*Fly Ash Utilisation for Value Added Products*
*Eds. B. Chatterjee, K. K. Singh & N. G. Goswami*


# Performance of fly ash based multicomponent blended cements

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## ABSTRACT

*Multicomponent blended cements were developed at CBRI with reduced amount of portland cement clinker and industrial by-product/wastes, viz, flyash and granulated blast furnace slag along with desired amount of gypsum. These cements provide excellent restrance under assressive environments beside being advantageous in saving energy as well as ordinary portland cement to the extent of 50 per cent this providing economy in construction activities.*

***Key words** : Fly ash utilisation, Multi component blended cement, Building materials*

## 1.0 INTRODUCTION

The ordinary portland cement (OPC) contains ground cement clinker and gypsum as set retarder. Normal blended cements, e.g. portland pozzolana cement (PPC), portland slag cement (PSC), etc. contain one more component, viz, burnt clay pozzolana or natural or industrial pozzolanic by-product materials or blast furnace slag, other than the ordinary portland cement. Multicomponent blended cements (mbcs) are new types of cements containing more than one component by partial substitution of portland cement by pozzolanic industrial by-products/wastes to produce value-added products. The MB cements have recently been introduced in the world[1-3] because of less energy consumption per unit volume, compared to other cements for their production. These cements are being utilized in plain as well as reinforced concrete construction in almost all the advanced countries, like USA, UK, Japan, Germany, France, etc[4, 5]. Morevoer, the MB cements are economical apart from solving problems of the environmental pollution and waste disposal to a considerable extent. M.B. cements are being produced by incorporating two or more ground industrial by-products/wastes with portland cement. The most common ingredients for the production of such M. B. Cements besides portland cement are pozzolanas and latent hydraulic materials which are important means of saving energy. Furthermore, utilization of industrial wastes such as flyash,. blast furnace slag or silica fume, as components of MBCs, make it possible to reduce power con-

sumption and increase cement production without altering the quality and performance of the resultant M.B. cements. These cements were found better when compared to OPC and the other normal blended cements (like PPC and PSC) with respect to strength, soundness and other physical properties. The present study highlights the combined role of industrial by-products, viz, flyash and ground granulated blastfurnace slag in the development of high strength M.B. cement which can be utilized in plain as well as reinforced concrete structures[6,7].

## 2.0 EXPERIMENTAL

Portland Cement Clinker, flyash, granulated blast furnace slag and mineral gypsum used in the present study were obtained from a major cement plant, thermal power station, steel plant and local source, respectively. These materials were evaluated for their chemical and physical characteristics and the results are given in Tables 1 to 3. Portland cement clinker, flyash, granulated blast furnace slag and gypsum were finely ground separately in ball mill to a fineness of about 5,000 $cm^2/g$

***Table 1 : Chemical Composition of Materials***

| Constituents, percent | Materials | | | |
|---|---|---|---|---|
| | Clinker | Granulated blast furnace slag | Flyash | Mineral gypsym |
| Loss on Ignition | 1.32 | 0.72 | 5.39 | 14.15 |
| $SiO_2$ | 21.97 | 31.61 | 58.06 | 5.34 |
| $Al_2O_3$ | 4.36 | 21.53 | 26.40 | 1.27 |
| $Fe_2O_3$ | 3.96 | 0.95 | 4.81 | 0.35 |
| CaO | 61.50 | 34.71 | 2.23 | 30.54 |
| MgO | 4.05 | 7.12 | 0.69 | 10.08 |
| $SO_3$ | 2.09 | 0.10 | 0.28 | 37.58 |
| $Na_2O$ | 0.47 | 0.49 | 0.40 | -- |
| $K_2O$ | 0.32 | 0.36 | 0.12 | -- |

*Table 2 : Physical Properties of Cement*

| Property | Values |
|---|---|
| Fineness, $cm^2/g$ | 5,255 |
| Setting Time, | |
| Initial (min) | 78 |
| Final (min) | 186 |
| Compressive strength, $N/mm^2$ | |
| 3-day | 20.8 |
| 7-day | 27.4 |
| 28-day | 35.8 |
| 90-day | 38.6 |
| Expansion, mm (Lechatelier) | Nil |

*Table 3: Physical Properties of Flyash*

| Property | Values |
|---|---|
| Fineness, $cm^2/g$ | 5,038 |
| Lime Reactivity $N/mm^2$ | 5.9 |

A number of blended cement mixes incorporating the above ingredients were prepared by blending them homogeneously in the stipulated proportions in a powder mixer. A number of mixes were prepared to select promising compositions for the studies. The details of compositions of these preliminary mixes of M.B.Cements as prepared are given Table 4. First of all the preliminary mixes were studied by determining compressive strength on 12.5mm cubes of 1:3 cement-sand mortar by weight. The sand was passed through 600 micron sieve and retained on 300 micron sieve. The water requirement of such M.B. Cement mortar was kept equal to the standard consistency of the cement which was found sufficient for filling cube moulds by hand compactions. The cubes, after casting, were demoulded after 24 hours and curing was done under water at 27 ± 2°C. Compressive strength of cured cubes of these trial mixes were determined at different periods upto one year which are shown in Table 5. On the basis of desired strength obtained by mixes, three blended cement mixes represented by A, B and C were selected for detailed study. The compositions of the finalized blended cement mixes are shown in Table 6. Compressive strength of these select mixes (A, B and C) was determined on 70. 6mm cubes as per IS: 4031-1998. The setting time, fineness and expansion characteristics were also determined as per the Indian Standard mentioned above. All these physical properties are depicted in table 7.

To achieve better strength with MBC 4, the effect of gypsum content was evaluated by enhancing the same to 6, 7 and 8 per cent levels from 4 per cent. Compressive strength was determined on 12.5mm cubes of 1:3 cement sand mortar. The results are shown in table 8.

***Table 4 : Composition of Preliminary Mixes of M. B. Cements***

| Sl. No. | Code | Composition of Blended cement, % | | | Percent of Gypsum |
|---|---|---|---|---|---|
| | | Portland cement clinker | Granulated blast furnace slag | Flyash | On the basis of multiblend cement |
| 1 | MB-1 | 40 | 60 | 0 | 4 |
| 2 | MB-2 | 40 | 50 | 10 | 4 |
| 3 | MB-3 | 40 | 45 | 15 | 4 |
| 4 | MB-4 | 40 | 40 | 20 | 4 |
| 5 | MB-5 | 40 | 35 | 25 | 4 |
| 6 | MB-6 | 50 | 50 | 0 | 4 |
| 7 | MB-7 | 50 | 40 | 10 | 4 |
| 8 | MB-8 | 50 | 35 | 15 | 4 |
| 9 | MB-9 | 50 | 30 | 20 | 4 |
| 10 | MB-10 | 50 | 25 | 25 | 4 |
| 11 | MB-11 | 60 | 40 | 0 | 4 |
| 12 | MB-12 | 60 | 30 | 10 | 4 |
| 13 | MB-13 | 60 | 25 | 15 | 4 |
| 14 | MB-14 | 60 | 20 | 20 | 4 |
| 15 | MB-15 | 60 | 15 | 25 | 4 |
| 16 | OPC | 100 | 0 | 0 | 4 |

***Table 5 : Compressive Strength of Prelimenary Mixes of M.B.Cements***

| S. No. | Code No. | Compressive Strength, N/mm² — days | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 7 | 28 | 90 | 180 | 365 |
| 1 | MB-1 | 9.7 | 13.2 | 17.4 | 20.4 | 23.1 | 25.0 |
| 2 | MB-2 | 7.4 | 14.4 | 16.1 | 17.4 | 20.6 | 22.4 |
| 3 | MB-3 | 9.2 | 17.8 | 21.4 | 22.1 | 27.2 | 33.4 |
| 4 | MB-4 | 8.8 | 12.5 | 15.7 | 16.8 | 20.9 | 23.7 |
| 5 | MB-5 | 6.9 | 10.3 | 15.5 | 15.7 | 20.5 | 22.6 |
| 6 | MB-6 | 11.2 | 18.4 | 23.8 | 24.0 | 26.4 | 29.7 |
| 7 | MB-7 | 9.5 | 15.3 | 20.5 | 27.3 | 29.2 | 32.0 |
| 8 | MB-8 | 15.3 | 17.8 | 23.0 | 27.6 | 29.6 | 33.2 |
| 9 | MB-9 | 10.6 | 15.1 | 22.8 | 26.5 | 29.0 | 31.6 |
| 10 | MB-10 | 10.4 | 14.9 | 21.1 | 22.9 | 25.8 | 29.0 |
| 11 | MB-11 | 14.0 | 21.5 | 24.3 | 30.2 | 32.6 | 35.3 |
| 12 | MB-12 | 14.1 | 25.8 | 27.3 | 28.7 | 31.7 | 34.8 |
| 13 | MB-13 | 14.9 | 27.5 | 27.8 | 28.9 | 32.2 | 35.0 |
| 14 | MB-14 | 10.6 | 20.8 | 24.7 | 26.0 | 27.8 | 32.2 |
| 15 | MB-15 | 14.1 | 17.2 | 21.1 | 25.3 | 26.3 | 28.6 |
| 16 | OPC | 12.4 | 14.0 | 17.1 | 20.6 | 25.0 | 27.6 |

***Table 6 : Finalized Composition of Multicomponent Blended Cement Mixes***

| Sl. No. | Code | Composition of Blended cement, % | | | Percent of Gypsum |
|---|---|---|---|---|---|
| | | Portland cement clinker | Granulated blast furnace slag | Flyash | On the basis of multiblend cement |
| 1 | A | 50 | 35 | 15 | 4 |
| 2 | B | 60 | 30 | 10 | 4 |
| 3 | C | 60 | 25 | 15 | 4 |

***Table 7 : Comparision of Physical Properties of Finalized multicomponent Blended Cements***

| S. No. | Property | M. Blended Cement Code No. | | | Specifications according to BIS | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | OPC 269-1989 | PSC 455-1989 | PPC 1489-1991 |
| 1 | Fineness, $cm^2/g$ | 5150 | 5165 | 5175 | 2250 | 2250 | 2250 |
| 2 | Setting time | | | | | | |
| | Initial min. | 86 | 85 | 88 | 30 | 30 | 30 |
| | Final, min. | 200 | 190 | 195 | 600 | 600 | 600 |
| 3. | Compressive Strength ($N/mm^2$) Days | | | | | | |
| | 3 | 24.7 | 26.1 | 27.7 | 16 | 16 | — |
| | 7 | 32.7 | 34.7 | 30.7 | 22 | 22 | 22 |
| | 28 | 35.8 | 39.6 | 40.4 | 33 | 33 | 33 |
| | 90 | 45.1 | 49.0 | 49.6 | — | — | — |
| | 180 | 44.4 | 52.3 | 52.7 | — | — | — |
| | 365 | 53.5 | 56.4 | 57.1 | — | — | — |
| 4 | Soundness Le-chatelier's expansion in mm | Nil | Nil | Nil | 10 | 10 | 10 |

*Table 8 : Effect of gypsum on MBC-4 Mix*

| S.No. | % of gypsum added | Compressive Strength, N/mm² Days 3 | 7 | 28 | 90 |
|---|---|---|---|---|---|
| 1 | 4 | 22.8 | 28.8 | 31.9 | 36.2 |
| 2 | 5 | 23.0 | 29.1 | 33.0 | 36.8 |
| 3. | 6 | 22.1 | 25.9 | 28.6 | 29.9 |
| 4. | 7 | 15.7 | 21.9 | 25.9 | 27.1 |
| 5. | 8 | 13.2 | 18.3 | 21.7 | 23.9 |

## 2.1 Studies under aggressive environment

The three finalized M. B. Cement samples A, B and C alongwith one OPC sample of 33 grade as control were studied under aggressive conditions also, viz, 10 percent sodium sulphate solution and artificial sea-water composition. 12.5mm cubes of 1:3 cement mortar by weight with graded sand as mentioned before, in each of four, were cast and cured under water at controlled temperature of 27 ±2°C. After 28 days of water curing, compressive strength was determined on a few cubes of OPC as well as the three M.B. Cements. All the test specimens in three sets were cured sparately, viz, in plain water, sulphate solution and artificial sea-water composition at controlled temperature of 27 ±2°C, and compressive strengths at various periods, i.e., 28, 90, 180 and 365 days were determined. The performance of M. B. Cement samples as well as OPC under corrosive conditions are given in Figure 1, 2 and 3.

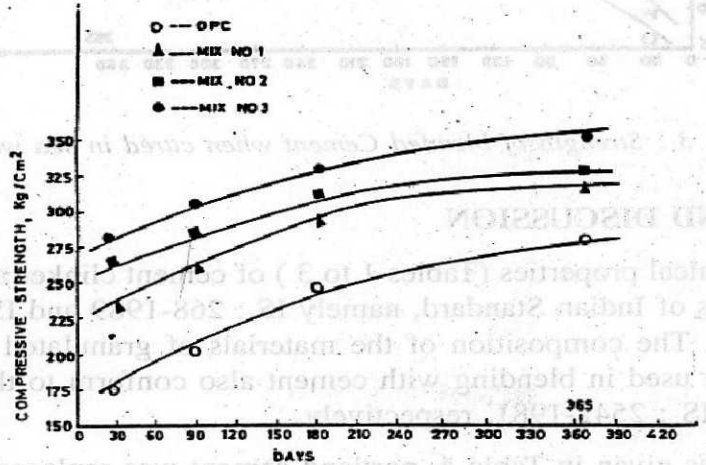


*Fig. 1 : Strength of blended Cement when cured in water*

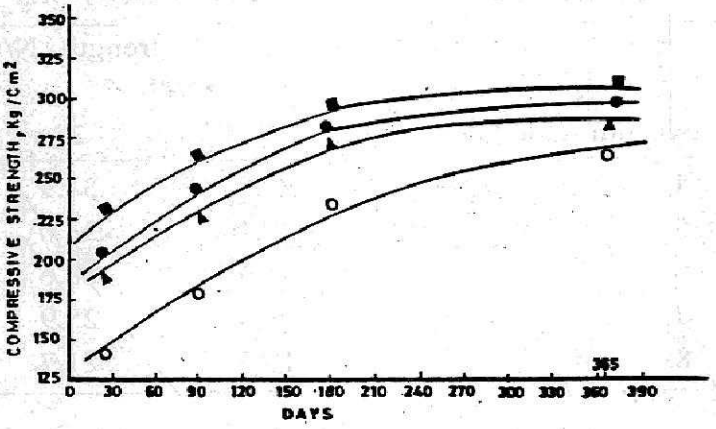


*Fig. 2 : Strength of blended Cement when cured in 10% sodium sulphate solution*

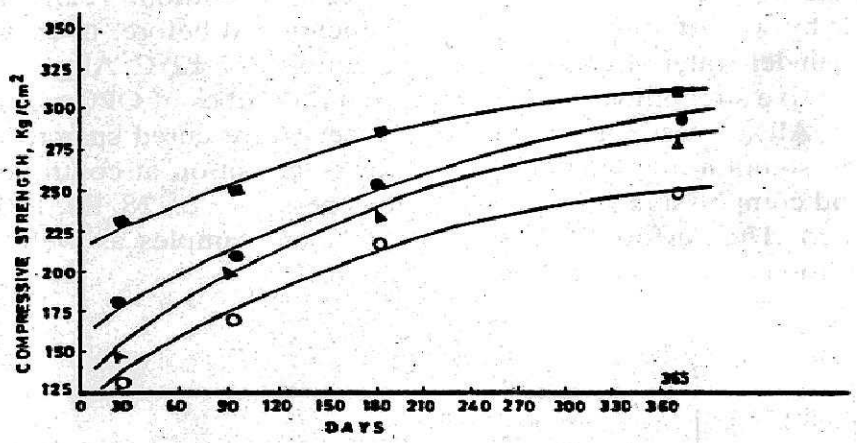


*Fig. 3 : Strength of blended Cement when cured in sea water*

## 3.0 RESULTS AND DISCUSSION

Physical and chemical properties (Tables 1 to 3 ) of cement clinker and flyash conform to the requirements of Indian Standard, namely IS : 268-1989 and IS : 3812 ( Part - I) 1981, respectively. The composition of the materials of granulated blast furnace slag (gbfs) and gypsum used in blending with cement also conform to the Indian Standard IS : 455-189 and IS : 2542-1981, respectively.

In the trial mixes as given in Table 4, portland cement was replaced by 40, 50 and 60 per cent of flyash and gbfs combined in which flyash component was 10, 15, 20 and 25 per cent respectively. So, three sets of M.B. Cements having 40, 50 and 60 per cent

clinker were evolved and the results of compressive strengths of these blended cements are shown in Table 5. Replacement of clinker by flyash and gbfs on longer periods, viz, 90, 180 and 365 days did not adversely effect the strength as compared to that of the OPC. This is because the reaction products formed with slag and flyash grain, in general, retard the hydration of C3 S at initial stages, but enhance it at the later stages [5]. Both these factors, become helpful in obtaining appreciable strength on longer therm curing periods.

Results of compressive strength in MBC 8, 12 and 13 mixes indicate that with optimum replacement of cement clinker, viz, 40 to 50% of the cement clinker, the percentage of flyash works out to be 10 to 15 and gbfs 25 to 35. The physical properties by these three M.B. Cements (A, B and C) are given in table -7. It may be noticed that to obtain 33 $N/mm^2$ of compressive strength of M.B. Cements to compare well with OPC 33 grade, portland slag cement (PSC) and portland pozzolana cement (PPC), a minimum amount of 50 per cent of OPC was found essential in all these studied M. B. Cements. Rest of the percentage proportions comprise flyash and gbfs. The optimum content of flyash in these blended cement mixes may be taken as 15 percent.

The results of compressive strength of these blended cement as well as OPC samples are represented in figure 1. These results indicate that the replacement of clinker by flyash and gbfs has beneficial effect as strength moves on higher side than provided by OPC specimen. This happens due to the fact that lime released due to hydration of cement reacts with flyash and activates gbfs at the active sides of their grains and reaction extends slowly inward. It was also observed that maximum gain in strength is obtained in these finalized M. B. Cement samples containing 10-15 wt. % of flyash, 25-35 wt. % gbfs and 50-60 wt. % clinker establishing that 50 per cent cement clinker can be safety incorporated by the judicious mixing of gbfs and flyash to obtain multi component blended cement having comparable/better strength than that of OPC.

### 3.1 Performance under aggressive environments

The results on the performance of these three blended cement samples containing 10-15 wt per cent flyash with varying amount of gbfs and cement clinker and OPC under corrosive conditions of immersion in 10 per cent sodium sulphate solution and artificial sea-water composition are shown in figures 2 and 3. It can be observed that there is no effect on strength of these developed M.B. Cements under these aggressive environments, as the strength of these three blended cement mortar cubes under normal water is always lower than that produced when cured under sodium sulphate and sea-water composition. The behavior of M.B. Cement is, therefore, excellent as there is no deterioration of strength in aggressive environment and it behaves perfectly sound and remains unaffected under studied aggressive conditions.

## 4.0 CONCLUSIONS

From the studies carried out, it can be concluded that range of optimum mix proportion in M. B. Cement contents comes out to be cement clinker : 50-60 wt. per cent, flyash:

10-15 wt. per cent and granulated blast furnace slag 25-35 wt. per cent. These M. B. Cements are quite sound in nature.

The Blains fineness of M. B. Cement should not be less than 5,000 $cm^2/g$ and the cement so prepared gives physical properties as envisaged for OPC, PSC and PPC; and hence can be used in the same way as these cements are used. M. B. Cement at the same time reduces environmental pollution due to utilization of some of the industrial wastes.

These M. B. Cements provide excellent resistance under aggressive environments besides being advantageous in saving energy as well as portland cement (OPC) of the order of 50 per cent. The effectiveness of these cements under aggressive environments may increase the durability of construction also. Apart from this, these M. B. Cements will provide economy in construction activities.

## 5.0 ACKNOWLEDGEMENT

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