrete which gives us the compressive strength of the concrete at on-site and off-site. When the plunger of rebound hammer is pressed against the surface of concrete, a spring with a mass is made jump on applying some pressure to the concrete. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale.

MIX ID	REBOUND NUMBER (RN)			AVG RN
	Sample 1	Sample 2	Sample 3	
M1	30	31	30	30.33
M2	34	36	36	35.33

Based on the RN values we know the quality or grade of concrete since the RN value is above 30 the quality of concrete is good.

b) UPV test

UPV test is used to find the quality of concrete. The device has emitter and receives to check the pulse velocity. If the value of the pulse is almost equal then the quality of concrete is higher. Based on the UPV value the quality of the concrete is determined.

Mix ID	PULSE VELOCITY (Km/s)		
	Sample 1	Sample 2	Sample 3
M1	3.627	3.520	3.77
M2	4.31	4.25	4.99

Since the value of the pulse velocity of M1 is above 3.5 and 4.5 for mix M2 there quality of concrete is good and excellent.

b) Mechanical properties

a) Compressive strength

After curing the cubes are tested by the CTM having a capcity of 2000kN.

Mix	7^{th} day (N/mm^2)	14^{th} day (N/mm^2)	28^{th}day (N/mm^2)
M1	44.37	48.52	56.6
M2	44.33	52.77	61.8

It can be noted that the strength of the M2 is higher than that of M1. The increase of strength of M1 and M2 at the28^{th} day is around 8.31%. The increment in the strength of M1 is 24.65% from 7^{th} to 28^{th} day and the increase in strength of M2 is about 26.9%. from the above table you can conclude that increase in the percentage of metakaolin increases the compressive strength of concrete.

b) Split tensile strength

The cylindrical specimen of diameter 150mm and 300mm height is tested in CTM. The specimen is placed between the base plates and uniform load is applied across the longitudinal section of the specimen.

Mix	7^{th} day (N/mm^2)	14^{th} day (N/mm^2)	28^{th}day (N/mm^2)
M1	1.81	3.01	4.31
M2	2.18	3.17	4.94

The tensile strength of concrete for M1 is increased by 58% from 7^{th} to 28^{th} day. And M2 is increased 55.8 %. The strength increases of 12.8% from M1 and M2.

c) Flexural strength

The beam specimen were 150mm x 150mm x 700mm. the beam was tested with one point load to find the flexural strength of GPC beams HYSD bars of 10 mm dia as longitudinal reinforcement. Two legged striupps of 8mm dia at 90mm c/c spacing is provided

Mix	Initial crack kN	Ultimate load kN	Max displacement mm	Max stress N/mm^2	Max strain N/mm^2
M1	50	65.8	7.8	17.86	1.99
M2	49.5	71.65	11	17.88	3.14

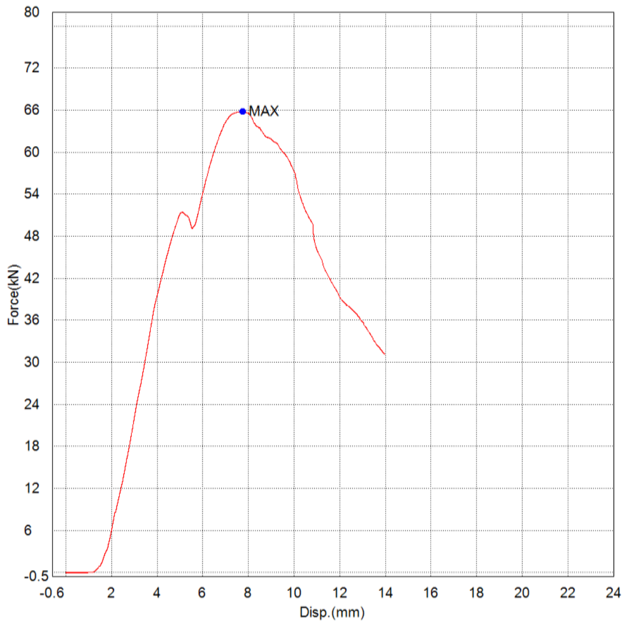

Figure1. M1 force- displacement curve

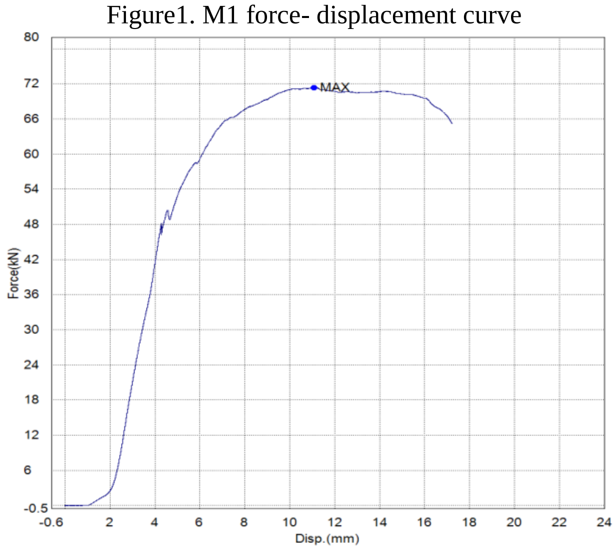

Figure 2. M2 force -displacement curve

c) Durability studies

a) Chloride attack test

The cubes are immersed in sodium chloride solution of 5% of weight solution. Weight of the specimen is noted after it is dried and then the cube is tested. The chloride content attacks the specimen and the area may have been changed. Therefore the loss of weight is found. It is observed that there is decrease of strength in the cubes.

	Compressive strength after exposure , N/mm^2		
Mix	28^{th} day (N/mm^2)	56^{th} day (N/mm^2)	90^{th}day (N/mm^2)
M1	55.01	53.73	53.41
M2	60.26	59.97	57.91

The cubes are test after few days, there is decrease in strength of 5.6% and 6.3% for mixes M1 and M2 respectively.

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b) Sulphate attack test

After the cubes are immersed in the solution of 5% of sodium sulphate by weight of water. Sulphate attack on concrete leads to the formation of ettringite that causes crack and scale. The sulphate is attacked by the both internal and external factor. Loss in compressive strength and % loss in weight of the specimen determined the concrete resistance to sulphate attack.

Mix	Compressive strength after exposure , N/mm^2		
	28th day (N/mm^2)	56th day (N/mm^2)	90thday (N/mm^2)
M1	54.73	51.83	49.19
M2	59.42	56.01	54.11

There is a decrease in strength in mixes M1 and M2 about 8.6% and 9.2 % respectively compared to the 90th day.

c) Acid attack

After curing the specimen were immersed in water containing 5% of concentrated sulphuric acid by weight. The pH is maintained throughout the immersion period and tested

Mix	Compressive strength after exposure , N/mm^2		
	28th day (N/mm^2)	56th day (N/mm^2)	90thday (N/mm^2)
M1	54.73	51.83	49.47
M2	59.42	56.01	52.77

The cubes after immersed in the acid solution starts to deteriorate due to the attack of attack the shape of concrete will not absolutely be a perfect cube. So before testing the cubes the new area of concrete is calculated and strength of the concrete is calculated for 28,56and 90 days. Compared to other durability test the reduction in strength and weight reduced is more in acid attack

VI. CONCLUSION

1) The mix M2 gives a higher compressive strength compared to the Mix M1 by 9.6%. And M2 has high split tensile strength of 12.8% higher than the Mix M1.
2) Geopolymer beams with 20% metakaolin ahs 9.8% higher load capacity compared with the beam with 10% metakaolin.
3) Geopolymer concrete with 20% metakaolin have a better resistance of 7.7 % on chloride attack, 9.1% better resistance on sulphate attack and 6.2% better resistance to acid compared to the GPC specimen with 10% metakaolin.
4) GPC beam with 20% metakaolin has a displacement of 11mm compared to the other mix.
5) The strength of the concrete increases with increase in the percentage of metakaolin.

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AUTHORS PROFILE

ROHITH. R was born in vellore. He currently doing his M.E Structural engineering in VIT University in Chennai.

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Dr.S.Elavenil is working as a Professor in School of Mechanical and Building Sciences, Building Sciences,Vellore Institute of Technology, Chennai, India. She obtained the Ph.D degree in Dynamic response of plates under impact loading in 2006 from Anna University and M.E degree in Structural Engineering in 1994 from NIT Trichy, India. She did B.E degree in Civil Engineering from PSNA College of Engineering, Dindugal, India. She published more than 60 papers in the National and International Journals.She has published 3 books. Her research interest includes Finite Element Method, Fibre reinforced concrete, Structural Dynamics and Earthquake engineering.