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Metakaolin bottom ash blend geopolymer mortar – A feasibility study

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HIGHLIGHTS

- Combination of Bottom Ash and Metakaolin were used to prepare the geopolymer Mortar.
- Liquid to Solid ratio was ranged from 0.48 to 0.54 with incremental of 0.02.
- Results showed that Liquid to Solid ratio 0.5 exhibits effective compressive strength in mortar.

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ABSTRACT

This paper presents an experimental study on the effective usage of bottom ash (BA) and metakaolin (MK) in geopolymer mortar. Sodium based alkaline activators were used for different mix proportions of bottom ash and metakaolin. Bottom ash was replaced with metakaolin from 0 to 100% at an interval of 25%. Liquid to solid ratio ranged from 0.48 to 0.54 with an increment of 0.02. River sand is used as fine aggregate. The ratio of sodium silicate to sodium hydroxide was kept as 2. Ambient curing mode was used to cure mortar instead of heat curing mode. The test results indicated that the mix with equal proportion of BA and MK with liquid/binder ratio of 0.50 yielded higher compressive strength.

1. Introduction

Ordinary Portland cement (OPC) has been widely used as a traditional binding material in concrete. The production of cement is energy intensive and consumes huge amount of natural resources. In order to reduce the consumption of cement, supplementary cementing materials such as fly ash, GGBS, rice husk ash, silica fume, metakaolin, etc, are used. The supplementary materials can partially replace cement and address the global warming issues to a certain extent. However, in the present scenario, it is not sufficient to replace the cement partially. A need is felt to develop an alternative binding material to cement which is having less foot print than cement. Geopolymer is a such alternative material which transfer industrial by-product like fly ash, GGBS, as well as bottom ash into mortar and concrete [7,23]. Bottom ash has also been used to partially replace sand in making fly ash based geopolymer mortar [12].

Geopolymers are amorphous to semi-crystalline three dimensional alumino-silicate polymers which very much resemble zeolites. Xu and Deventer [32] states that geopolymers are polymeric Si–O–Al framework with silicon and aluminium tetrahedral alternately linked together in 3-D by sharing all the oxygen atoms. The negative charge induced by aluminium is balanced by the availability of positive ions in Na^+, K^+ & Ca^+. The empirical formula of these mineral polymers is $M_n[-(SiO_2)_z-AlO_2]_n \cdot wH_2O$, where M = alkali cation such as potassium (or) sodium, the symbol-indicates the presence of a bond, Z is 1, 2 (or) 3 or higher up to 32 and n the degree of polymerization [8,9,21,24].

The development of fly ash-based geopolymers over the past decade or more shows remarkable progress in this area [28]. Extensive research work on low-calcium fly ash-based geopolymer concrete was carried out by geopolymer concrete research group at Curtin University of Technology [11,31]. Rangan [24] stated that the polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon-aluminium minerals that results in a three-dimensional polymeric chain and ring structure. Alkaline activators such as sodium based or potassium based is required to liberate the Si and Al from source material. Heat curing must be applied to promote polymerization [10,24].

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Subsequently, Ilker Bekir Topcu and his associates Topcu and Ugurtoprak [15] reported that geopolymer mortar made of coal bottom ash and Rice husk ash yielded promising result at ambient curing temperature. The fine bottom ash was more reactive and thereby imparted higher compressive strengths to geopolymer mortar than those made of coarser fly ashes [14,30]. Sathonsaowaphak et al. [1] observed that addition of NaOH solution slightly improved the strength of lignite bottom ash geopolymer mortar. The proper selection of Na_2SiO_3/NaOH ratio is the key factor in achieving best geopolymerisation even at ambient temperature [25]. Generally, Na_2SiO_3/NaOH ratio 2–2.5 is found satisfactory.

The flue gas desulfurization gypsum (FGDG) has been used as an additive with sodium based alkaline activators to improve polymerization of mortar made of bottom ash (BA) and fly ash (FA) [17]. The FGDG as an additive up to 10% significantly increased the strength of geopolymer. The increase in compressive strength was due to increase in Al leached from BA in the presence of SO_4 and the formation of additional calcium silicate hydrate. Subsequently, Revathi [26] made concrete paver blocks using alkali activated bottom ash and GGBS blended geopolymer to impart remarkable compressive strength under steam curing as well as ambient curing temperature.

Metakaolin (MK) is a pozzolanic microfiller for high-performance mortars [4,27]. However, joint effect of several factors influence the strength of alkali-activated metakaolin based mortars [20,16]. Also, Marin-Lopez et al. [19] reported that metakaolin based geopolymer compressive strength was higher than Portland cement concrete. Further, addition of GBFS in MK-based geopolymer concrete has improved its performance at elevated temperature Bernal Susan et al. [3]. The geopolymer mortar made of blended source material are yielding better strength than the Geopolymer mortars made of single source material [29,5,6].

The compressive strength of geopolymer materials mainly depends on the selection of source materials, molar ratio and the curing mode [22]. Generally, geopolymerisation between source materials and alkaline activators occurs under heat curing environment [11,31]. Heat curing has restricted the applications of geopolymer technology only to precast construction work. Geopolymer as a binding material could be widely acceptable when it can be made with less sodium hydroxide solution and cured under ambient conditions [7]. Therefore, an attempt has been made in the present study to develop high strength BA and MK blend geopolymer mortar cured at ambient temperature conditions.

2. Material used

2.1. Bottom ash (BA)

The bottom ash used in this study was obtained from Mettur thermal power plant. The sample was ground to finer by using ball mill at a speed of 180 rev/min for 12 h. The machine consisted of 200 pieces of ball bearings weighing about 15 kg. The specific surface area of BA is 3460 cm^2/g and the specific gravity is 2.17. The chemical properties of bottom ash are presented in Table 2.1.

Table 2.1
Chemical properties of bottom ash.

Chemical compositions	Percentage by weight
SiO_2	51.5
Al_2O_3	32.58
SO_3	5.19
CaO	0.50
MgO	0.21
Na_2O	1.35
LOI	1.50
K_2O	0.58

Table 2.2
Chemical properties of metakaolin.

Chemical compositions	Percentage by weight
SiO_2	53.18
Al_2O_3	42.72
K_2O	0.41
CaO	0.28
MgO	0.0
Na_2O	0.09
LOI	0.34
Fe_2O_3	0.97

2.2. Metakaolin (MK)

The metakaolin used in this study is purchased from Chennai. The specific gravity of metakaolin used in the study is 2.5 and specific surface area is 20,000 cm^2/gm. The chemical properties of metakaolin are presented in Table 2.2.

2.3. Alkaline activator

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. The sodium silicate solution was purchased from a local supplier in bulk. The sodium hydroxide (NaOH) in flakes having 97–98% purity was also purchased from local supplier in bulk. The NaOH flakes were dissolved in distilled water to make the solution.

2.4. River sand

Locally available river sand was used as one of the constituent of geopolymer mortar in this work. The physical properties of river sand were analyzed in accordance with BIS 2386-1963. Fineness modulus and specific gravity of river sand in the natural state was found to be 2.26 and 2.63 respectively. River sand is conforming to Grading Zone III (BIS 383-1970).

3. Experimental program

In the study on bottom ash metakaolin based geopolymer mortar (BM-GPM) with river sand, several mixes were proposed. Totally, five MK contents with 0%, 25%, 50%, 75% and 100% by total weight of the dry MK and BA for the source material were pro-

Table 3.1
Mix proportions of bottom ash metakaolin geopolymer binder.

Mix identity	Bottom ash (kg/m^3)	Metakaolin (kg/m^3)	Fine aggregate kg/m^3	Na_2SiO_3 (kg/m^3)	Sodium hydroxide solution (kg/m^3)
Liquid/binder ratio: 0.48					
aBM_0	–	568.1	1705.03	189.45	88.48
aBM_{25}	426.07	142.02	1705.03	189.45	88.48
aBM_{50}	284.17	284.17	1705.03	189.45	88.48
aBM_{75}	142.02	426.07	1705.03	189.45	88.48
aBM_{100}	568.1	–	1705.03	189.45	88.48
Liquid/binder ratio: 0.50					
bBM_0	–	568.1	1705.03	189.45	91.22
bBM_{25}	426.07	142.02	1705.03	189.45	91.22
bBM_{50}	284.17	284.17	1705.03	189.45	91.22
bBM_{75}	142.02	426.07	1705.03	189.45	91.22
bBM_{100}	568.1	–	1705.03	189.45	91.22
Liquid/binder ratio: 0.52					
cBM_0	–	568.1	1705.03	189.45	94.77
cBM_{25}	426.07	142.02	1705.03	189.45	94.77
cBM_{50}	284.17	284.17	1705.03	189.45	94.77
cBM_{75}	142.02	426.07	1705.03	189.45	94.77
cBM_{100}	568.1	–	1705.03	189.45	94.77
Liquid/binder ratio: 0.54					
dBM_0	–	568.1	1705.03	189.45	117.3
dBM_{25}	426.07	142.02	1705.03	189.45	117.3
dBM_{50}	284.17	284.17	1705.03	189.45	117.3
dBM_{75}	142.02	426.07	1705.03	189.45	117.3
dBM_{100}	568.1	–	1705.03	189.45	117.3