International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-3 Issue-6, August 2014

Strength Studies on Metakaolin Blended High-Volume Fly Ash Concrete

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Abstract— The usage of blended cement is growing rapidly in construction industry due to the considerations of cost saving and environmental protection. The addition of fly ash in concrete improves certain properties such as workability, later age strength development and few durability characteristics. The major disadvantage observed in such concrete is the slower development of strength. This drawback can be addressed by adding superpozzolanic materials such as silica fume, Metakaolin and rice husk ash. This report presents the results of an experimental investigation dealing with concrete incorporating high volumes of Class F Fly Ash and Metakaolin as a partial replacement of ordinary Portland cement. Portland cement was replaced with 50% volume of cement with Class F Fly Ash, and again the remaining cement content was replaced by four different percentage of Metakaolin content 5%, 10%, 15%, and 20%. Tests were performed on fresh and hardened concrete to determine its workability and mechanical strength properties. A concrete mix of grade M30 was investigated keeping water binder ratio as 0.44 with a total cementatious material content of 399 kg/m3 of concrete. Two different curing conditions investigated are boiling and normal curing condition. Test results indicated that the use of High volumes of Class F Fly Ash and Metakaolin as a partial replacement of cement in concrete decreased its compressive strength, splitting tensile strength and modulus of elasticity, Poisson's ratio of the concrete. However, the strength properties like impact resistance, abrasion resistance of concrete was increased which may be due to the pozzolanic reaction of Fly Ash.

Index Terms— metakaolin, boiling curing, high volume fly ash concrete, ternary blend

I. INTRODUCTION

Concrete is the most widely used man made construction material in civil engineering world. As the demand for concrete as a construction material increased, the world production of cement has greatly increased since 1990. The global warming is caused by the emission of greenhouse gases such as CO_2 to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% to global warming. The cement industry is responsible for about 6% of all CO_2 emissions, because the production of one tonne of Portland cement emits approximately 0.9 tonne of CO_2 into the atmosphere. Although the use of Portland cement is still unavoidable until the anticipated future, many efforts are being made in order to reduce the use of Portland cement in concrete. These efforts include the utilisation of supplementary cementitious materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and Metakaolin, and finding alternative binders to Portland cement. The usage of blended cement is growing rapidly in construction industry due to the considerations of cost saving and environmental protection. Increasing the use of by-products such as Fly Ash for partially replacing the Portland cement in concrete not only reduces the amount of cement used, but also significantly enhances the properties of concrete, reduces the emission of CO_2 and conserves the existing resources. Inclusion of Fly Ash in concrete greatly improves consistency. Research work done on Metakaolin [1] has shown that the partial replacement of Portland cement with Metakaolin in concrete significantly affects consistency and early strength [2], [3]. However, unlike Fly Ash, increased replacement levels of Metakaolin increases water demand due to its high chemical activity and high specific surface. Concrete containing fly ash more than about 50% of total cementatious materials is classified as high volume fly ash concrete [4], [5]. The addition of fly ash in concrete improves certain properties such as workability, later age strength development and few durability characteristics [6]. The major disadvantage observed in such concrete is the slower development of strength. This drawback can be addressed by adding superpozzolanic materials such as silica fume, Metakaolin and rice husk ash. This type of ternary blending of cementatious materials may improve the quality of concrete in different dimensions [7], [8].

II. MATERIALS AND METHODS

A. Materials

Materials used in the present investigation was carefully selected and tested in the laboratory to assess the quality and suitability in making concrete of required strength.

Cement: Ordinary Portland Cement (OPC) confirming to **IS 12269** [9] was used for the present experimental work. The reason for selecting high grade cement is that the replacement of cement with other supplementary cementitious materials should not cause undue reduction in strength at early ages.

***Fly Ash*:** Fly Ash used in the present study was obtained from Tuticorin Thermal Power Plant. From the laboratory tests, the specific gravity was obtained as 1.84 and density as 1.23 gm/cc.

Metakaolin: Metakaolin (specific gravity 2.55) was supplied by the M/S English Indian Clay Ltd. under the commercial name HIMACEM.

***Fine aggregate*:** Locally available good quality river sand having specific gravity 2.72 and fineness modulus 2.36 was used as fine aggregate. Fine aggregate used conforms to **IS 383:1970** [10] specifications (Zone II).

***Coarse aggregate*:** Crushed stone aggregate of size between 20mm and 4.75mm and specific gravity 2.72 and fineness modulus 6.97 was used as coarse aggregate.

***Water*:** Clean drinking water available in the college water

Manuscript Received on August 2014.

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supply system was used for mixing and curing of concrete.

B. *Mix Proportion*

The grade of concrete prepared for the experimental study was M30. The design basically involves the determination of water-binder ratio for a given compressive strength. After selecting the suitable water content, the cement requirement was determined. The coarse aggregate content was fixed depending on the shape of the aggregate and the fine aggregate content was calculated from the absolute volume basis. In the design, the volume of entrapped air was assumed to be 2 percent. Different mixes were prepared and tested for their properties. The mix proportion is slightly modified depending on the requirements. The final proportion after adjustment was 1: 1.37: 3.163 (cement: fine aggregate: coarse aggregate) with w/b of 0.444. The cement content in concrete was 399.19 kg/m3. In High Volume Fly Ash mixes, the cement is replaced by Fly Ash by 50% volume of cement (183.44 kg/m3). In other mixes, the cement is replaced by Metakaolin at 5, 10, 15, and 20% by mass. The cementitious material content in different mixes is shown in **Table 1.**

Two curing conditions are considered in the present investigation. For normal curing, the specimens were demoulded after 24 hours of casting and were kept in a curing tank (at room temperature) for water curing till the test. In case boiling curing the specimens were demoulded after 24hrs of casting and were kept in boiling champers (100^0C) for next 3 hours, and then to normal curing.

Table 1 Materials for 1m3 Concrete

Mix designation	Cement (kg)	Metakaolin (kg)	Fly Ash (kg)
CM	399.19	0	0
HVF	215.75	0	183.44
Me 5	195.80	19.95	183.44
Me 10	175.83	39.91	183.44
Me 15	155.87	59.88	183.44
Me 20	135.912	79.838	183.44

C. *Methods*

Workability: The workability of various mixes was assessed by determining the compacting factor, flow index and Vee-Bee time as per the **IS 1199:1959** [11] specifications.

Compressive Strength: Compressive strength test on cubes is the most common test conducted on hardened concrete because it is an easy test to perform and most of the desirable properties of concrete are comparatively related to its compressive strength. The compression test was carried out on cubical specimen of size 100mm in a compression testing machine of capacity 2000 kN, at a loading rate of $14N/mm^2$per minute [12]. The strength is determined at 3, 7, 14, 28 and 56 days of casting.

Split Tensile Strength: split tensile strength of concrete cylinders 150mm diameter and 300mm long were tested as per the procedure explained in **IS 5816** [13]. The slump test results were not reported, as it does not give relevant values throughout the experimental work.

Modulus of Elasticity: The modulus of elasticity was determined by subjecting cylinder specimen having 150 mm diameter and 300 mm height to uniaxial compression by the method outlined in **IS 516** [12].

Impact Strength: The impact strength of concrete is determined using a drop-weight impact testing method prescribe in **ACI 544-2R-89** [14]**.**

III. RESULTS AND DISCUSSIONS

A. *Workabilty*

All freshly mixed concrete were tested for workability by three methods, viz. compacting factor, flow index and Vee-Bee time. It was observed that, the workability decrease with decrease in cement content in the mix. The mix with cement as the only binder the workability was maximum. An attempt has been made to correlate the reduction in workability as a function of metakaolin content in the high-volume fly ash concrete. The variation of each workability measure with metakaolin content is presented in **Fig. 1** to **Fig. 3**. In **Fig. 1**, it may be observed that the variation of compacting factor with the metakaolin content in the mix almost linear. A linear correlation equation as indicated in Eqn. 1 can be used to estimate the workability measure of metakaolin blended high-volume fly ash concretes.

$$CF_m = CF_0 - 0.0057m \qquad (R^2 = 0.9893) \qquad \textbf{Eqn. 1}$$

Where CF_m is the compacting factor of HVFA concrete containing *m* percentage of metakaolin.

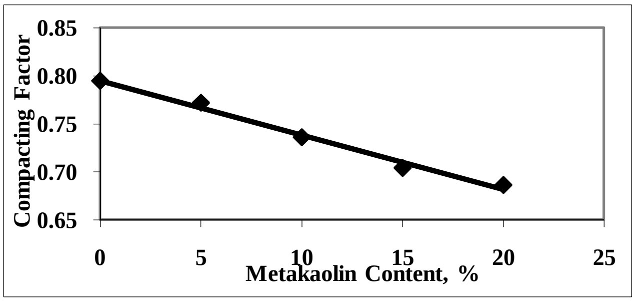

Fig. 1 Compacing Factor vs Metakaolin Content

A similar attempt is made to correlate the flow index of different mixes with the metakaolin content in the mix. **Figure 2** shows the correlation curve of exponential nature, with reasonable accuracy. The relation is in the following form;

$$FI_m = FI_0\, e^{-0.1025m} \qquad (R^2 = 0.9612) \qquad \textbf{Eqn. 2.}$$

Where FI_m is the flow index of HVFA concrete containing *m* percentage of metakaolin.

Figure 3 illustrate the variation of Vee Bee time with metakaolin content in the HVFA mixes. The drop in the consistency with the addition of metakaolin can be represented by a second order polynomial function as indicated in Eqn.3

$$VB_m = VB_0 - 0.1574m + 0.0606m^2 (R^2 = 0.9733) \qquad \textbf{Eqn. 3}$$

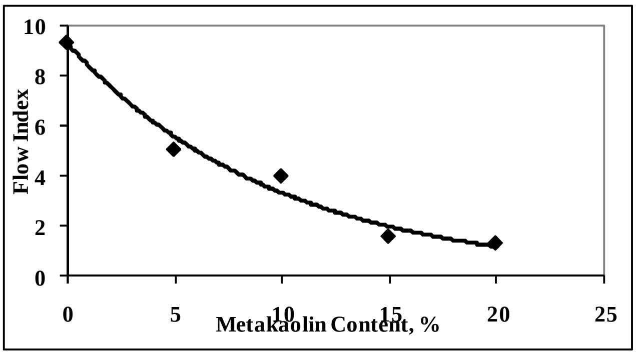

Fig. 2 Flow Index vs Metakaolin Content

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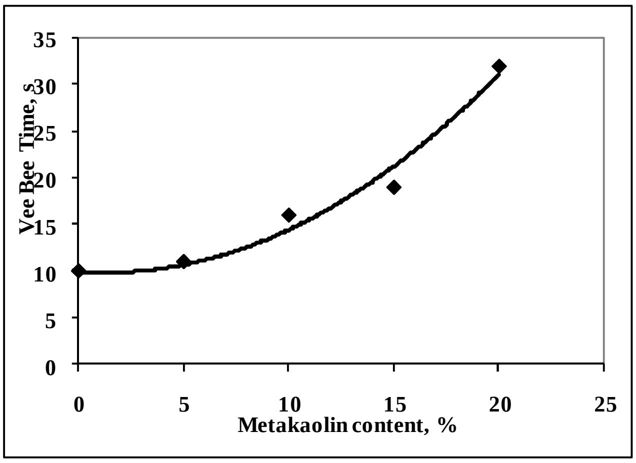

Fig. 3 Vee Bee Time vs Metakaolin Content

B. Compressive Strength

The compressive strength of 100mm concrete cubes was determined after normal curing **Figure 4** illustrates the variation of compressive strength with age of concrete. It may be observed that the compressive strength of control mix (the mix with cement as the only binder) is more than that of any other binary or ternary mixes. It may also be observed that the strength-time history of all mixes follow a linear logarithmic relation in the form;

$$\sigma_{cu} = A \ln T + B \qquad \textbf{Eqn. 4}$$

where σ_{cu} is the cube strength after T days of casting and A and B are constants.

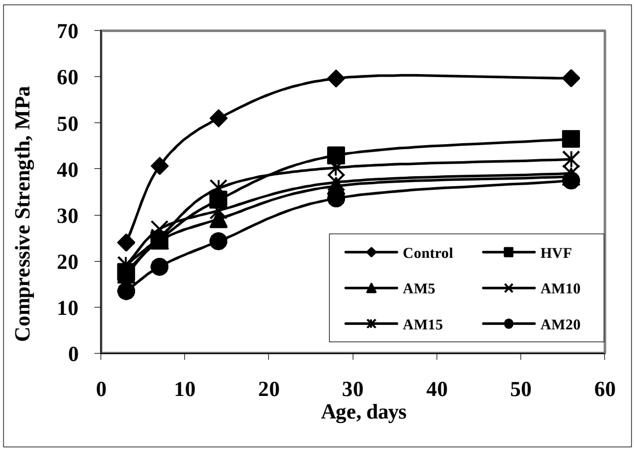

Fig. 4 Compressive Strength vs Age (Normal Curing)

An attempt has been made to determine the values of constants A and B depending on the metakaolin content in the HVFA concrete mixes. It was observed that, there exists a polynomial relation as indicated below;

$$A_m = A_0 - 0.6\,m + 0.03\,m^2 \quad (R^2 = 0.78) \qquad \textbf{Eqn. 5}$$

$$B_m = B_0 + 1.42\,m - 0.08\,m^2 \quad (R^2 = 0.96) \qquad \textbf{Eqn. 6}$$

Where A_m and B_m are the values for mixes containing $m\%$ of metakaolin.

The variation of compressive strength of concrete specimens with age which are cured initially in boiling water is presented in **Fig. 5**. It may be observed that the increase in strength of concrete beyond 28days was very nominal irrespective of the composition of the mix. Also, there exixt a correlation as indicated in **Eqn. 4**, with the constants A and B as follows;

$$A_m = A_0 - 0.75\,m + 0.03\,m^2 \quad (R^2 = 0.98) \qquad \textbf{Eqn. 7}$$

$$B_m = B_0 + 1.00m - 0.04\,m^2 \quad (R^2 = 0.66) \qquad \textbf{Eqn. 8}$$

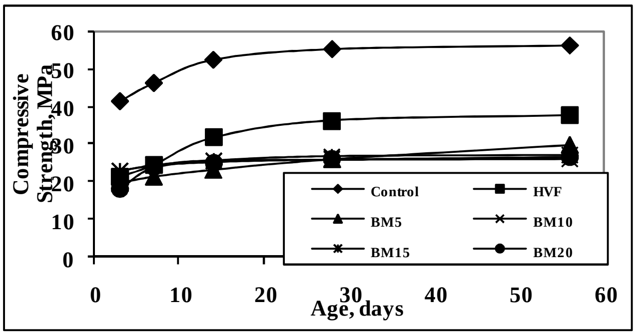

Fig. 5 Compressive Strength vs Age (Boiling Curing)

C. Split Tensile Strength

The values of split tensile strength of cylindrical specimens subjected to different curing conditions are presented in **Fig.6.** It is seen that control specimens have higher split tensile strength than that of high volume fly ash and other types of concrete mixes. Also, the split tensile strength decreases with increase in cement replacement level. It is also observed that, beyond a Metakaolin content of 15% there is a trend in decreasing the tensile strength of concrete irrespective of curing methods.

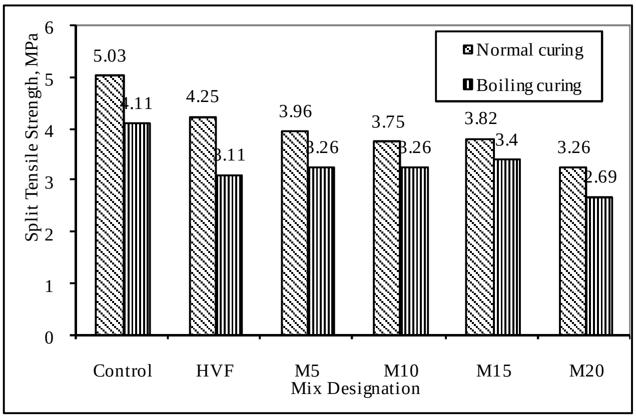

Fig. 6 Split Tensile Strength

An attempt has been made to correlate the reduction in split tensile strength of metakaolin admixed high-volume fly ash concrete with the metakaolin content in the mix. It is observed that there exists a linear relationship in the following form;

$$\sigma_{spm} = \sigma_{sp0} - 0.0436\,m \quad (R^2 = 0.86) \qquad \textbf{Eqn. 9}$$

where σ_{spm} is the split tensile strength of high-volume fly ash concrete containing $m\%$ metakaolin.

D. Modulus of Elasticity

The modulus of elasticity (kN/mm^2) determined for different mixes cured in two different methods is presented in **Table 2.** It may be observed that in normal curing conditions, the elasticity decreases with the metakaolin content in the mix.

Table 2 Modulus of Elasticity (kN/mm^2)

	Normal curing	Boiling curing
Control	67.04	55.55
HVF	53.99	44.20
M5	44.85	33.91
M10	43.31	19.38
M15	37.86	34.62
M20	32.93	25.21

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An attempt has been made to correlate the modulus of elasticity of metakaolin admixed high-volume fly ash concrete with the metakaolin content in the mix. There exists a linear relationship in the following form;

$$E_m = E_0 - 1.09\,m \qquad (R^2 = 0.94) \qquad \textbf{Eqn. 10}$$

Where E_m is the modulus of elasticity of mix containing $m\%$ metakaolin.

E. Impact Strength

Dynamic energy absorption or strength is called as impact resistance and is one of the major attributes of concrete. Here the repeated impact test or drop weight test was conducted to determine the number of blows to achieve a prescribed level of distress of the specimen. To determine the improved impact resistance of concrete the first crack and ultimate failure of specimens are determined. The number of blows required for the development of first crack in the test specimen for different curing conditions are presented in **Table 3**. **Table 4** shows the values of number of blows required for specified failure if the specimen.

Table 3 Number of Blows for Initial Crack

	Normal curing	Boiling curing
Control	3	8
HVF	20	10
M5	23	15
M10	35	17
M15	37	15
M20	27	9

Table 4 Number of Blows for Failure

	No. of blows at failure	
	Normal curing	Boiling curing
Control	9	14
HVF	26	15
M5	28	20
M10	41	22
M15	42	21
M20	32	15

It may be observed that, high-volume fly ash concrete can withstand high amount of energy before cracking and complete failure. Further addition of metakaolin as partial replacement to cement in high-volume fly ash concrete progressively improve the impact resistance up to 15% metakaolin content. Also the binary and ternary blended concrete mixes initially cured by boiling method shows reduced impact resistance compared to the corresponding mixes cured conventionally.

IV. CONCLUSIONS

The conclusions based on the limited observations from the present investigation on properties of fresh and hardened high-volume fly ash concrete and mixes modified by addition of metakaolin are:

- Addition of Fly Ash and Metakaolin in concrete reduces the workability.
- The decrease in the workability of high-volume fly ash concrete modified with the addition of metakaolin shall be expressed as a function of metakaolin content in the mix.
- Mechanical properties such as compressive strength, split tensile strength and modulus of elasticity shows decreasing trend with the addition of metakaolin.
- The impact resistance of both binary blended and ternary blended mixes shows markable improvement compared to concrete mix with cement as the only binder.

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