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Influence of Metakaolin on Concrete Containing Bottom Ash as Fine Aggregate

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Abstract-Concrete a widely used construction material consumes natural resources like lime, aggregates, water, etc. The worldwide production of cement has greatly increased and its production results in a lot of environmental pollution as it involves the emission of CO_2 gas.On the other hand the usage of natural aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled aggregate can be used as a replacement for natural aggregate.Metakaolin is a pozzolanic material used in wide range in partial replacement of cement which is found to be economical and its pozzolanic action increases strength properties of concrete. Disposal of bottom ash from coal fire boiler power plant is one of the serious environmental problem facing now and this can be reused as an alternative to natural fine aggregate. The study aims at evaluating the performance of concrete containing metakaolin and bottom ash replacing cement and fine aggregate on strength and workability properties of concrete. The results showed that the combination of metakaolin and bottom ash provides a positive effect on mechanical properties. The samples incorporating the concrete with 10% metakaolin and 45% bottom ash showed better strength than that of the normal concrete.

Keywords: *Metakaolin, Pozzolan, Bottom ash, Industrial Waste, Normal concrete.*

1. GENERAL

Concrete is one of the most widely used man-made construction material in the world, and its properties have been undergoing changes through technological advancements. Waste material has gained attention among researchers as replacement to natural aggregate or cement in concrete making. The sense of using waste materials is more significant in protecting environment than economic factor since the solid wastes are increasing day by day.

Pozzolanic additives are the materials or admixtures that can improve concrete properties such as concrete strength, durability and impermeability. They are used either as partial substitutes of Portland cement or as an addition [4]. The use of pozzolanas for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. Metakaolin is a pozzolanic material which is manufactured from selected kaolins, after refinement and calcination under specific conditions. It is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium alumino silicate hydrates [1]. Metakaolin differs from other supplementary cementitious materials like fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under controlled conditions [3]. It is a fine, natural white clay which contains the highest content of siliceous, so called as High Reactivity Metakaolin (HRM). Himacem, which is an efficient pozzolana in cement concrete, is the grade of HRM. Hence by partially replacing Portland cement with Metakaolin not only reduces carbon dioxide emissions but also increases the service life of buildings.

River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive and also scarce. In the backdrop of such a bleak atmosphere, there is large demand for alternative materials from industrial waste. There are two types of ash, fly ash of 80 % and bottom ash of 20 % are produced at coal power plant. When coal is burned in a coal fired boiler, it leaves behind ash, some of which is removed from the bottom of the furnace known as bottom ash, and some of which is carried upward by the hot combustion gases of the furnace, and removed by collection devices known as fly ash [2]. Most of them are being dumped as the waste disposal site near the factory. This will pollutes the environment and it is creating a disposal problem because a large space of dump yard is required. It is expected that bottom ash can be used as fine aggregate replacement in making concrete when natural sand is expensive. Although there are a lots of studied related to the properties of coal ash, but the investigation about the local coal ash is very limited. Therefore, it is necessary to provide the information based on the laboratory and field education of the locally available coal ash particularly the bottom ash for potential construction uses.

2. EXPERIMENTAL PROGRAM

The main aim of this experimental program is to investigate the performance of concrete containing Metakaolin (MK) and Bottom ash (BA) replacing cement and fine aggregate on strength and workability properties of concrete.

2.1. *Materials*

2.1.1. *Cement*

Portland pozzolana cement (PPC) flyash based available in local market is used in the investigation. The different laboratory tests were conducted on cement. The results are tabulated in Table 1. The results conforms to the IS recommendations.

Table 1 Physical properties of Portland pozzolana cement

Properties		Results	Permissible limits as per IS 1489 (Part 1):1991
Standard consistency		30 %	26% to 33%
Specific gravity		3.1	3.1 to 3.15
Fineness		0.85%	< 5%
Compressive strength (MPa)	3 days	29.4	> 16 MPa
	7 days	38.0	> 22 MPa
	28 days	40.1	> 33 MPa
Setting time	Initial	120 Minute	> 30 Minute
	Final	310 Minute	< 600 Minute

2.1.2. *Fine Aggregate*

Locally available M-sand was used as fine aggregate. The sand used for the study was locally procured and conformed to grading zone II as per IS: 383-1970. The results are tabulated in Table 2. The sieve analysis results are shown in figure 2.

Table 2 Properties of coarse and fine aggregate

Properties	Coarse aggregate	Fine aggregate
Specific gravity	2.80	2.50
Fineness modulus	3.55	3.83
Bulk density	1690 kg/m^3	1725 kg/m^3
Loose density	1503 kg/m^3	1636 kg/m^3
Water absorption	0.80%	1.50%

2.1.3. *Coarse Aggregate*

The coarse aggregate was used in the experimental program were of 20 mm and down size aggregate and tested as per IS: 2386-1963 (I, II and III) specifications. The results are tabulated in Table 2.

2.1.4. *Metakaolin*

The mineral admixture MK was obtained from the ENGLISH CLAY LIMITED company at CochuVeli in Trivandrum. The MK was in conformity with the general requirements of pozzolana. Properties of MK are given in below Table 3 & 4.

Table 3 Physical properties of MK

Particulars	Values
Appearance	Off- White Powder
PH (10% of solids)	4.0 - 5.0
Bulk density (Kg/l)	0.4 - 0.5
Specific gravity	2.5
Loss of Ignition (%)	1.5
Lime reactivity	1050 mg $Ca(OH)_2$/g

Table 4 Chemical composition of MK

Chemical composition	Mass (%)
SiO_2	52-54
Al_2O_3	44-46
Fe_2O_3 (Max)	0.6-1.2
TiO_2 (Max)	0.65
CaO (Max)	0.09
MgO (Max)	0.03
Na_2O (Max)	0.10
K_2O (Max)	0.03

Fig. 1 Metakaolin

2.1.5. *Bottom Ash*

The Bottom ash was procured from the Hindustan newsprint limited at Mavellor in Kottayam. The specific gravity of BA is 2.3. The testing was done as per IS: 383-1970. The results are tabulated in Table 5.

The particle size distribution curve for fine aggregate and BA are shown in figure 2.

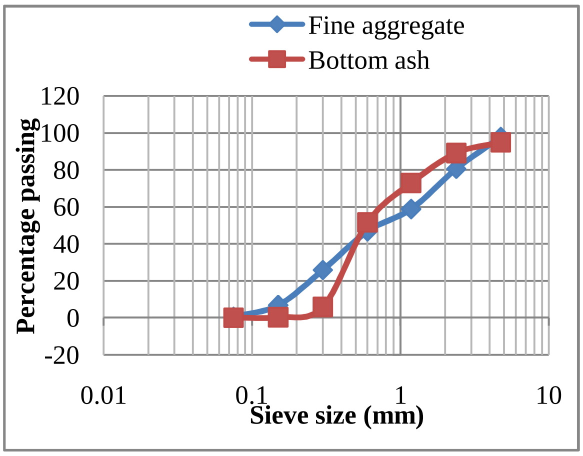

Fig. 2 Particle size distribution of fine aggregate and bottom ash

Table 5 Properties of Bottom ash

Properties	Test results
Specific gravity	2.30
Fineness modulus	3.86
Grading	Zone-II
Bulk density	1520 kg/m^3
Loose density	1390 kg/m^3
Water absorption	1.80%

Fig. 3 Bottom Ash

2.1.6. *Water*

Water is needed for the hydration of cement and to provide workability during mixing and for placing. In this study, potable water which is free from salts andimpurities was used for washing aggregates, mixing and curing purposes.

2.1.7. Super Plasticizer

Super plasticizer used in this study is CONPLAST SP430 in the form of sulphonated naphthaline polymer confirms to IS: 9103-1999 was used to improve the workability of concrete.

2.2. *Mix Design and Proportions*

The control mix containing cement, natural sand and coarse aggregates was designed as per Indian Standard Recommended Guidelines IS: 10262-2009. M-sand was partially replaced with BA in the range of 0, 15, 30, and 45% by weight. And the cement constituent was subsequently replaced with percentage of MK (by mass). The percentage of the Cement was varied between 0 and 15%, at 5% intervals. In this study sixteen mix proportions were made. In each mix, water cementitious materials ratio was fixed at 0.45 and coarse aggregate kept constant. The mix proportions are given in table 6.

Table 6 Mix proportions

Material	Mix proportion	By weight (kg/m^3)
Cement	1	377.78
Fine aggregate	1.73	655
Coarse aggregate	3.3	1246
Water (liter)	0.45	170

2.3 Methodology

The fresh concrete properties such as compaction factor was conducted and the hardened properties such as compressive strength, flexural strength and split tensile strength were performed for 28 days at varying percentages of MK and BA in accordance with the provisions of the Indian Standard Specification IS: 516-1959.

2.3.1. *Concrete Mixes*

In this study, the early age properties of fresh concrete and mechanical performance of hardened concrete were examined. All tests were conducted using the following sample groups as in table 7.

2.3.2. *Casting and Curing of Specimen*

Cubes of size 150 mm x 150 mm x 150 mm, cylinders with 150 mm diameter and 300 mm height and prisms of size 100 mm x 100 mm x 500 mm were prepared using the standard moulds. The samples are cast using the 16 different combinations. The samples are demoulded after 24 hours of casting and kept in a water tank for 28 days curing.

Table 7 Sample groups

Mix Id	MK (%)	BA (%)	Mix Id	MK (%)	BA (%)
M1	0	0	M9	0	30
M2	5	0	M10	5	30
M3	10	0	M11	10	30
M4	15	0	M12	15	30
M5	0	15	M13	0	45
M6	5	15	M14	5	45
M7	10	15	M15	10	45
M8	15	15	M16	15	45

2.3.3. *Testing of Specimens*

The effect MK and BA on workability of fresh concrete was found out using compaction factor apparatus. The compressive strength, flexural strength and Split Tensile Strength of different mixes were found out at 28 days as per the procedure laid down in IS: 516 - 1959. The concrete specimens were tested for compressive strength and split tensile strength in an automatic compression testing machine of capacity 2000 kN and flexural Strength was tested in a flexure strength testing machine respectively. Three specimens were used in computing the mean on each testing age of each mix and the final results are tabulated in comparison with reference mix.

2.4 Result and Discussion

2.4.1. *Workability*

The workability of concrete mixtures was measured by performing compaction test. The variation in compaction factor of different % replacement of MK and BA on concrete is given in Figure 4 and Table 8.

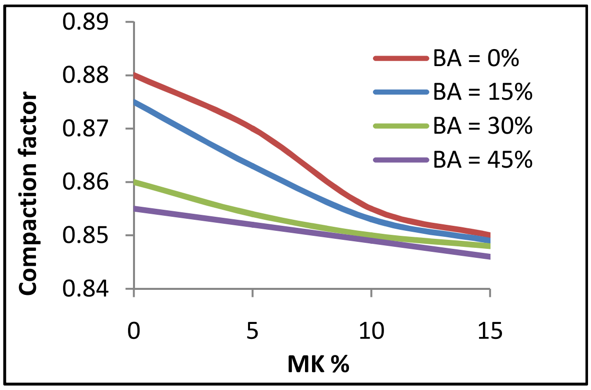

Fig. 4 Workability in terms of compaction factor

The fixed quantity of water was added in all the concrete mixtures. While observing the characteristic of fresh concrete of different mixes, it was noted that, the concrete matrix when replaced by different proportion of MK and BA, the workability decreased with increasing quantity of MK and BA. This is due to the extra fineness of MK in the concrete mix. Also the water absorption of BA is higher than that of sand. As a result, it became difficult to have the same level of good workability.

Table 8 Workability in terms of compaction factor

Mix	Compaction factor
M 1	0.880
M 2	0.870
M 3	0.855
M 4	0.850
M 5	0.875
M 6	0.863
M 7	0.853
M 8	0.849
M 9	0.860
M 10	0.854
M 11	0.850
M 12	0.848
M 13	0.855
M 14	0.852
M 15	0.849
M 16	0.846

2.4.2. *Compressive Strength*

The variation in compressive strength of concrete mixes made with and without MK and BA of cubes size 150 mm × 150 mm × 150 mm was determined after 28 days of curing. The results of different % replacement of MK and BA on concrete are given in Figure 5 and Table 9.

Table 9 Compressive strength

Mix	Compressive Strength (MPa)	Percentage increase (%)
M 1	40.00	0
M 2	42.20	5.20
M 3	50.20	25.2
M 4	39.00	-2.70
M 5	40.60	1.20
M 6	42.70	6.50
M 7	45.40	13.2
M 8	39.80	-0.70
M 9	39.30	-2.00
M 10	43.30	8.00
M 11	44.93	12.0
M 12	40.90	2.00
M 13	45.03	12.3
M 14	45.43	13.3
M 15	47.60	18.7
M 16	42.24	5.30

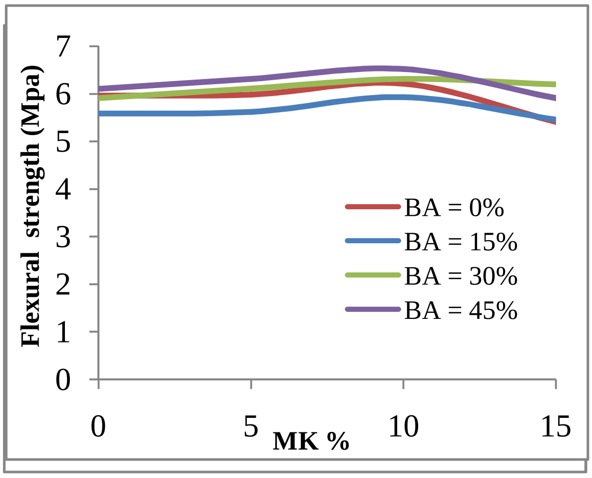

Fig. 5 Compressive strength

The increase in compressive strength is due to pozzolanic reaction of MK. From 0 -10 %, allthe mixes attains higher compressive strength than corresponding control mix because as hydration proceeds more hydration products and more cementing materials are formed. These hydration products possess large specific volume than unhydrated cement. Therefore, accumulation and compaction of these products leads to an increase in compressive strength of hardened concrete.At the curing age of 28 days, the optimum percentage of replacement of BA as fine aggregate is 45 %. From 0 – 45 % the increase in compressive strength is due to decrease in free water cement ratio of the bottom ash concrete mixtures. During the mixing process the porous particles of the BA internally absorb a part of water. It helped in improving the compressive strength of bottom ash concrete mixtures.

2.4.3. *Split Tensile Strength*

Split tensile strength of concrete mixed made with and without MK and BA of cylinders with 150 mm diameter and 300 mm height was determined.

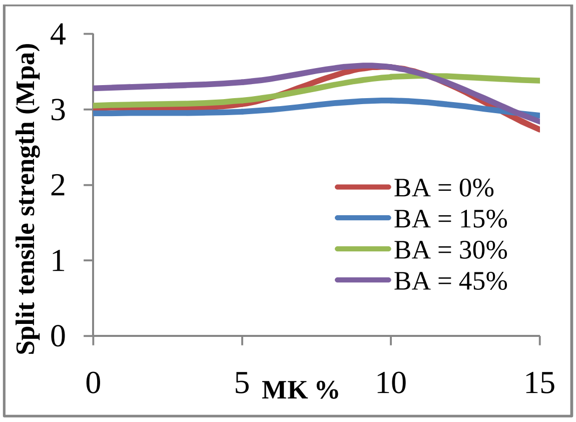

Fig. 6 Split tensile strength

The variation in 28 days results of different % replacement of MK and BA on concrete is given in Fig. 6 and Table 10.

Table 10 Split tensile strength

Mix	Split tensile strength (MPa)	Percentage increase (%)
M 1	3.02	0
M 2	3.07	1.70
M 3	3.56	17.9
M 4	2.73	-9.60
M 5	2.95	-2.30
M 6	2.97	-1.70
M 7	3.12	3.30
M 8	2.92	-3.30
M 9	3.05	1.00
M 10	3.12	3.30
M 11	3.43	13.6
M 12	3.38	11.9
M 13	3.28	8.60
M 14	3.36	11.3
M 15	3.56	17.9
M 16	3.07	1.70

2.4.4. *Flexural Strength*

The variation in flexural strength on concrete is given in Fig. 7 and Table 11. Maximum flexural strength is obtained for the mix M15 and the increase is 9.4% when compared with control concrete.

Table 11 Flexural strength

Mix	Flexural strength (MPa)	Percentage increase (%)
M 1	5.96	0
M 2	5.98	0.34
M 3	6.21	4.19
M 4	5.41	-9.23
M 5	5.58	-6.38
M 6	5.62	-5.70
M 7	6.10	2.35
M 8	5.46	-8.39
M 9	5.98	0.34
M 10	6.11	2.52
M 11	6.31	5.87
M 12	6.20	4.03
M 13	6.10	2.35
M 14	6.31	5.87
M 15	6.52	9.40
M 16	5.98	0.34

Fig. 7 Flexural strength

3. CONCLUSIONS

- The workability measured in terms of compaction factor test decreases with the increase of the replacement level of the fine aggregates with the BA and cement with MK.
- The incorporation of 10% MK and 45% BA in concrete results in significant improvements in its mechanical properties compared to the control mix.
- The greatest increase in compressive strength was achieved for M15 mix at the age of 28 days. The percentage increase in compressive strength for M15 mix is about 18.7 %.
- The split tensile strength for all mixes with 10 % MK and 45 % BA was observed to be more than control mix at the age of 28 days.
- The percentage increase in flexural strength for M15 mix is 9.4 %.

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