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Phenomenological Model to Re-proportion the Ambient Cured Geopolymer Compressed Blocks

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Abstract: Geopolymer mortar compressed blocks were prepared using fly ash, ground granulated blast furnace slag, silica fume and metakaolin as binders and sand/quarry dust/pond ash as fine aggregate. Alkaline solution was used to activate the source materials for synthesizing the geopolymer mortar. Fresh mortar was used to obtain the compressed blocks. The strength development with reference to different parameters was studied. The different parameters considered were fineness of fly ash, binder components, type of fine aggregate, molarity of alkaline solution, age of specimen, fluid-to-binder ratio, binder-to-aggregate ratio, degree of saturation, etc. The compressed blocks were tested for compression at different ages. It was observed that some of the blocks attained considerable strength within 24 h under ambient conditions. The cardinal aim was to analyze the experimental data generated to formulate a phenomenological model to arrive at the combinations of the ingredients to produce geopolymer blocks to meet the strength development desired at the specified age. The strength data was analyzed within the framework of generalized Abrams' law. It was interesting to note that the law was applicable to the analysis of strength development of partially saturated compressed blocks when the degree of saturation was maintained constant. The validity of phenomenological model was examined with an independent set of experimental data. The blocks can replace the traditional masonry blocks with many advantages.

Keywords: fly ash, geopolymer, mortar, compressed block, compressive strength, Abrams' law, phenomenological model.

1. Introduction

The emission of carbon dioxide is on the rise due to many reasons causing global warming. Cement industry is partially responsible for this phenomenon. The production of each ton of cement releases an equal amount of carbon dioxide into the atmosphere. The use of cement can be reduced or eliminated by employing other possible cementing materials without compromising on strength and durability. Therefore, there is a strong need to develop alternative building materials which are eco friendly. This can be achieved by using many marginal materials like fly ash, slag, quarry dust etc. There is considerable rise in thermal power generation which results in the production of a huge quantity of fly ash, creating disposal problems. Building materials is an area which can absorb considerable innovation in the composite materials using marginal materials alternative to conventional cement for eco-friendly and sustainable development in material technology and construction industry.

Geopolymers are synthesized by the activation of source materials which are rich in silica and alumina by alkaline media. The chemical reaction that takes place in this process is a polymerisation process (Davidovits 1994, 1999), resulting in products resembling the structure of natural zeolitic materials of geological origin and hence the widely used and accepted term "geopolymer" to represent a wide range of alkali activated (alumino-silicate) binders.

The term "alkali activation" refers to the chemical dissolution of aluminosilicate raw materials in a strongly alkaline environment caused by an aqueous solution of sodium or potassium hydroxide or silicate or their combination. Geopolymers belong to the family of inorganic polymers, which are macromolecules, linked by covalent bonds having –Si–O–M–O– backbone, where M denotes principally aluminium and secondarily other metals such as iron (Davidovits 1988).

The heavy demand for widely used clay bricks and concrete blocks as masonry units is quite understandable with the boom in the construction industry. Brick industry consumes considerable amount of fertile soil necessitating a "rethink" on the use of clay bricks to conserve the top fertile soil. Concrete blocks consume traditional cement, the drawbacks of the production of which have been well

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documented. It is in this context, the research reported in this paper regarding the synthesis and methods to re-proportion the ambient cured geopolymer mortar compressed blocks assumes great significance.

1.1 Previous Research

Wallah and Rangan (2006) reported that heat-cured fly ash-based geopolymers have excellent resistance to sulphate attack. Their study shows that there was no mechanism to form gypsum or ettringite from the main products of polymerisation. Bakharev (2005a, b) reports that the geopolymer specimens exhibit good resistance when exposed to acid and sulphate solutions.

Geopolymer composites have a very small greenhouse footprint when compared to traditional cement composites. The study by Shi and Fernández-Jiménez (2006) concluded that alkali-activated cements result in better matrix for solidification/stabilization of hazardous and radioactive wastes than Portland cement. According to Li et al. (2002), thermal-cured low-calcium fly ash-based geopolymer concrete offers several economic benefits over Portland cement concrete. Davidovits (1994) reported that in the production of geopolymer, about <3/5 of energy is required and 80–90 % less CO_2 is generated than in the production of OPC. Thus, the development and application of geopolymer cement and its composites is of great significance in terms of environmental protection.

1.2 Proportioning of Geopolymers

Proportioning of geopolymer composites is scarcely reported in the open literature. The available literature focuses more on strength, durability and performance of geopolymer composites. Also the research on partially saturated geopolymer mortar is rare. However, Radhakrishna et al. (2006, 2008a, b, 2010) have reported that heat-cured geopolymers can be re-proportioned by generalised Abrams' (Nagaraj and Banu 1996; Abrams 1918) and Bolomey's laws (1927). As per the reported research, by using single input parameter in the model, the binder-to-fluid ratio for any other desired strength can be calculated using the phenomenological model. The objective of this paper is to re-proportion ambient cured geopolymer compressed blocks.

2. Materials and Methods

The characteristics of the materials used are shown in Tables 1 and 2. Blaine's fineness of different ash samples is indicated in Table 2. The specific gravity and fineness modulus of the sand used were 2.6 and 2.9, respectively. The specific gravity of quarry dust used was 2.58. The grain size distribution of sand, quarry dust and pond ash are given in Fig. 1.

Alkaline solution of different molarities was prepared using tap water, sodium hydroxide flakes and sodium silicate powder. The ratio of sodium silicate and sodium hydroxide was maintained as 0.4. Static compaction device/hydraulic press was used for casting cylindrical specimens/blocks of required densities. The diameter and height of the cylindrical specimen were 36 and 72 mm, respectively. To cast cylindrical specimens of geopolymer mortar, the fine aggregate and binder (different combinations of fly ash, GGBFS, metakaolin, silica fume) were mixed in dry condition in the specified ratio by weight. Then, the alkaline solution of required quantity was added and mixed properly by hand covered with gloves to eliminate clustering. As the alkaline solution causes health hazards, use of hand gloves would be mandatory. If the alkaline solution comes into contact with the human skin, it cusses severe irritation on the skin. In such cases, the affected area of skin need to splashed with a jet of tap water to avoid any major illness. If the alkaline solution splashes to eyes, consultation of a doctor is mandatory.

Fresh mortar was cast into cylindrical specimens in a static compaction device. The degree of saturation of the mortar was maintained at 40 % unless specified. The prepared cylindrical specimens of geopolymer mortar were kept in open air at ambient conditions. The specimens were tested for unconfined compressive strength at different ages as indicated. The mix details of all the series are shown in Table 3.

3. Results and Discussion

In fresh state, geopolymer mortars, exhibit high workability at fluid-to-binder ratio of 0.35 and more (Radhakrishna et al. 2006). Up to the fluid-to-binder ratio of 0.3, the mixes were of the consistencies that need compaction effort to obtain the end product as blocks. Beyond this level, consistency would be at the level of self-compacting cement composites, adequate enough to be cast into moulds without requiring any vibrations. At lower fluid-to-binder ratios, the alkaline fluid required would be comparatively less, resulting in harsh mortar exhibiting high frictional resistance. At this fluid-to-binder ratio, external effort is required for proper compaction to achieve higher strength and denser structure with lower permeability. The present study deals with the development of ambient cured compressed geopolymer mortar blocks, re-proportioning and the strength assessment.

It is essential to study the strength development with respect to various parameters for the analysis and for developing a model to re-proportion the materials required. The parameters considered for this are:

- Fineness of fly ash alkaline activator
- Molarity of the activator solution
- Binder composition
- Ratio of binder-to-aggregate
- Fine aggregate type
- Degree of saturation
- Age of the specimen
- Fluid-to-binder ratio

It is necessary to study strength development of various base materials (fly ash) procured from different sources to assess the suitability of a particular fly ash for making

Table 1 Chemical properties of fly ash, GGBFS, silica fume and metakaolin.

Binder	Chemical composition (%)							
	Al_2O_3	Fe_2O_3	SiO_2	MgO	SO_3	Na_2O	Total chlorides	CaO
Fly ash-FA1	31.23	1.5	61.12	0.75	0.53	1.35	0.06	3.2
Fly ash-FA2	31.2	2.1	61.5	1.1	1.14	0.91	0.027	1.2
Fly ash-FA3	30.36	3.74	59.34	1.79	0.92	1.04	0.039	1.4
Fly ash-FA4	33.3	2.34	52	1.02	0.65	1.25	0.028	1.84
GGBFS	13.24	0.65	37.21	8.65	0.1	0.9	0.003	37.23
Silica fume	0.06	0.03	97.2	1.1	0.2	0.1	0.02	0.5
Metakaolin	44.5	0.4	51.5	1.35	0.34	0.56	0.39	0.6

Table 2 Physical properties of fly ash, GGBFS, silica fume and metakaolin.

Binder	Source	Specific gravity	Percentage coarser than 45 microns	Fineness (m^2/kg)	Loss on ignition	Lime reactivity (MPa)
Fly ash-FA1	Thermal power plant-unprocessed	2.40	0.00	1,134.1	0.9	7.23
Fly ash-FA2	Thermal power plant-processed	2.30	2.1	524	0.8	8.2
Fly ash-FA3	Thermal power plant-processed	2.40	16.12	350	1.2	5.4
Fly ash-FA4	Thermal power plant-processed	2.00	71.98	110	4.0	3.2
GGBFS	Commercially procured	2.50	10.45	370	0.3	–
Silica fume	Commercially procured	2.20	0.0	29,200	0.89	8.1
Metakaolin	Commercially procured	2.5	0.5	1,500	2.3	–

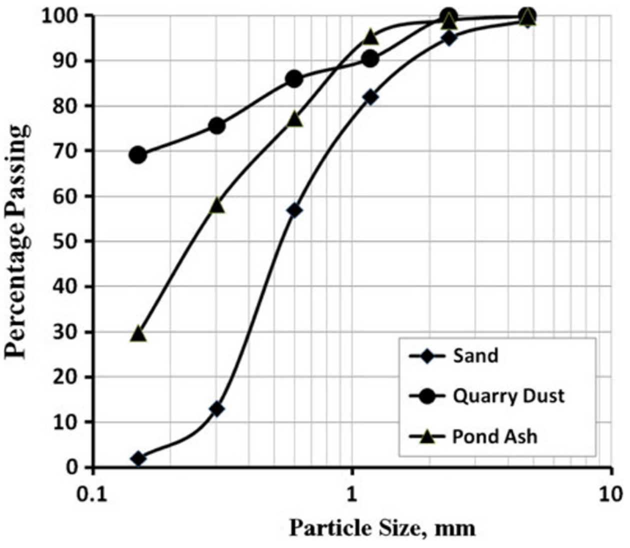

Fig. 1 Grain size distribution of various fine aggregates.

geopolymer compressed blocks. Figure 2 shows the strength development of the blocks with the fineness of the fly ash used. The series considered to study this effect was ABS7, ABS8, ABS9 and ABS10. In the designation of fly ash from different sources (i.e. FA1, FA2, FA3, FA4), the ascending order goes with the increase in the coarseness of fly ash. The strength developed was proportional to the fineness of ash used as indicated. It is observed that the higher the fineness, higher will be the strength developed. This may be attributed to higher surface area of fly ash available for the polymerisation process resulting in increased formation of polymeric gel.

Different alkaline activators have been tried by several researchers to activate the source materials in synthesizing the geopolymers. Sodium hydroxide and potassium hydroxide are the popular choices, the latter being more expensive than the first. The series considered for this study was ABS4 and ABS5. The strength development for both the activators is shown in Fig. 3. The use of potassium hydroxide as activator increases the strength of the compressed blocks compared to sodium hydroxide. Potassium hydroxide can be considered only when cost is not a constraint.

The series considered to study the effect of molarity of the activator was ABS2, ABS4, ABS6, and ABS7. The variation of strength with molarity (Fig. 4) shows that the strength developed is proportional to the molarity of the alkaline

Table 3 Mix details of the series.

Series ID	Binder-to-aggregate ratio	Fly ash type	Binder composition	Degree of saturation (%)	Alkaline activator with molarity	Curing conditions	Fine aggregate
ABS1	1:1	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS2	1:2	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS3	1:3	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS4	1:2	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 8 M	Ambient	Sand
ABS5	1:2	FA1	FA:GGBFS = 1:1	40	KOH, 8 M	Ambient	Sand
ABS6	1:2	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 10 M	Ambient	Sand
ABS7	1:2	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 12 M	Ambient	Sand
ABS8	1:2	FA4	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS9	1:2	FA3	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS10	1:2	FA2	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS11	1:2	FA2	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Quarry Dust
ABS 12	1:2	FA2	FA:GGBFS = 1:1	60	$Na(OH)_2$, 14 M	Ambient	Sand
ABS13	1:2	–	GGBFS:Metakaolin = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS14	1:2	–	GGBFS:SF = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS15	1:1	FA1	FA:GGBFS = 2:3	60	$Na(OH)_2$, 12 M	Ambient	Sand
ABS16	1:2	FA1	FA:SF = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS17	1:2	FA1	FA:Metakoalin = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Sand
ABS18	1:2	FA1	FA:GGBFS = 1:1	40	$Na(OH)_2$, 14 M	Ambient	Pond ash

ABS ambient cured blocks series.

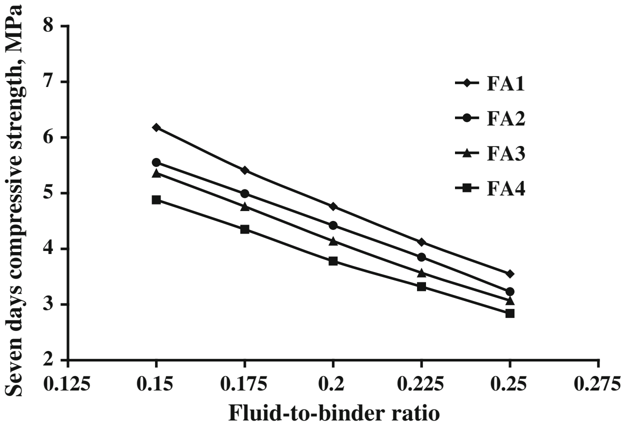

Fig. 2 Variation of 7 days strength with different fly ash having different fineness.

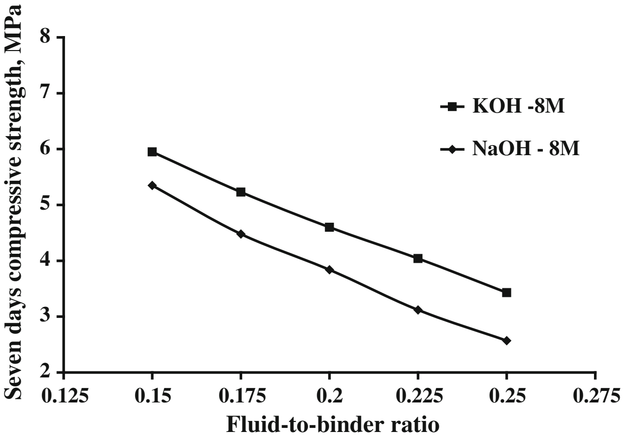

Fig. 3 Variation of 7 days compressive strength of the blocks with different alkaline activator.

activator solution used. As the molarity of the activator increases, the formation of alumino silicates and CSH gel (when GGBFS is used as one of the binder component) increases. This results in higher strength. At molarity of <8, the strength developed would be very less and was not considered. When the molarity is increased beyond 14, the salts tend to deposit making it extremely difficult to maintain homogeneity of the solution. Thus, molarity ranging from 8 to 14 would be desirable and practicable.

Strength development in the compressed blocks depends on composition of the source materials and will be influenced by variation in their physical and chemical properties. Different binders can be used to prepare geopolymer composites. The base materials used should be rich in alumina and silica. To study the strength development with binders, different combinations of fly ash, GGBFS, metakaolin and silica fume, were considered (Fig. 5). The series considered for this study was ABS2, ABS13, and ABS14. The strength development of geopolymer mortar with silica fume as one of the binder component was almost four times that when GGBFS forms part of the binder. At fluid-to-binder ratio of 0.15, the 7 days strength was more than 23 MPa when silica fume was part of the binder compared to 6 MPa for GGBS based binder. The higher strength is not only due to the presence of higher silica content in silica fume but also due to higher fineness of SF particles. If the strength requirement is more, silica fume can be recommended as binder component. The mortar block was very light (white) in colour compared to other blocks and are ideal for architectural purposes. However, the cost of the silica fume shall be kept in mind before considering it as binder. The strength developed with GGBFS as binder is marginally higher compared to metakaolin due to the presence of calcium in GGBFS. It is advantageous to use GGBFS in place of metakaolin on cost considerations.

The binder-to-aggregate ratio plays a major role in the development of geopolymer compressed blocks. As in the case of cement mortar, in geopolymer mortar too, it is a significant parameter influencing strength. The series considered for this study was ABS1, ABS2, and ABS3. Figure 6 shows variation of strength with the binder-to-aggregate ratio. As the binder-to-aggregate ratio increases, the strength increases and vice versa. This parameter helps in economising the product cost, keeping an eye on the strength. At the lower fluid-to-binder ratio of 0.15, the variation of strength with binder-to-aggregate ratio is marginal.

Natural sand resource is fast depleting and needs to be preserved. There are efforts in construction industry to use manufactured sand/quarry dust/pond ash as alternatives to sand. This prompted to use quarry dust and pond ash as fine aggregate in the present investigation. The series considered for this study was ABS2, ABS11, and ABS18. Geopolymer compressed mortar blocks with both quarry dust and pond ash as fine aggregate developed higher strength than when natural sand was used as fine aggregate (Fig. 7). Quarry dust is better placed compared to pond ash. This encourages the efforts of replacing sand with both pond ash and quarry dust.

Since relatively dry mortar is a partially saturated material, its degree of saturation (the index of air content present in the material) affects the strength. The influence of the degree of saturation of the mortar on strength development is investigated with reference to the series ABS10 and ABS12. The strength development of the compressed blocks is shown in Fig. 8. It is well established that the strength decreases as the air content increases. This is true even in the case of geopolymer compressed blocks. The blocks prepared

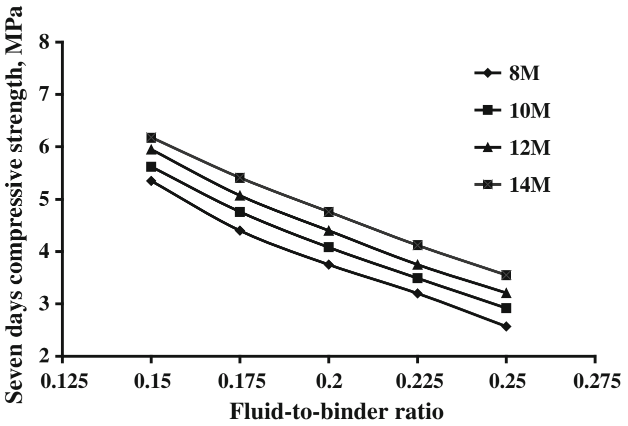

Fig. 4 Variation of 7 days compressive strength with different molarities of alkaline activator.

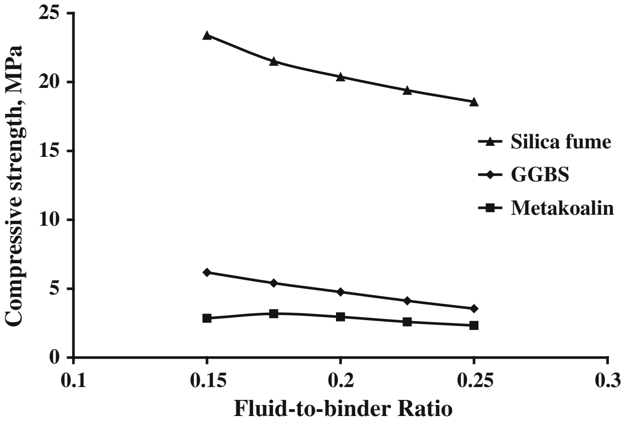

Fig. 5 Variation of strength of the blocks with different binder materials along with fly ash at 7 days.

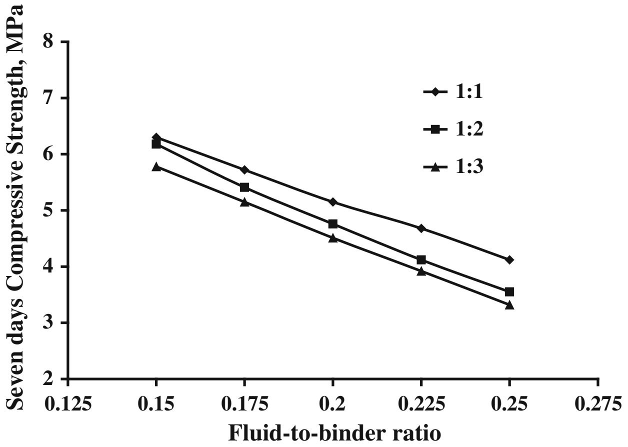

Fig. 6 Strength variation of the blocks with binder-to-aggregate ratio (mortar proportion).

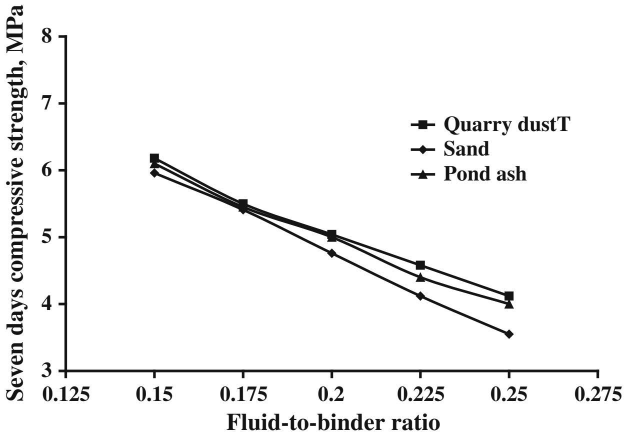

Fig. 7 Variation of compressive strength with different fine aggregates.

with lower degree of saturation (40 %) possess higher strength compared to those with higher degree of saturation (60 %). As the degree of saturation increases, the mortar becomes too wet rendering casting of specimens almost impossible. On the other hand, if the degree of saturation is less, more compaction effort is required to cast the specimens. Hydraulic press can be used to cast the samples at lower degree of saturation.

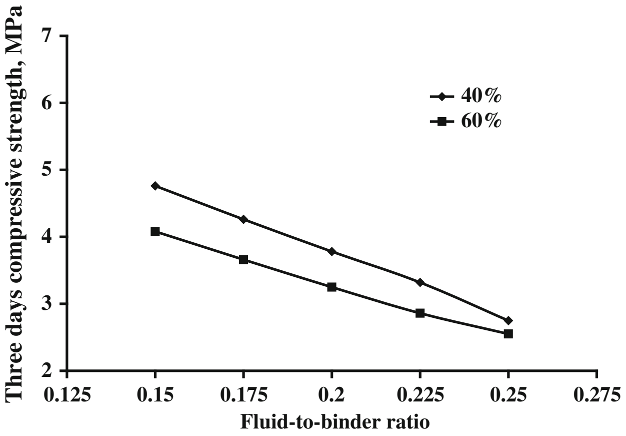

Fig. 8 Variation of strength with the degree of saturation.

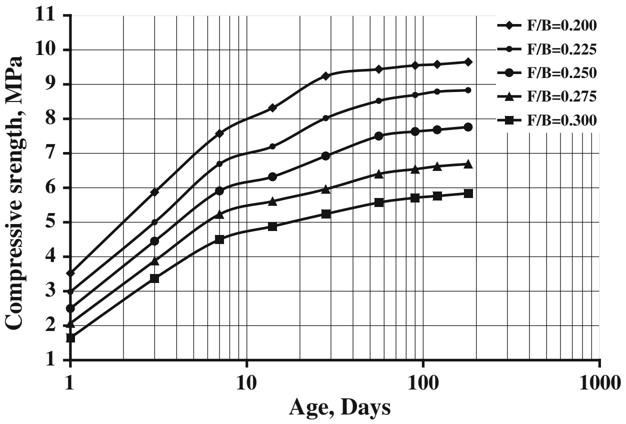

Fig. 9 Variation of strength of compressed blocks with age.

To study strength development with age, the series considered was ABS15. The variation of strength of the blocks with age is shown in Fig. 9. The strength of compressed blocks increases with age. Unlike the thermally cured geopolymers, ambient cured geopolymers attain strength with age. This is due to the continuous formation of CSH gel as GGBFS was used as part of the binder. Strength development is rapid till the age of about 28 days. Later, the rate of development of strength reduces drastically as represented by flatter profile of the curves. It can be observed that more than 90 % of 90 days strength gets developed at the age of 28 days. Further, it is interesting to note that, the minimum 1 day strength attained for fluid-to-binder ratio of 0.3 is 1.6 MPa. This strength would be sufficient for handling the blocks for the purpose of transportation. This facilitates the early clearance of the stock from the casting yard, thereby increasing the productivity.

The vast results of the experimental investigation suggest that, at constant degree of saturation, fluid-to-binder ratio governs the strength development keeping all other parameters the same. This is true with all the parameters considered. This trend was the same in the case of cement compressed blocks (Nagendra Prasad et al. 2005).

The discussions based on the present investigation reveals that many factors affect the strength development in geopolymer compressed blocks. It would be a herculean task to proportion the materials required to achieve the required strength at a given age in view of a large number of parameters associated with the geopolymer synthesis. The task would be further complicated if the number of materials proposed to be used increases from the consideration of strength, economy, eco-friendliness and sustainability. A

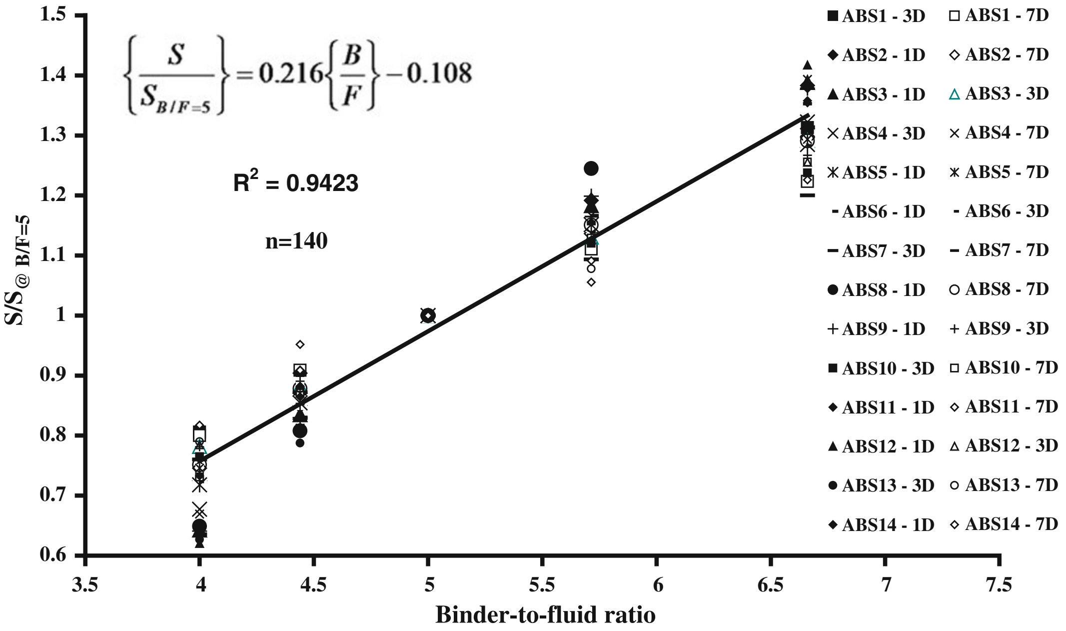

Fig. 10 Graphical representation of phenomenological model.

Table 4 Comparison of data.

Series ID	Fluid-to-binder ratio	Binder-to-fluid ratio	Predicted value based on model (MPa)	Experimental value (MPa)	Percentage error
ABS1-1D	0.15	6.66	4.43	4.26	−3.90
	0.175	5.714	3.75	3.78	0.88
	0.2	5	3.23	3.32	2.60
	0.225	4.44	2.83	2.75	−2.96
	0.25	4	2.52	2.5	−0.61
ABS2-3D	0.15	6.66	5.04	4.76	−5.87
	0.175	5.714	4.27	4.26	−0.14
	0.2	5	3.68	3.78	2.60
	0.225	4.44	3.22	3.32	2.90
	0.25	4	2.86	2.75	−4.14
ABS3-7D	0.15	6.66	6.01	5.78	−4.03
	0.175	5.714	5.09	5.15	1.17
	0.2	5	4.39	4.51	2.60
	0.225	4.44	3.85	3.92	1.88
	0.25	4	3.42	3.32	−2.91
ABS4-1D	0.15	6.66	2.68	2.92	8.23
	0.175	5.714	2.27	2.44	7.04
	0.2	5	1.96	2.01	2.60
	0.225	4.44	1.71	1.6	−7.14
	0.25	4	1.52	1.5	−1.52
ABS5-3D	0.15	6.66	5.39	5.2	−3.58
	0.175	5.714	4.56	4.62	1.32
	0.2	5	3.93	4.04	2.60
	0.225	4.44	3.45	3.49	1.28
	0.25	4	3.06	2.95	−3.75
ABS6-7D	0.15	6.66	5.44	5.62	3.21
	0.175	5.714	4.60	4.76	3.27
	0.2	5	3.97	4.08	2.60
	0.225	4.44	3.48	3.49	0.30
	0.25	4	3.09	2.92	−5.86
ABS7-1D	0.15	6.66	3.20	3.2	0.01
	0.175	5.714	2.71	2.79	2.92
	0.2	5	2.34	2.4	2.60
	0.225	4.44	2.05	2.02	−1.32
	0.25	4	1.82	1.8	−1.01

Table 4 continued

Series ID	Fluid-to-binder ratio	Binder-to-fluid ratio	Predicted value based on model (MPa)	Experimental value (MPa)	Percentage error
ABS8-3D	0.15	6.66	3.81	3.78	−0.87
	0.175	5.714	3.23	3.27	1.30
	0.2	5	2.79	2.86	2.60
	0.225	4.44	2.44	2.52	3.21
	0.25	4	2.17	2.15	−0.78
ABS9-7D	0.15	6.66	5.52	5.36	−2.98
	0.175	5.714	4.67	4.76	1.85
	0.2	5	4.03	4.14	2.60
	0.225	4.44	3.53	3.57	1.10
	0.25	4	3.14	3.07	−2.16
ABS10-1D	0.15	6.66	3.51	3.66	4.20
	0.175	5.714	2.97	3.12	4.87
	0.2	5	2.56	2.63	2.60
	0.225	4.44	2.24	2.24	−0.13
	0.25	4	1.99	1.87	−6.55
ABS11-3D	0.15	6.66	4.17	4.25	1.81
	0.175	5.714	3.53	3.74	5.56
	0.2	5	3.05	3.13	2.60
	0.225	4.44	2.67	2.82	5.34
	0.25	4	2.37	2.2	−7.79
ABS12-7D	0.15	6.66	4.57	4.24	−7.85
	0.175	5.714	3.87	3.82	−1.33
	0.2	5	3.34	3.43	2.60
	0.225	4.44	2.93	3.02	3.14
	0.25	4	2.60	2.7	3.76
ABS13-1D	0.15	6.66	1.69	1.77	4.34
	0.175	5.714	1.43	1.44	0.47
	0.2	5	1.24	1.27	2.60
	0.225	4.44	1.08	1.15	5.82
	0.25	4	0.96	1.01	4.74
ABS14-3D	0.15	6.66	20.97	20.22	−3.72
	0.175	5.714	17.75	17.25	−2.91
	0.2	5	15.32	15.73	2.60
	0.225	4.44	13.41	14.64	8.37
	0.25	4	11.92	12.5	4.66

phenomenological model would be a viable solution for this. Such models have been reported for heat cured geopolymer compressed blocks (Radhakrishna et al. 2006, 2008a, b, 2010).

4. Phenomenological Model

A phenomenological approach is the one by which several combinations of parameters would be tried within the basic framework of scientific laws. The use of the phenomenological model needs an input data from experimental investigation of a single trial to account for the synergy between different constituents of a given set of materials. If any parameter with regard to a set of ingredients changes, a new input data is to be generated again to use the phenomenological model to obtain the corresponding fluid-to-binder ratio and in turn to arrive at the appropriate mix proportions to meet the specific strength requirement. This exercise is termed as 'Re-proportioning Method'. This is akin to making adjustments to the trial mix until the specified requirements are met with. Instead of repeated laboratory trials, desired results can be achieved through simple calculations by introducing the experimentally determined reference strength value in the phenomenological model. This rapid exercise has further potential to determine the parameters that would lead to a wide spectrum of mixes possessing strength over a desired range for a given set of materials.

It is now intended to formulate the phenomenological model for assessment of strength development at different fluid-to-binder ratios at different ages. A reference strength data shall be considered within the specified range of fluid-to-binder ratio. In this investigation, strength, i.e. at binder-to-fluid ratio of 5.0 (inverse of fluid-to-binder ratio of 0.2), is considered as reference for normalization of respective compressive strength. This chosen value of binder-to-fluid ratio is purely arbitrary and only a matter of convenience having no other significance. The strength values are normalised at $S_{B/F=5.0}$. All the strength values have been divided by the strength at B/F = 0.5. A plot between $\frac{S}{S_{B/F=5}}$ on Y-axis and B/F on X-axis results in a linear relation having a correlation coefficient of R = 0.94 (Fig. 10). The resulting phenomenological model is

$$\left\{\frac{S}{S_{B/F=5}}\right\} = 0.216\left\{\frac{B}{F}\right\} - 0.108 \tag{1}$$

where B/F is the binder-to-fluid ratio for any specified strength and $S_{B/F=5}$ is the experimentally evaluated strength at binder-to-fluid ratio of 5, an input for Eq. (1).

To use this relation for a given set of materials, the strength developed at a specified age for a binder-to-fluid ratio of 5.0 is to be determined experimentally. Using this as an input parameter in the equation, the binder-to-fluid ratio for any other desired strength can be calculated using the phenomenological model. Conversely, if the strength S is known, the corresponding B/F ratio can be estimated. Thus the model would be useful in re-proportioning the materials required for making geopolymer mortar compressed blocks.

5. Possible Application

To use ambient cured geopolymer compressed blocks as masonry units/pavers, blocks were cast using hydraulic press for the series ABS1. The sizes considered for this purpose were: 220 × 190 × 90, 220 × 150 × 60, 220 × 110 × 60 mm. It was found that the compressive strength of these blocks was 4 MPa at the age of 3 days and 22 MPa at 28 days. This range of strength practically suits the requirement as masonry units. Also the water absorption of the blocks was 4.5 % at the age of 28 days with a good dimensional stability.

6. Validation

Separate sets of independent experimental data were generated to examine the validity of the predictions made by the use of phenomenological model. From each of these sets, the compressive strength at reference binder-to-fluid ratio of 5.0 is taken into consideration in the denominator of the left hand side of phenomenological model. The strength developed at other binder-to-fluid ratios is calculated and tabulated in Table 4 for comparison with experimental values. There is close match between the experimental and predicted values reinforcing the applicability of phenomenological model. With more data being generated for still wider range of binder-to-fluid ratio, the scope of this phenomenological model can be expanded further.

7. Concluding Remarks

From the limited study on strength development of compressed geopolymer blocks, the following broad conclusions can be drawn.

- Geopolymer mortar compressed blocks can be prepared without conventional cement and curing at ambient conditions.
- Apart from fluid-to-binder ratio, air content in compressed blocks (degree of saturation) also affects strength development with age.
- If the air content is maintained constant then the strength development is in accordance with Abrams' law for the specified range of fluid-to-binder ratio.
- Silica fume can be used as one of the components of binder if the strength required is high and also in situations where architectural aesthetic appeal is called for.
- The phenomenological model developed is valid for the range of fluid-to-binder ratio of 0.15–0.25. This is also the range at which the partially saturated mortar needs external effort to transform into a block. The phenomenological model developed can be used for a given set of materials and conditions. If there is any change in the properties of materials or conditions, a fresh reference value of strength at F/B ratio of 0.2 ($S_{F/B=0.2}$) shall be generated to make use of the model.
- Wide range of reference strength data would be useful to proportion the materials for the given strength at ambient conditions.

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