Reprinted from "The Indian Concrete Journal", June 1963.

# EVALUATION OF INDIAN FLY ASHES

## C. B. R. I. Investigations Assess Suitability for Use as Pozzuolana, Admixture, or Fine Aggregate in Concrete

by S. S. REHSI and S. K. GARG*

*The article reports investigations carried out at the Central Building Research Institute, Roorkee, on samples of fly ash obtained from Bokaro, Durgapur, Kanpur and Madras to assess their suitability for use as pozzuolana, as admixture, or as fine aggregate in mortar and concrete.*

*All the fly ashes are found suitable for use as pozzuolana replacing 20 or 25 per cent of cement whilst none is suitable for use as admixture. The fly ashes can also be advantageously used to replace sand in mortars and concretes, thereby saving substantial quantities of cement.*

FLY ash is a finely divided residue resulting from the combustion of pulverised coal in boilers. It is transported from the boiler by flue gases and collected by means of electrical or mechanical precipitators. It is generally finer than Portland cement and consists mostly of small spheres of glassy compounds of complex chemical composition, together with miscellaneous materials such as quartz, feldspar, iron oxides, and carbon.[1]

Fly ash produced at thermal power stations in India totals about 1½ million tons per year. Production is expected to rise to about 3½ million tons per year by the end of the Third Five-Year Plan.

Investigations were carried out at the Central Building Research Institute, Roorkee, to examine the suitability of Indian fly ashes for different uses—as pozzuolana for producing Portland-pozzuolana cement, as an admixture, and as fine aggregate in mortar and concrete. The results obtained are reported and discussed below.

### Materials used in tests

The materials used in these tests were as follows :

*Fly ash :* Samples of fly ash were obtained from the thermal power stations at Bokaro, Durgapur, Kanpur and Madras.

*Portland cement :* The properties of the Portland cement used in preparing mortars and concretes for the tests are shown in *Table* 1.

*Lime :* The lime used conformed to the requirements of IS : 712—1956[2] for class *C* lime. Its $CaO + MgO$ content was 97·8 per cent and it was slaked to form a putty. The weight of hydrated lime in the putty was calculated by using the following formula[3]

$$W_H = \frac{G}{G-1}(W_P - 62{\cdot}4)$$

where

$W_H$ = weight of dry hydrate in 1 ft³ of the putty

$G$ = specific gravity of hydrate = 2·25

$W_P$ = weight of the putty per ft³

*Standard sand :* Standard Ennore sand passing I.S. sieve 85 and retained over I.S. sieve 60 was used.

*Sand and gravel :* The sieve analyses of sand and gravel used in making mortar and concrete for the tests are given in *Table* 2.

**TABLE I Properties of ordinary Portland cement used in preparing mortars and concretes containing fly ash**

| | |
|---|---|
| *Chemical analysis* | |
| Loss on ignition | 1·90 per cent |
| Insoluble residue | 0·82 |
| Soluble silica | 22·03 |
| $Al_2O_3$ | 5·98 |
| $Fe_2O_3$ | 2·41 |
| $CaO$ | 62·59 |
| $MgO$ | 0·85 |
| $SO_3$ | 2·35 |
| Free $CaO$ | 0·65 |
| *Compound composition* (computed according to ASTM Designation : C 150–55) | |
| $C_3S$ | 37 per cent |
| $C_2S$ | 35 |
| $C_3A$ | 11 |
| $C_4AF$ | 8 |
| *Physical properties* | |
| Fineness (Blaine) | 3553 cm²/g |
| Normal consistency | 29·25 per cent |
| Compressive strength | |
| at 7 days | 4843 lb/in² |
| at 28 days | 5767 lb/in² |
| Setting time | |
| Initial | 2 h 8 m |
| Final | 3 h 33 m |

### Tests carried out

The suitability of the fly ash samples for use as pozzuolana was tested according to IS : 1727—1960.[4] The tests carried out included chemical analysis, fineness, lime reactivity, compressive strength, setting time, and drying shrinkage. The pozzuolanic activity of the fly ashes was also tested by the Fratini test.[5] The properties of the Portland-pozzuolana cement prepared by blending different amounts of Portland cement and fly ash were examined in accordance with IS : 1489—1962.[6]

The suitability of the fly ash samples for use as admixture in Portland cement concrete was tested according to A.S. T.M. Designation : C. 350-54 T.[7]

The workability of the mortar and concrete in terms of flow and compacting factor was measured according to A.S.T.M. Designation : C 109—54 T[8] and IS : 1199—1959,[9] respectively.

All concrete specimens were cast on a standard vibrating table and cured under water kept in a room maintained at a temperature of 27 ± 2°C.

* Central Building Research Institute, Roorkee.

**TABLE 2 Sieve analysis of sand and gravel used in making mortars and concretes**

| *Material* | *Sieve size* | *Per cent retained* |
|---|---|---|
| Gravel | $\frac{3}{4}$ in | 0 |
| | $\frac{3}{8}$ in | 51·06 |
| | $\frac{3}{16}$ in | 81·35 |
| | B.S. No. 7 | 95·66 |
| Sand | $\frac{3}{16}$ in | 0 |
| | B.S. No. 7 | 1 |
| | 14 | 6 |
| | 25 | 52 |
| | 52 | 92·6 |
| | 100 | 97·6 |

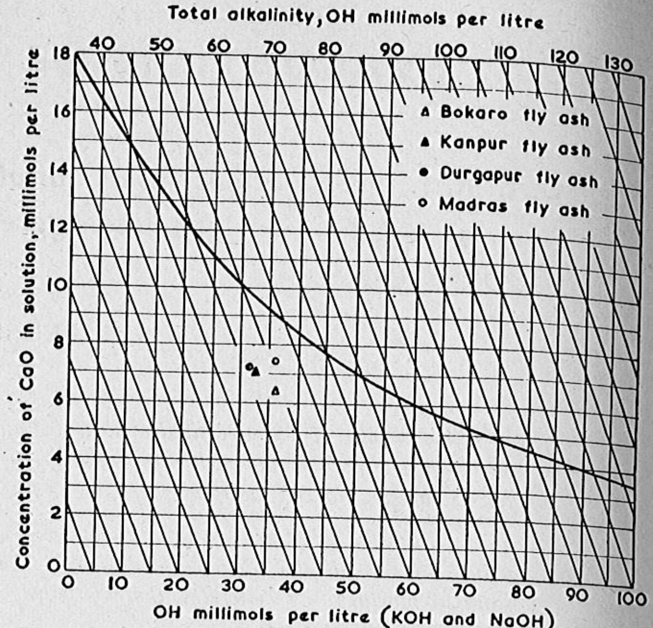


Fig 1 Solubility isotherm (40°C) for $Ca(OH)_2$ in the presence of alkalies

## Suitability of fly ash as pozzuolana

The results of the tests carried out to assess the suitability of the fly ash samples for use as pozzuolana are given in *Tables* 3 *and* 4 and in *Fig* 1.

Of ten samples of the fly ash tested, only five samples comprising of sample no. 4 from Bokaro, samples nos. 7 and 8 from Durgapur, sample no. 9 from Kanpur, and sample no. 10 from Madras pass the specified limit of 40 kg/cm$^2$ (600 lb/in$^2$) for the compressive strength in the lime reactivity test. The compressive strength, setting time, and drying shrinkage of Portland cement containing 20 per cent of fly ash are within the specified limits, except sample no. 7 from Durgapur which gives only 77·5 per cent of the strength of the control specimen. These fly ashes therefore make suitable pozzuolanas. The results of the Fratini test further supports these observations. As required under the test, the point representing the concentration in lime in function of the alkalinity in respect of these samples of fly ash fall below the isotherm of solubility (*Fig* 1). The cement used in the Fratini test consisted of 4 parts Portland cement and 1 part fly ash by weight.

## Properties of Portland-pozzuolana cement

Portland-pozzuolana cement can be produced either by intimately and uniformly blending Portland cement and fly ash or by grinding together Portland cement clinker and fly ash at a cement works. Because of convenience, and the fact that fly ash is in itself a fine powder, the former method is generally preferred.

Samples of Portland-pozzuolana cement were therefore prepared by blending 15, 20 and 25 per cent of fly ash by weight of the Portland cement. Only those fly ashes which were found to be suitable pozzuolanas were used. The properties of these cements were determined and are reported in *Table* 5.

It will be seen that Portland-pozzuolana cement containing any of the four samples of fly ash upto 25 per cent by weight fulfils all specified physical requirements. The specified chemical requirements limit the contents of $MgO$, $SO_3$ and of loss on ignition to 5·0, 2·75, and 5·0 per cent, respectively. From the results of the chemical analyses of Portland cement and fly ash samples (*Tables* 1 *and* 3), it will be seen that the blended cements are also within the specified chemical requirements, except that the loss on ignition exceeds the limit in cements containing 25 per cent Kanpur or Madras fly ash. The amount of Kanpur or Madras fly ash in a blended cement should therefore be limited to 20 per cent.

A series of compressive strength tests was carried out on 1 : 3 cement-standard sand mortar specimens (cubes of

**TABLE 3 Chemical analysis of fly ash samples**

| *Sample no.* | *Source* | *Chemical analysis (oven-dry basis)* Loss on ignition, per cent | Silicon dioxide, $SiO_2$, per cent | Aluminium oxide, $Al_2O_3$, per cent | Ferric oxide, $Fe_2O_3$, per cent | Calcium oxide, $CaO$, per cent | Magnesium oxide, $MgO$, per cent | Available alkalies as $Na_2O$, per cent | Sulphur trioxide, $SO_3$, per cent |
|---|---|---|---|---|---|---|---|---|---|
| 4 | Thermal power station, Bokaro (riverside) | 10·8 | 57·14 | 27·71 | 4·32 | 0·62 | 0·28 | — | — |
| 7 | Thermal power station, Durgapur (2nd stage) | 6·13 | 49·30 | 20·05 | 19·60 | 2·28 | 1·53 | 0·93 | Trace |
| 8 | Thermal power station, Durgapur (3rd stage) | 5·53 | 51·65 | 19·65 | 18·80 | 2·20 | 1·49 | 0·70 | Trace |
| 9 | KESA, Kanpur | 15·81 | 49·20 | 22·00 | 7·50 | 2·84 | 0·98 | 1·44 | 0·24 |
| 10 | Basin bridge, MES power house, Madras | 15·47 | 46·90 | 21·55 | 8·45 | 3·19 | 1·29 | 3·23 | — |

**TABLE 4 Results of physical tests of fly ash samples for use as pozzuolana**

| *Sample no.* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Thermal power station, Bokaro* | | | | | *Thermal power station, Durgapur* | | | | | |
| *Test* | *Dust collector hopper* | *Rear hopper* | *Hopper below boiler* | *River-side* | *River-side reject* | *Shot hopper economiser section* | *Fuller-Kinyon conveyor pump* | *Discharge hopper of ash and dust bunker* | *KESA, Kanpur* | *MES power house, Basin bridge, Madras* | *Specified limits* |
| Specific gravity, g/cm³ | 2·22 | 2·29 | 2·19 | 2·19 | 2·04 | 2·57 | 2·35 | 2·41 | 2·24 | 2·24 | — |
| Fineness (Blaine), cm²/g* | 4697 | 2864 | 2197 | 5301 | 4246 | 1205 | 3296 | 3267 | 6091 | 5283 | 3200 |
| Lime reactivity strength, kg/cm² | 30·6 | 20 | 29·2 | 59·6 | 39·2 | 35·6 | 50·2 | 53·2 | 54·0 | 51·6 | 40 |
| Compressive strength at 28 days, per cent of strength of control specimen, lb/in² | ** | ** | ** | 82·3 | ** | ** | 77·5 | 85·5 | 80·4 | 83·7 | 80 |
| Setting time, min Initial | — | — | — | 188 | — | — | — | 153 | 115 | 144 | ≮ 30 |
| Final | — | — | — | 293 | — | — | — | 193 | 217 | 252 | ≯ 600 |
| Drying shrinkage, per cent | — | — | — | 0·1 | — | — | — | 0·1 | 0·11 | 0·12 | 0·15 |

* As the bed could not be prepared at 0·5 porosity, the porosity of the bed was changed.
** not determined.

7·07-cm sides) containing different percentages by weight of fly ash as replacement for cement. The amount of water used in gauging the mortar was calculated from the standard consistency of the paste prepared and tested according to IS : 1727—1960. The results of the tests are given in *Table* 6.

The results show that the initial loss of strength caused by the replacement of cement by fly ash for all the samples of fly ash remains uncovered even at one year. This is quite unexpected as the fly ash like any other pozzuolana is known to furnish sufficient pozzuolanic activity at later ages to overcome the early deficiency in strength. The reason for lower strengths even at one year can be attributed to the greater amount of water used in mortars containing fly ash. For this reason, the initial strength of the mortar decreased to such an extent that it could not be made up in one year. That the pozzuolanic activity of the fly ashes did, in fact, contribute substantially to the development of strength is indicated by the per cent increase over the 7-day strengths of mortars containing fly ash as compared to the figures for the control specimen containing no replacement of cement. Thus, it will be seen that the increase in strength of the control specimen at 1 year is only 45 per cent as compared to 65 per cent (or more), and 112 per cent (or more), in the case of mortars containing 15 and 30 per fly ash, respectively. It seems, therefore, that if the same amount of water was used in the mortar with and without fly ash, the strength of mortar containing fly ash would have equalled if not exceeded the strength of plain mortar at 1 year. Though there is little relationship between the development of strength in mortar and concrete, the above statement is supported by the method adopted by the Rihand dam authorities for proportioning concrete containing Bokaro fly

**TABLE 5 Properties of Portland-pozzuolana cements prepared by intimately blending Portland cement and fly ash**

| *Source of fly ash* | Bokaro (*Sample no.* 4) | | Durgapur (*Sample no.* 8) | | Kanpur (*Sample no.* 9) | | Madras (*Sample no.* 10) | | *Specified requirements* |
|---|---|---|---|---|---|---|---|---|---|
| *Amount blended, per cent* | 20 | 25 | 20 | 25 | 20 | 25 | 20 | 25 | |
| Fineness Specific surface (cm²/g) by air permeability method | 4246 | 4311 | 3484 | 3492 | 4343 | 4401 | 4117 | 4188 | ≮ 3,000 |
| Soundness Expansion (Le Chatelier method), mm | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | 0·5 | ≯ 10 mm |
| Setting time, min Initial | 188 | 218 | 153 | 218 | 115 | 187 | 144 | 202 | ≮ 30 |
| Final | 293 | 330 | 193 | 318 | 217 | 277 | 252 | 290 | ≯ 600 |
| Compressive strength, kg/cm² at 7 days | 249 | 227 | 239 | 157 | 248 | 233 | 237 | 213 | ≮ 140 |
| at 14 days | — | — | — | 254 | — | — | — | — | ≮ 210 |
| Drying shrinkage, per cent | 0·1 | 0·11 | 0·1 | 0·11 | 0·11 | 0·12 | 0·12 | 0·13 | ≯ 0·15 |

**TABLE 6 Compressive strength of 1 : 3 cement-standard san**

| Source of Fly Ash | Bokaro (Sample no. 4) | | | | | |
|---|---|---|---|---|---|---|
| Replacement of cement by fly ash, per cent | Standard consistency, per cent | Compressive strength, kg/cm² 7 days | 28 days | 90 days | 180 days | 365 days |
| 0 (control specimen) | 29·25 | 341·5 | 407 | 426 | 468 | 495 |
| Per cent increase over 7-day strength | | — | 19·2 | 24·8 | 37·1 | 45 |
| 15 | 36·00 | 252 | 389 | 395 | 405 | 418 |
| Per cent increase over 7-day strength | | | 54·4 | 56·7 | 60·7 | 65·9 |
| Per cent of strength of control specimen at equal age | | 73·2 | 95·6 | 93 | 86·5 | 84·5 |
| 20 | 37·00 | 249 | 334 | 414 | 399 | 400 |
| Per cent increase over 7-day strength | | — | 34·2 | 66·3 | 60·2 | 60·6 |
| Per cent of strength of control specimen at equal age | | 73 | 82·3 | 97·4 | 85·5 | 80·8 |
| 25 | 38·75 | 227·5 | 344 | 388·5 | 415 | 408 |
| Per cent increase over 7-day strength | | — | 46·8 | 70·7 | 82·4 | 79·3 |
| Per cent of strength of control specimen at equal age | | 66·6 | 84·7 | 91·2 | 88·7 | 82·5 |
| 30 | 41·25 | 160·5 | 270 | 344 | 389 | 425 |
| Per cent increase over 7-day strength | | — | 68·2 | 114·5 | 142·5 | 165 |
| Per cent of strength of control specimen at equal age | | 47·1 | 66·5 | 80·7 | 83·2 | 85·6 |

| Source of Fly Ash | Durgapur (Sample no. 8) | | | | | |
|---|---|---|---|---|---|---|
| Replacement of cement by fly ash, per cent | Standard consistency, per cent | Compressive strength, kg/cm² 7 days | 28 days | 90 days | 180 days | 365 days |
| 0 (control specimen) | 29·25 | 341·5 | 407 | 426 | 468 | 495 |
| Per cent increase over 7-day strength | | — | 19·2 | 24·8 | 37·1 | 45 |
| 15 | 32·50 | 270 | 371 | 420 | 427·5 | 460 |
| Per cent increase over 7-day strength | | — | 37·4 | 55·5 | 58·4 | 70·4 |
| Per cent of strength of control specimen at equal age | | 79·4 | 91·3 | 99 | 91·5 | 93·1 |
| 20 | 33·37 | 239 | 347·5 | 389·5 | 454 | 466 |
| Per cent increase over 7-day strength | | — | 45·5 | 63·0 | 90 | 95 |
| Per cent of strength of control specimen at equal age | | 70 | 85·5 | 91·5 | 97 | 94·1 |
| 25 | 36·00 | 157 | 312·5 | 350·5 | 391 | 398 |
| Per cent increase over 7-day strength | | — | 99 | 123·5 | 149 | 153·5 |
| Per cent of strength of control specimen at equal age | | 56·4 | 77 | 82·5 | 83·5 | 80·5 |
| 30 | 38·00 | 168·5 | 292 | 364 | 369·5 | 389 |
| Per cent increase over 7-day strength | | — | 73·4 | 116 | 119 | 130·5 |
| Per cent of strength of control specimen at equal age | | 49·4 | 71·8 | 85·5 | 79·0 | 78·5 |

ash (riverside) for use in the dam[10]. To get the strength of the concrete containing fly ash equal to that of the corresponding plain cement concrete, the method made adjustments for the extra water requirement by treating the extra carbon content as fine aggregate, as well as increased the total cementing materials so as to maintain a constant water-cement ratio.

The general decline after 90 days in the ratio of the strength of the mortars containing fly ash to the strength of the control specimen containing no fly ash may be attributed to cement characteristics. Brink and Halstead found that the strength ratio varies directly with the tricalcium silicate content of the cement used ; with cement having a tricalcium silicate content between 27 to 39 per cent, the strength of mortar containing fly ash have been shown to decrease at later ages[11]. It is to be noted that the tricalcium silicate content of the Portland cement used in the present investigations is 37 per cent (*Table* 1). Therefore, subject to verification with cements having different contents of tricalcium silicate, the decrease in the strength ratios may be taken to have been caused by the lower content of tricalcium silicate in the Portland cement used.

## Suitability of fly ash as admixture

Fly ash having a low carbon content and high fineness when used in concrete as an admixture is known to promote its workability and plasticity. The grains of fly ash, being minute spheres, are believed to act essentially as small ball bearings between aggregate particles, reducing friction between them and imparting great freedom to their movement during mixing and placing of concrete[12].

Tests carried out to determine the suitability of fly ash samples nos. 4, 8, 9 and 10 for use as an admixture in Portland cement concrete showed that :

(*i*) all the fly ash samples undergo drying shrinkage greater than the specified limit of 0·1 per cent (*Table* 7),

(*ii*) the loss on ignition in sample no. 9 and the loss on ignition and available alkalies in sample no. 10, are higher than the specified limits of 12·0 and 1·5 per cent, respectively (*Table* 3).

**TABLE 7 Drying shrinkage of mortar containing fly ash***

| Sample no. | Drying shrinkage, per cent |
|---|---|
| 4 (Bokaro) | 0·12 |
| 8 (Durgapur) | 0·13 |
| 9 (Kanpur) | 0·13 |
| 10 (Madras) | 0·14 |

* Tested in accordance with A.S.T.M. Designation C 311–54 T.

None of the fly ash is thus suitable for use as an admixture in Portland cement concrete. A few trials made with sample no. 8 confirmed these observations when the workability of a concrete was actually found to decrease.

## Use of fly ash as fine aggregate

Lean mortars and concretes generally have the defects of poor workability, bleeding of mixing water, and segregation of aggregates. These defects arise mainly due to the lack of mortar containing fly ash as replacement of cement by weight

| Kanpur (Sample no. 9) Standard consistency per cent | Compressive strength, kg/cm² 7 days | 28 days | 90 days | 180 days | 365 days | Madras (Sample no. 10) Standard consistency per cent | Compressive strength, kg/cm² 7 days | 28 days | 90 days | 180 days | 365 days |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 29·25 | 341·5 | 407 | 426 | 468 | 495 | 29·25 | 341·5 | 407 | 426 | 468 | 495 |
| | — | 19·2 | 24·8 | 37·1 | 45 | | — | 19·2 | 24·8 | 37·1 | 45 |
| 33·90 | 291 | 399 | 474 | 446 | 494 | 35·13 | 271·5 | 387 | 412·5 | 439 | 502·5 |
| | — | 37·1 | 62·9 | 53·2 | 69·7 | | — | 42·6 | 52·0 | 61·7 | 85 |
| | 85·1 | 98·4 | 111·3 | 95·6 | 99·6 | | 79·5 | 95·3 | 97 | 93·9 | 101·5 |
| 36·25 | 248·5 | 326·5 | 379 | 436 | 452·5 | 36·63 | 237 | 341 | 401 | 432 | 454 |
| | — | 31·4 | 52·5 | 75·5 | 82 | | — | 44 | 69·2 | 82·2 | 91·5 |
| | 72·9 | 80·4 | 89 | 93·2 | 91·2 | | 69·5 | 83·7 | 94·2 | 92·4 | 91·7 |
| 37·90 | 233·5 | 329 | 432 | 415 | 481 | 38·50 | 213 | 319 | 348·5 | 385 | 439 |
| | — | 41 | 85 | 77·6 | 106 | | — | 49·8 | 63·6 | 80·7 | 107 |
| | 68·5 | 81·0 | 101·5 | 87·8 | 97·2 | | 62·5 | 78·5 | 82·0 | 82·3 | 88·5 |
| 40·25 | 175·5 | 295 | 352 | 331·5 | 371·5 | 40·75 | 171 | 273 | 326 | 356 | 385 |
| | — | 68 | 101 | 89 | 112 | | — | 59·6 | 90·6 | 108·2 | 125 |
| | 51·4 | 72·8 | 82·8 | 71 | 75 | | 50·1 | 67·2 | 76·7 | 76·2 | 78·5 |

fines. Addition of fine material like fly ash as part replacement of sand have been reported to eliminate these defects mostly.[13, 14]

Fly ash samples nos. 4, 8, 9 and 10 were used to replace 15 and 20 per cent of the sand used in 1 : 6, 1 : 8, 1 : 10 and 1 : 12 cement-sand mortars and 1 : 3 : 6 and 1 : 4 : 8 cement-sand-gravel concretes. While these fly ashes reduce the bleeding of the mixing water and segregation of the aggregates (observed visually) by absorbing the excess water and providing extra paste, their effectiveness in increasing the workability varies (*Table* 8) and appears to be related to the content of unburnt fuel (as indicated by the loss on ignition) in the fly ash and the leanness of mix. Fly ash samples nos. 9 and 10 (loss on ignition 15·8 and 15·4 per cent, respectively) do not increase the workability in any of the mortar or concrete mixes. On the contrary, they absorb so much of the mixing water that the workability actually decreases, except in the case of 1 : 3 : 6 concrete where the workability with 15 per cent replacement of sand remains the same as for the mix without any fly ash. Fly ash sample no. 4 (loss on ignition 10·8 per cent) behaves slightly better and can be used to replace upto 20 per cent of sand in 1 : 10 and 1 : 12 mortars and upto 15 per cent of sand in 1 : 3 : 6 and 1 : 4 : 8 concrete. Fly ash sample no. 8 which has the lowest content of unburnt fuel (loss on ignition 5·5 per cent) is the most effective and can be used to replace upto 20 per cent of sand in all the mortar and concrete mixes except in 1 : 6 cement sand mortar where it can replace only 15 per cent sand without decreasing workability.

Measurements of the water retaining capacity of mortars showed that fly ash substitution for 15 or 20 per cent of sand also has the beneficial effect of increasing the water retaining capacity of mortars (*Table* 9).

*Table* 10 gives the 7-day compressive strength of mortars and concretes with and without fly ash substitution for 15 and 20 per cent of sand. The compressive strength of the mixes in which the fly ash reduced the workability was not determined. It will be seen that the strength of mortars and concretes containing fly ash is much higher than the strength of the corresponding plain mortars and concretes without fly ash. This obviously is an advantage which can be availed of in reducing the quantity of the cement used. In *Figs* 2 and 3 the compressive strength of mortars and concretes with and without fly ash sample no. 8 is plotted against the quantity of cement used. It will be seen that a 1 : 11 cement-sand mortar or 1 : 4 : 8 cement-sand-gravel concrete with fly ash replacing 20 per cent of the sand will have the same strength as a plain 1 : 8 cement-sand mortar or a plain 1 : 3 : 6 cement-sand-gravel concrete, respectively. Besides the additional advantages of increased workability, reduced bleeding of mixing water, and reduced segregation of the aggregates, a substantial amount of cement (shown by the shaded portion) can thus be saved.

## Conclusion

The results of investigations carried out on samples of fly ash taken at Bokaro, Durgapur, Kanpur, and Madras show that

1. these fly ashes are suitable pozzuolanas and can be used upto 20 per cent (Kanpur and Madras) and 25 per cent (Bokaro and Durgapur) in the manufacture of Portland-pozzuolana cement;
2. none of the fly ash is suitable for use as an admixture to increase the workability of Portland cement concrete;
3. Durgapur fly ash can be used to replace upto 20 per cent of the sand in 1 : 8, 1 : 10 and 1 : 12 cement-sand

**TABLE 8  Workability of lean mortars and concretes containing fly ash as replacement of sand**

| *Mix composition by volume* | *Replacement by weight, per cent* | *Water-cement ratio* | *Workability* | | | | |
|---|---|---|---|---|---|---|---|
| | | | *No fly ash* | *Sample no. 4* | *Sample no. 8* | *Sample no. 9* | *Sample no. 10* |
| *Mortars* | | | | *Flow, per cent* | | | |
| 1 : 6 cement-sand | 0 | 1·60 | 103 | | | | |
| | 15 | 1·60 | | 85·4 | 103 | 35·8 | 49·7 |
| | 20 | 1·60 | | — | 91·5 | — | — |
| 1 : 8 cement-sand | 0 | 2·18 | 101 | | | | |
| | 15 | 2·18 | | 95·6 | 122 | 60·5 | 68·5 |
| | 20 | 2·18 | | — | 117 | — | — |
| 1 : 10 cement-sand | 0 | 2·86 | 101 | | | | |
| | 15 | 2·86 | | 126 | 137 | 84·5 | 92·3 |
| | 20 | 2·86 | | 101 | 114 | — | — |
| 1 : 12 cement-sand | 0 | 3·53 | 100·3 | | | | |
| | 15 | | | 135·7 | 141·3 | 91·0 | 99 |
| | 20 | | | 165·5 | 135·5 | — | — |
| *Concretes* | | | | *Compacting factor* | | | |
| 1 : 3 : 6 cement-sand-gravel | 0 | 1·18 | 0·93 | | | | |
| | 15 | 1·18 | | 0·94 | 0·97 | 0·93 | 0·94 |
| | 20 | 1·18 | | 0·90 | 0·97 | 0·87 | 0·88 |
| 1 : 4 : 8 cement-sand-gravel | 0 | 1·54 | 0·93 | | | | |
| | 15 | 1·54 | | 0·93 | 0·95 | 0·91 | 0·92 |
| | 20 | 1·54 | | 0·89 | 0·94 | | |

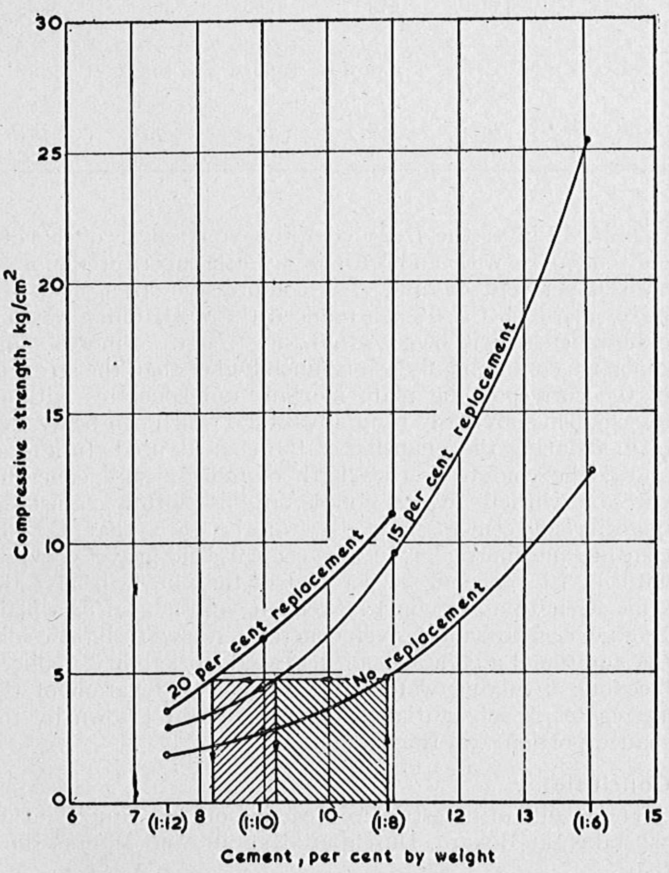


Fig 2  The 7-day compressive strength of mortars with and without replacement of sand with fly ash sample no. 8

mortars and 1 : 3 : 6 and 1 : 4 : 8 cement-sand-gravel concretes ; Bokaro fly ash can be used to replace upto 20 per cent of the sand in 1 : 10 and 1 : 12 cement-mortars and upto 15 per cent of the sand in 1 : 3 : 6 and 1 : 4 : 8 cement-sand-gravel concretes ; and Kanpur and Madras fly ashes can be used to replace upto 15 per cent of the sand in 1 : 3 : 6 cement-sand-gravel concrete only ;

4. the use of fly ash as a part replacement of the sand increases workability and reduces bleeding of mixing water and segregation of aggregates, particularly in lean mortars and concretes ;
5. with 20 per cent of sand replaced by fly ash, leaner mortars and concretes can be used to give the same strength ; thus saving a substantial quantity of cement.

## Acknowledgments


The authors' thanks are due to Mr S. K. Chopra for his helpful discussions during the course of these investigations. The authors also thank the authorities in charge of the thermal power stations located at Bokaro, Durgapur, Kanpur and Madras for supplying samples of fly ash. The investigations formed part of the normal programme of research at the C.B.R.I. and this article reporting them is published with the permission of the Director.


**TABLE 9  Water retaining capacity of mortar containing fly ash as replacement of sand**

| *Mix composition by volume* | *Replacement by weight, per cent* | *Water retaining capacity, per cent* |
|---|---|---|
| 1 : 6 cement-sand | 0 | 2·1 |
| | 15 | 8·6 |
| 1 : 8 cement-sand | 0 | nil |
| | 15 | 13·9 |
| | 20 | 25·5 |
| 1 : 10 cement-sand | 0 | nil |
| | 15 | 12·9 |
| | 20 | 24·3 |
| 1 : 12 cement-sand | 0 | nil |
| | 15 | 20·7 |
| | 20 | 32·3 |

**TABLE 10 7-day compressive strength of lean mortar and concrete containing fly ash as replacement of sand**

| *Mix composition by volume* | *Replacement by weight, per cent* | *Compressive strength, kg/cm²* No fly ash | *Sample no. 4* | *Sample no. 8* | *Sample no. 9* | *Sample no. 10* |
|---|---|---|---|---|---|---|
| *Mortars* | | | | | | |
| 1 : 6 cement-sand | 0 | 12·8 | — | — | — | — |
| | 15 | | — | 25·5 | — | — |
| 1 : 8 cement-sand | 0 | 4·8 | — | — | — | — |
| | 15 | | — | 9·5 | — | — |
| | 20 | | — | 11·1 | — | — |
| 1 : 10 cement-sand | 0 | 2·75 | — | — | — | — |
| | 15 | | 6·6 | 4·4 | — | — |
| | 20 | | 8·5 | 6·3 | — | — |
| 1 : 12 cement-sand | 0 | 1·8 | — | — | — | — |
| | 15 | | 4·7 | 2·9 | 5·3 | — |
| | 20 | | 4·8 | 3·5 | — | — |
| *Concretes* | | | | | | |
| 1 : 2 : 4 cement-sand-gravel* | 0 | 79 | — | — | — | — |
| | 20 | | — | 132 | — | — |
| 1 : 3 : 6 cement-sand-gravel | 0 | 26·2 | — | — | — | — |
| | 15 | | 41·5 | 45·7 | 35·4 | 41·8 |
| | 20 | | — | 49·0 | — | — |
| 1 : 4 : 8 cement-sand-gravel | 0 | 14·2 | — | — | — | — |
| | 15 | | — | 25·6 | — | — |
| | 20 | | — | 25·6 | — | — |

* w/c ratio 1·0, compacting factor 0·93 for plain mix and 0·97 for concrete containing fly ash.

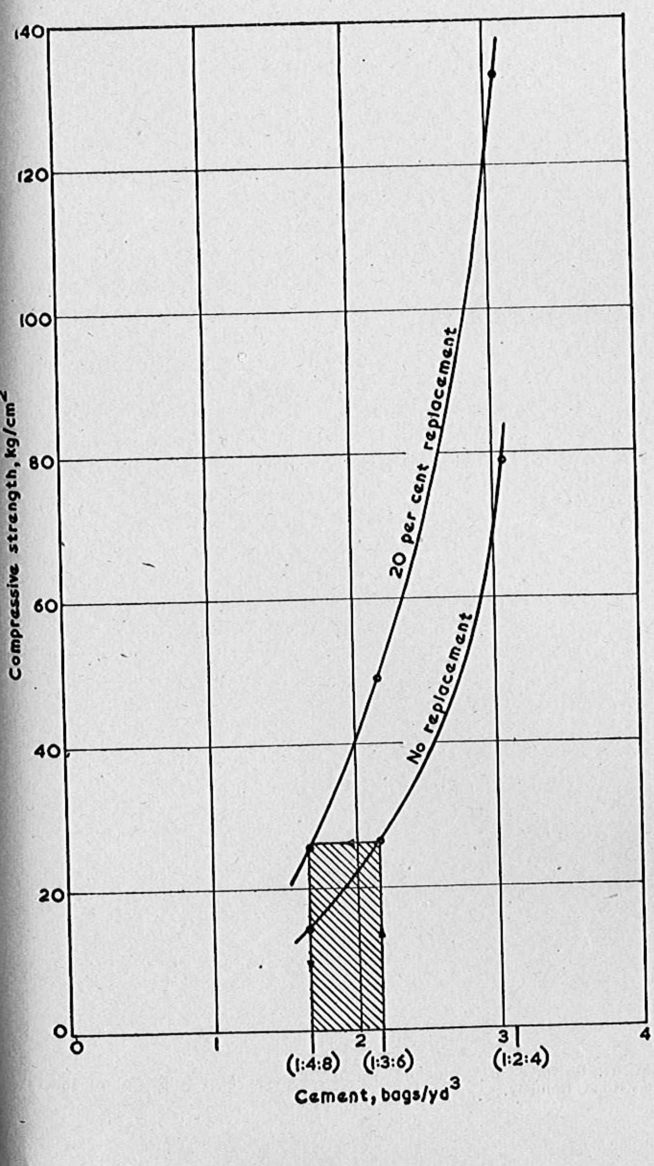


Fig 3 The 7-day compressive strength of concrete with and without replacement of sand with fly ash sample no. 8


**References**

1. Davis, Raymond E., Davis, Harmer E., and Kelly, J. W. "Weathering resistance of concretes containing fly ash cements". *Jour. Am. Concrete Inst.*, January 1941. Proc. Vol. 37, pp. 281-293.
2. —— IS : 712–1956 "Specification for building limes". Indian Standards Institution, New Delhi.
3. Voss, Walter C. "Exterior Masonry Construction", Bulletin No. 324, National Lime Association, Washington 5, D.C.
4. —— IS : 1727–1960 "Methods of test for pozzuolanic materials." Indian Standards Institution, New Delhi.
5. Giovani Malquori, "Portland-pozzuolan cement", *Proc. 4th International Symposium on the Chemistry of Cement*, Washington, 1960.
6. —— IS : 1489–1962 "Specification for Portland-pozzuolana cement". Indian Standards Institution, New Delhi.
7. —— A.S.T.M. Designation : C 350-54 T, "Specification for fly ash for use as an admixture in Portland cement concrete". American Society for Testing Materials, Philadelphia.
8. —— A.S.T.M. Designation : C 109–54 T, "Method of test for compressive strength of hydraulic cement mortars". American Society for Testing Materials, Philadelphia.
9. —— IS : 1199–1959, "Methods of sampling, and analysis of concrete". Indian Standards Institution, New Delhi.
10. Jain, S. K., Maheshwari, K. M., Agarwal, G. D., Misra, R. K., and Joshi, G. D. "Bokaro fly ash for Rihand dam", *Jour. Inst. Engrs.* (*India*), June 1961.
11. Brink, Russel H., Halstead, Woodrow J., "Studies relating to the testing of fly ash for use in concrete," *Public Roads*, February 1957. Vol 29, pp. 121–141.
12. Meissner, H. S., "Pozzuolans used in mass concrete", *Symp. Use of Pozzuolanic Materials in Mortars and Concretes.* Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia.
13. Murdock, L. J. Concrete Materials and Practice, 2nd edition, 1955. Edward Arnold, London.
14. Frederick, Harry H., "Application of fly ash for lean concrete mixes", *Proc. Am. Soc. Testing Materials*, 1944. Vol. 44, p. 810.