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Proportioning of Geopolymer Mortar and Properties of Geopolymer Masonry Blocks

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Abstract

The main objective of this research was to proportion the geopolymer mortar and to study the properties of geopolymer blocks. The materials used are flyash, Ground Granulated Blast Furnace Slag (GGBS), silicafume and metakaoline as binders, sand and rock dust as fine aggregate. Sodium hydroxide and sodium silicate were used for the preparation of alkaline solution. The proportioning of mortar indicates that the maximum strength developed for the combination of flyash and GGBS was 9.41MPa at the age of 7 days. The strength produced in other combinations are in the range of 0.32 - 5.95 MPa. The strength development was increasing at a faster rate till the age of 28days and it was almost constant later. The dry compressive strength of masonry units was in the range of 11.5- 28.03 MPa, IRA was in the range of 3.42- 9.7kg/m2/min, water absorption was in the range of 6.56-12.12%, wet strength was in the range of 7.71- 19.64 MPa, initial tangent modulus was in the range of 10207-15338 MPa, initial secant modulus was in the range of 9267-14176 MPa. The properties of the geopolymer blocks indicate that they can be used as masonry units in structural masonry.

Keywords: Geopolymers, Strength, IRA, Tangent Modulus

I. Introduction

Ordinary Portland Cement (OPC) is an important material in the production of concrete which acts as binder. Portland cement concrete (PCC) is the most popular and widely used building material, due to the availability of the raw materials and its easy preparation. Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. Another form of cementitious materials geopolymers has many advantages. These cements have been proposed as more ecologically friendly alternative material as their production does not involve limestone calcinations. Geopolymer binders are used together with aggregates to produce geopolymer concretes which are ideal for building and repairing infrastructures and for precasting units, because they have very high early strength, their setting times can be controlled and they remain intact for very long time without any need for repair.

II. Literature review

The geopolymer concrete results from the reaction of a source material that is rich in silica and alumina with alkaline liquid [Rangan et.al-2010(6)]. A simple method to design geopolymer concrete mixtures has been described and illustrated by an example. Geopolymer concrete has excellent properties and is well-suited to manufacture precast concrete products that are needed in rehabilitation and retrofitting of structures after a disaster. The economic benefits and contributions of geopolymer concrete to sustainable development have also outlined.

To study the chemical reaction, mechanism, role of materials, applications and microstructure of fly ash geopolymer cement, Mustafa Al Bakri et.al-2011[8] carried out an experimental investigation. The author concluded that an extensive research has already been carried out. The right name for these binders is alkali activated binders for the general case although the term ‘‘geopolymer’’ is accepted in some cases. The exact reaction mechanism of alkali-activated binders is not yet quite understood, although it depends on the prime materials and on the alkaline activator.

Bakril et.al-2011[11] reported that the consumption of Ordinary Portland Cement (OPC) caused pollution to the environment due to the emission of CO2. Fly ash is a by-product from the coal industry, which is widely available in the world. The compressive strength increases with the increasing of fly ash fineness and thus the reduction in porosity can be obtained. Fly ash based geopolymer also provided better resistance against aggressive environment and elevated temperature compared to normal concrete. The geololymer can be an encapsulation matrix for solid nuclear waste[Vandeperre et.al-2010(17)]. The study suggests that pure geopolymers cannot be used as an encapsulation matrix for solid nuclear waste because of shrinkage cracking. However, the formation of cracks in geopolymers can be reduced by adding inert filler. When the w/s ratio is below 0.518, geopolymers can be produced which do not crack on drying. In addition up to 35 wt.% of filler can be added without increasing the viscosity or decreasing the compressive strength.

Sarangapani et.al -2002 [20] has reported the characterization of properties of local low modulus bricks, mortars and masonry using these materials. The results reveal that the bricks around Bangalore have rather low module compared to cement mortar. The brick modulus is in the range of about 5 to 10% of the modulus of 1: 6 cement mortars. This kind of situation leads to a masonry where mortar joints develop lateral tension while brick develops lateral compression (triaxial) and this is an unfavorable situation due to the brittle nature of mortar.

The uniaxial monotonic compressive stress-strain behavior and other characteristics of unreinforced masonry and its constituents, i.e., solid clay bricks and mortar, have been studied by Kaushik et.al -2007 [23]. IRA was found to be more directly related to the compressive strength of bricks than WA. The compressive strengths of bricks with lower values of IRA were observed to be significantly higher. A much better correlation coefficient was found between IRA and compressive strength −0.77 than that for WA and compressive strength −0.24.Compressive behavior of mortar with lime was found to be better because of greater ductility; failure strain was about 45% more than that for strong mortar although the compressive strength was about 35% less. William and Nancy -2002[26] says four point bending (FPB) is a cornerstone element of the beam flexure portion of a sophomore level mechanics of materials course. The upgrades to the four point bending laboratory have succeeded in providing mechanical technology students a modern, DAQ-based learning experience. This upgrade has retained and enhanced the FPB laboratory's traditional emphasis on understanding of concepts through hands-on learning.

Maurenbrecher -1986 [27] says the new edition of the Canadian masonry design standard uses mortar-bedded area instead of net area in determining the load capacity of hollow block walls. The use of mortar-bedded area instead of net area will mean a significant reduction in the ultimate axial load capacity for face-shell bedded block work, using existing tabular values.

III. OBJECTIVE

The reported literature on geopolymers is silent about the geopolymer masonry. The data regarding the properties of geopolymer paste, mortar and concrete are already available. With the help of this data, it is possible to develop the geopolymer masonry. The properties of geopolymer masonry can be studied in similar lines to that of brick masonry or concrete block masonry.
The objectives of the research are

- To characterize the materials used for making geopolymers.
- To Proportion the geopolymer mortar using various binders.
- To study the compressive strength development of geopolymer mortar
- To use the geopolymer mortar in making geopolymer masonry units.
- To obtain the basic properties of geopolymer masonry units, such as dry and wet compressive strength, Initial Rate of Absorption (IRA), percentage of water absorption, modulus of elasticity etc.
- To study the durability characteristics of the geopolymer masonry units.

IV. METHODOLOGY

The materials required to prepare the geopolymer mortar were procured from different sources. The flyash was procured from Raichur Thermal power plant, Karnataka. GGBS was procured from Jindal Steel Works, Thorangal, Bellary District, and Karnataka. Commercially available metakaoline, silicafume sodium hydroxide and sodium silicate were used in this research. The materials were stored in air tight containers. They were characterized for physical, chemical, morphological and mineralogical properties using SEM, XRD etc.

The proportioning of mortar was done by casting the cylinders using geopolymer mortar. The different binders used were Flyash, GGBS, Silicafume and Metakaoline. Static compaction device was used to cast the cylindrical specimens. The size of the cylinders was 38mm in diameter and 72 mm in height. The procedure adopted to prepare the geopolymer mortar was same as that of conventional cement mortar. The parameters considered for the preparation of geopolymer mortar were ratio of binders, fluid-to-binder ratio, age, etc. The geopolymer mortar cylinders were cured in open air till the age of testing. The compressive strength was determined at the age of 7 days unless specified. Different specimens cast using geopolymer mortar is shown in Table 1.

For the combination of flyash: GGBS of 70:30, the cylinders were tested for compressive strength at the age of 1, 3, 7, 14, 28, 56 and 90 days. The different combinations of binders used include flyash-GGBS, flyash-silicafume, flyash-metakaoline, flyash-GGBS-silicafume, and flyash-GGBS-metakaoline. To study the properties of geopolymer masonry blocks, three different sizes of blocks are prepared. Cylinders of diameter 38mm and height 72mm, Blocks of size 190mm×230mm×100mm and brick of size 100mm×230mm×75mm. The composition of cylinders and Blocks are flyash and GGBS in the ratio 70:30, binder to aggregate ratio 1:1, and fluid binder ratio 0.20. The fluid used is 12M solution prepared using sodium hydroxide and sodium silicate. The composition of Bricks are flyash and GGBS in the ratio 70:30, Binder to aggregate (rock dust) ratio of 1:2, fluid binder ratio of 0.3 with a 8M fluid. The curing adopted is open air curing.

For all the above masonry blocks several tests were conducted. The tests include the dry compressive strength test, IRA (Initial Rate of Absorption) test, water absorption test, wet compressive strength test, alternate wetting and drying test, durability test (abrasion test) and modulus of elasticity test. All the tests were conducted at the age of 28 days.

V. EXPERIMENTAL WORK

Proportioning of binders is done by casting the cylinders and determining the compressive strength at age of 7days. As already discussed, geopolymer mortar is used for the preparation of blocks. To cast the cylinders, Static Compaction Device is used. The binders are used in different ratios with different combination and the fluid binder ratio is also varied which is shown

Table – 1

SERIES ID	COMBINATION	FLUID BINDER RATIO
S1	FA: GGBS= 90:10	0.2
S2	FA: GGBS= 80:20	
S3	FA: GGBS= 70:30	
S4	FA: GGBS= 60:40	
S5	FA: GGBS= 50:50	
S6	FA: GGBS= 90:10	0.25
S8	FA: GGBS= 70:30	
S10	FA: GGBS= 50:50	
S11	FA: META= 90:10	0.2
S13	FA: META= 70:30	
S15	FA: META= 50:50	
S16	FA: META= 90:10	0.25
S18	FA: META= 70:30	
S20	FA: META= 50:50	
S21	FA: SF = 90:10	0.2
S23	FA: SF = 70:30	
S25	FA: SF = 50:50	
S26	FA: SF = 90:10	0.25
S28	FA: SF = 70:30	
S30	FA: SF = 50:50	
S31	FA:GGBS:SF= 70:28:2	0.25
S32	FA:GGBS:SF= 70:26:4	
S33	FA:GGBS:SF= 70:24:6	
S34	FA:GGBS:SF= 70:22:8	
S35	FA:GGBS:SF= 70:20:10	
S36	FA:GGBS:META= 70:28:2	0.25
S37	FA:GGBS:META= 70:26:4	
S38	FA:GGBS:META= 70:24:6	
S39	FA:GGBS:META= 70:22:8	
S40	FA:GGBS:META= 70:20:10	

VI. RESULTS AND DISCUSSION

The proportioning was done by casting cylinders and determining the compressive strength at the age of 7days. Table 2 gives the combination, fluid binder ratio used and the results. It can be seen that the maximum strength developed for the combination of flyash and GGBS is 9.41MPa at the age of 7 days. The strength produced in other combinations are in the range of 0.32 -5.95 MPa. The strength development of various combinations of binders at a constant fluid-to-binder ratio is discussed

Table – 2

SERIES	DENSITY (Kg/m^3)	7DAYS STRENGTH (MPa)
S1	1820	2.60
S2	1835	5.44
S3	1840	8.60
S4	1822	8.90
S5	1842	9.41
S6	1837	1.35
S8	1838	4.95
S10	1836	7.62
S11	1822	2.20
S13	1811	0.89
S15	1794	0.77
S16	1830	1.40
S18	1830	1.10
S20	1810	0.70
S21	1808	0.80
S23	1803	1.62
S25	1800	1.62

The geopolymer mortar cylinders were tested at different ages for S3 series of specimes using fly ash GGBS in the ratio of 70:30 at fluid-to-binder ratio of 0.2. The respective compressive strengths are given in Table 3.The variation of strength with age is shown in Fig. 1. It is noticed that the strength development is rapid till the age of 28days and almost saturated after that. The minimum compressive strength at the age of 24 hours is about 2 MPa which is sufficient to handle the blocks for the purpose of transportation etc. At the age of 7 days, the strength is about 5MPa which is more than the strength required for a masonry unit as per IS 1077-1992. The highest strength achieved at the age of 56 days is around 11MPa.

Table – 3

AGE (DAYS)	*1*	*3*	*7*	*14*	*28*	*56*
DENSITY (kg/m³)	*1817*	*1784*	*1776*	*1788*	*1784*	*1796*
STRENGTH (MPa)	*2.06*	*2.80*	*5.25*	*6.27*	*11.50*	*11.72*

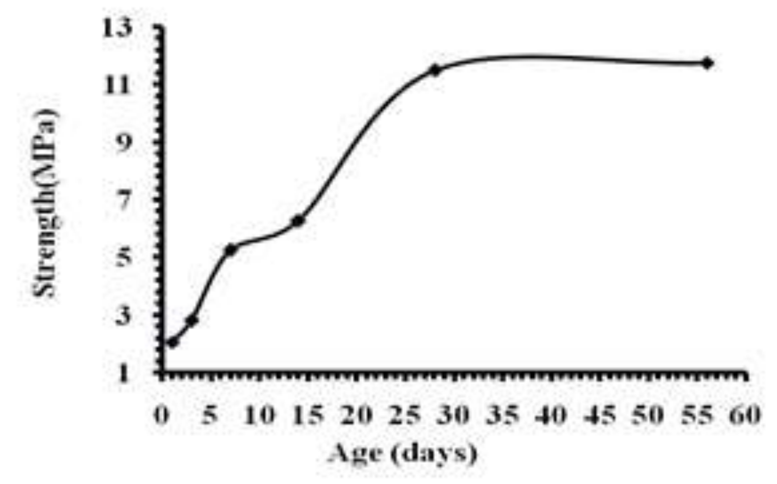

Fig. 1: Strength Development with Age

A. Tests on Masnory bloack

The tests on various masonry blocks were conducted at the age of 28days. A minimum of three specimens were used for all the tests. Table 4 provides the test results. It can be seen that the strength developed in all types of blocks were within the range of 3.5-35 MPa. This satisfies the requirements as per IS 1077-1992. As per G.Sarangapani, the IRA values for masonry units should be in the range 1.31-3.53 kg/m2/min. The IRA values of cylinder and blocks were nit in the range. But the IRA for bricks was within the range. The percentage water absorption for the blocks ranges from 6.5 – 13% which is in the limits (Max 20%) as per IS 3495-1976 PART 2.

Table - 4

TYPE OF BLOCK	*DRY STRENGTH TEST*	*IRA (kg/m²/min)*	*% WATER ABSORPTION*	*WET STRENGTH TEST*		
	DENSITY (kg/m³)	*STRENGTH (MPa)*			*DENSITY (kg/m³)*	*STRENGTH (MPa)*
CYLINDER	*1725*	*11.50*	*9.70*	*12.12*	*1934*	*7.71*
BRICKS	*2080*	*28.03*	*3.42*	*6.56*	*2230*	*19.64*
BLOCKS	*1779*	*14.73*	*4.63*	*11.70*	*1960*	*10.06*

Table – 5

SPECIMEN	*% wt. GAIN AFTER 7 CYCLES*	*COMPRESSIVE STRENGTH AFTER 7CYCLES (MPa)*	*28DAY STRENGTH (MPa)*	*%REDUCTION IN STRENGTH*
Cylinder	*0.67*	*5.57*	*11.49*	*51.6*
Brick	*3.70*	*23.07*	*28.03*	*17.7*
Block	*6.50*	*9.73*	*14.73*	*33.9*

Table – 6

SPECIMEN	*% wt. LOSS AFTER 12 CYCLES*	*COMPRESSIVE STRENGTH AFTER 12CYCLES (MPa)*	*28DAY STRENGTH (MPa)*	*% GAIN IN STRENGTH*
Cylinder	*4.70*	*11.67*	*11.50*	*1.46*
Bricks	*0.53*	*37.81*	*28.03*	*25.74*
Blocks	*-1.43*	*15.13*	*14.73*	*2.97*

Table – 7

Specimen	Regression Coefficient (R)	Initial Tangent Modulus (MPa)	Initial Secant Modulus (MPa)	q
BRICK	0.95	15338	14176	0.001480
BLOCK	0.97	10207	9267	0.001714

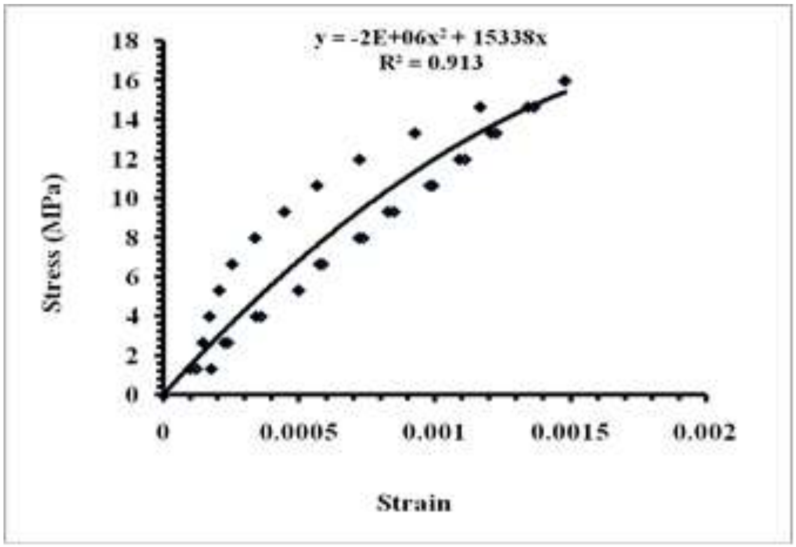

Fig. 2: Stress.Strain Curve for Bricks

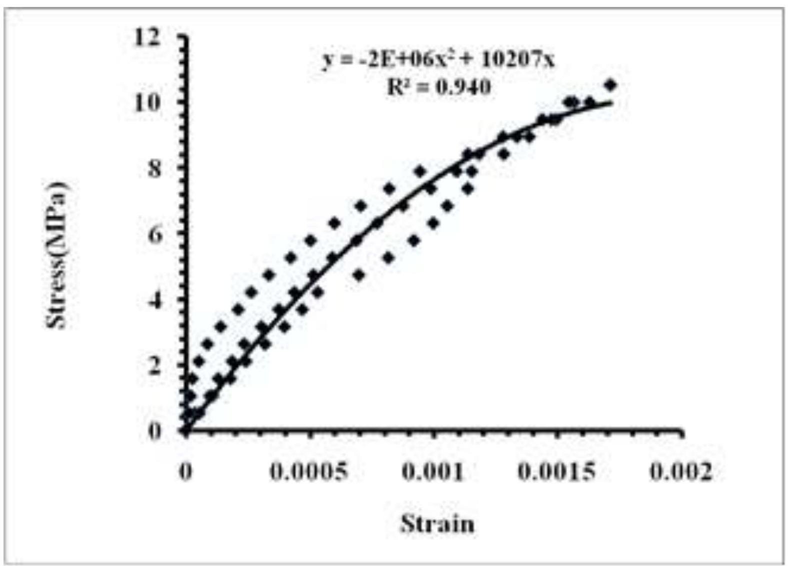

Fig. 3: Stress.Strain Curve for Blocks

Table – 8

Test	Geopolymer brick	Burnt brick	Geopolymer block	Concrete block	Remarks
Compressive strength (MPa)	28.03	3.5- 35	14.73	3.5-35	Satisfactory
IRA (kg/m^2/min)	3.42	1.31-3.53	4.63	1.31-3.53	High for blocks
Water absorption (%)	6.56	< 20	11.7	< 20	Satisfactory
Initial tangent modulus (MPa)	15338	500-2000	10207	2000-10000	Excellent
Initial secant modulus (MPa)	14176	400-2000	9267	2000-9000	Excellent
Maximum strain	0.001480	0.0010-0.0015	0.001714	0.0015-0.0025	Appreciable

VII. CONCLUSION AND SCOPE FOR FUTURE WORK

A. *Conclusion*

The following broad conclusion can be drawn with the limited study on ambient cured geopolymer mortar.

- The materials characterized viz. flyash, GGBS, silicafume and metakaoline are suitable to use as binders to prepare geopolymer mortar.

- The compressive strength of geopolymer mortar increases with the increase in the content of GGBS. The compressive strength ranges from 1.35- 9.41 MPa at the age of seven days.
- The use of metakaoline and silicafume may not be suitable due to economic constituents because the variation of compressive strength is very small by the use of these binders.
- The compressive strength of geopolymer mortar increases with age. The strength at the age of 28days was 11.5MPa and at 56days was 11.72MPa.
- Since the range of the compressive strength of the geopolymer mortar is 0.32- 30MPa, any combination of materials can be used to get any target strength in this range.
- It is possible to manufacture masonry blocks using geopolymer mortar without the use of cement. Open air curing can be adopted and no burning is necessary.
- The compressive strength of geopolymer masonry blocks is as high as 28MPa at 28 days, which is much above the minimum compressive strength as per IS 1077-1992.
- The properties of geopolymer masonry are far better compared to conventional burnt bricks or concrete blocks in case of IRA, water absorption, wet strength, durability and modulus of elasticity.
- The geopolymer blocks can be recommended for the use as masonry units for structural masonry.

B. Scope for Future Work

- The mortar can be subjected to X- Ray deformation (XRD), Scanning Electron Microscopy (SEM), and other tests for evaluating the properties.
- Use of super plastisizer in making mortar at lower fluid to binder ratio can be ascertained.
- The properties of the blocks made with different combination of materials can be studied.
- Structural behavior of geopolymer masonry like prism strength, masonry efficiency etc made with geopolymer units can be studied.

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