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Pozzolanic activity of various siliceous materials

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Abstract

The accelerated pozzolanic activity of various siliceous materials, like silica fume, fly ash (as received and fine ground), quartz, precipitated silica, metakaolin and rice husk ash (RHA; various fineness and carbon content), has been determined. The compressive strength of accelerated tests has been compared with cubes cured in water at 7 and 28 days. Maximum activity has been observed in case of RHA (<45 μ), followed by quartz and silica fume. The 10% replacement of cement by sand has shown accelerated pozzolanic index of 92% compared with 85% required in ASTM for silica fume as mineral admixture.

Keywords: Pozzolan; Cement; Fineness; Compressive strength; Particle size distribution

1. Introduction

The uses of various reactive pozzolanas as supplementary cementitious materials are fast growing in the development of more durable/high-performance concrete [1–10]. Slag, fly ash, silica fume, rice husk ash (RHA), metakaolin, etc., are being used as blended mineral admixtures in cement.

The pozzolanic activity, which is indicative of lime-pozzolana reaction, has been determined by various methods. In case of fly ash good correlation has been observed [11].

In the present paper, the accelerated pozzolanic index of silica fume, RHA with various fineness and carbon content, flyash (obtained from two sources, Dhanu and Dadri plant) as received and fine ground, fused quartz, metakaolin and precipitated silica has been determined as per ASTM [12]. The compressive strength of mortar cubes stored in water at 7 and 28 days has also been determined.

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2. Experimental

2.1. Materials

Ordinary Portland Cement 43 grade conforming to BIS 8112-1989 was used in the present study. The physical and chemical properties of the cement are given in Table 1.

The RHA was collected from paper mill using rice husk as fuel. The physical and chemical properties are given in Table 1.

Table 1
Physical and chemical analysis of RHA, silica fume and portland cement

Property	Portland cement (43 G)	Rice husk ash	Metakaolin
Insoluble residue	1.1	–	–
Magnesia	3.0	0.7	0.16
Alkalies	0.35	2.64	0.07
SO_3	2.10	–	–
Chloride	0.012	–	–
LOI	1.51	1.2	0.06
Specific surface (m^2/g)	2.91	22.0	14.0
Silica content	20.6	90.52	–
CaO	60.2	2.0	0.09
Specific gravity	3.14	2.04	2.6
$SiO_2+Al_2O_3+Fe_2O_3$	–	–	97.0

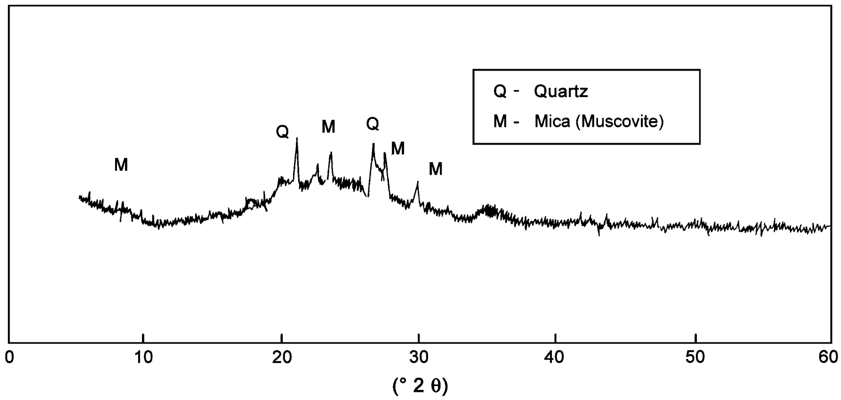

Fig. 1. XRD pattern of metakaolin.

A commercial metakaolin was used in the present work. Its chemical composition is given in Table 1, and the XRD pattern is shown in Fig. 1.

Two Class F fly ashes were collected from two different power stations, and their physical and chemical properties are given in Table 2.

The physical and chemical properties of silica fume and precipitated silica used in the present study are also given in Table 2.

2.2. Methods

2.2.1. Accelerated pozzolanic activity index with Portland cement

2.2.1.1. Control mixture. The control mixture was prepared with 250 g of 43 grade cement with 687.5 g of graded sand and 121 ml of water.

2.2.1.2. Test mixture. The test mixture was prepared with 225 g of cement and 25 g of pozzolana and requisite quantity of water required for flow of 110% to 115%.

Table 2
Physical properties and chemical analysis of fly ash, precipitated silica and silica fume

Physical tests	Silica fume	Precipitated silica	Fly ash Dadri	Fly ash Dhanu
Specific gravity	2.20	0.27	2.25	2.39
SiO_2	90.5	98	60.27	62.54
Al_2O_3	0.9	0.03	25.46	31.05
Fe_2O_3	0.1	–	6.02	1.65
MgO	2.0	1.0	0.29	0.43
Na_2O	0.5	0.8	–	–
CaO	0.4	–	3.68	3.97
SO_3	–	–	0.12	0.09
Surface area (m^2/g)	19.0	190.0	3.98	5.0
LOI	2.5	5.0	1.10	0.39

2.2.2. Mixing procedure

The mortar mixes were prepared using ELE (UK) Automatic Mortar Mixer. Fifty-millimeter cubes were cast for the present study.

2.2.3. Storage of specimens

After 24 h of initial curing in a moist room (23±2 °C) with relative humidity of not less than 95%, the cubes were placed in airtight glass containers and stored at 65±2 °C for 6 days.

2.2.4. Determination of compressive strength

The compressive strength of the mortar cubes after 7 days of demolding of control and test mixture was determined, and the average of the three samples is reported.

2.2.5. Particle size analysis

The particle size analysis of various pozzolanic materials was determined using 3600 Laser particle size analyzer manufactured by M/s Malvern, UK. Distribution graphs obtained are shown in Figs. 2–6.

3. Results and discussion

The evaluation of pozzolanic activity of various pozzolanas has been determined by several methods depending

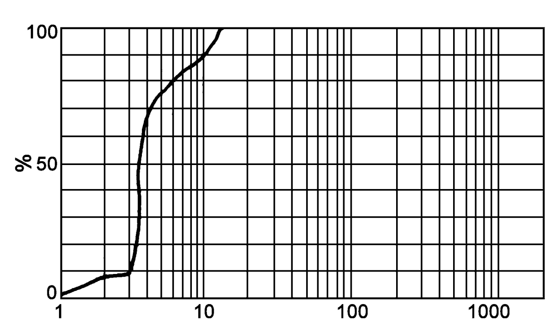

Fig. 2. Particle size analysis of Dhanu fly ash.

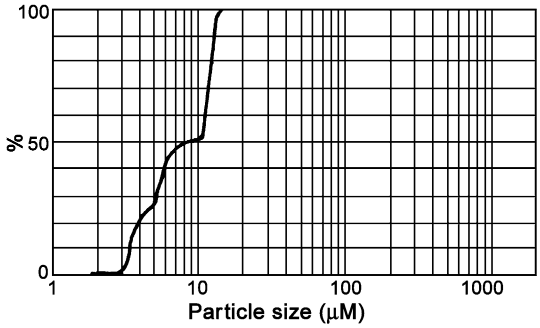

Fig. 3. Particle size analysis of Dadri fly ash.

upon physical, chemical and mechanical. In the present study, the pozzolanic activity of various pozzolanic materials has been determined based on compressive strength.

Table 3 gives the pozzolanic activity of various materials. The pozzolanic activity of the control mix has been found to 310 kg/cm^2. In case of fly ash as received from the thermal power station (collected dry from ESP), there is 10% increase in the case of Dhanu fly ash and 23% in the case of Dadri fly ash. When fly ash was ground, the activity index was found to be 16% and 26% higher compared with the control. The particle size distribution of both fly ashes is shown in Figs. 2 and 3. The fineness of fly ash is one of the most important properties affecting pozzolanic activity. Watt and Thorne [12–14] have suggested that fly ash with larger median particle size are more reactive than expected from the model. This was related to the spongy form of larger particles. The microscopic observation confirmed that the larger particle becomes perforated during reaction with lime. The higher activity found in case of Dadri fly ash can be attributed to the fact that the standard mean diameter (SMD) in case of Dadri fly ash is 6.2 μm compared with the 3.4 μm of Dhanu fly ash. The pozzolanic activity of silica fume has been found to be 23% more compare with that of the control and similar to Dadri fly ash. Normally, the activity of silica fume is more compared with fly ash. The less activity can be due to more water–binder ratio. It is 10% more in the present case. The particle size distribution of silica fume is shown in Fig. 5.

The high pozzolanic activity, 39% higher compared with that of the control, has been found in case of fused quartz (produced by volatilizing the silica at temperatures exceeding 2000 °C) when fine ground having similar particle size distribution, as shown in Fig. 6.

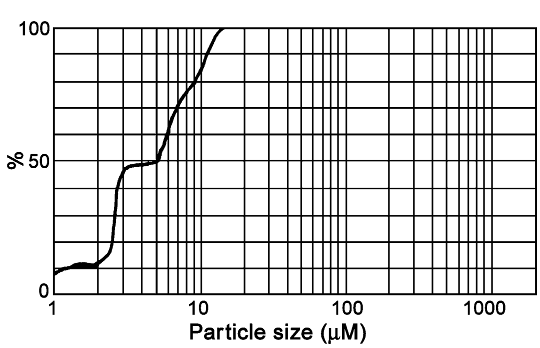

Fig. 4. Particle size analysis of RHA.

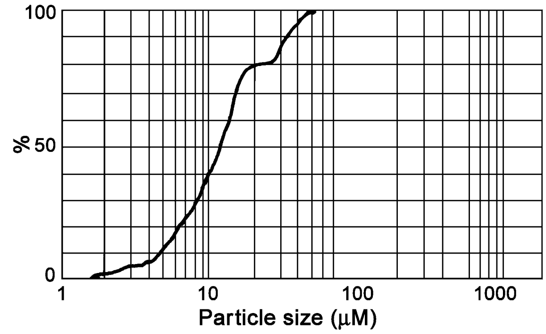

Fig. 5. Particle size analysis of silica fume.

Metakaolin, a calcined clay, shows 10% more accelerated pozzolanic activity when compared with the control.

In case of precipitated silica, the accelerated activity has been found to be 97% of the control. This lower value when compared with silica fume could be due to very high demand of water content for same flow (65% more than the control and 55% compared with silica fume at same percent of replacement). The high demand in content is due to the large surface area of the precipitated silica (about 10 times more than silica fume). However, when a superplastisizer was used, the water demand reduced to 30% from 65%. The effect on activity is immediately found (29% more than control). With further reduction in water content, enhanced activity can be obtained using ppt. silica.

RHA with variable fineness fractions and carbon content has been chosen for the pozzolanic activity. The RHA as received from the plant has shown 16% lesser activity, while the remaining fractions 150 μ passing (retaining 75 μ), 45 μ retaining and 45 μ passing have shown 10%, 35% and 48% gain in activity over the control. The RHA with 100% passing 45 μ has shown maximum accelerated activity compared with the pozzolanas reported in the present study. The RHA is known to be a highly pozzolanic material because of its microporous nature with high surface area [15]. The RHA with 13% and 20% carbon content has shown 26% and 23% higher activity, respectively. In case of fly ash, it has been observed that

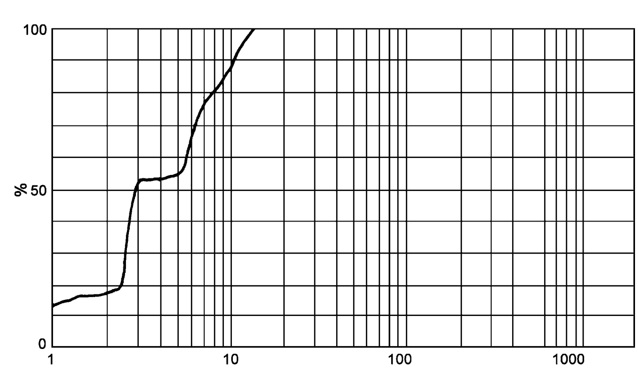

Fig. 6. Particle size analysis of ground quartz.

Table 3
Accelerated pozzolanic index of various siliceous materials as per ASTM 1240-98 and at room temperature (RT)

System	Accelerated Pozzolanic index [kg/cm^2]	% Of control	7 Day (RT) [kg/cm^2]	28 Day (RT) [kg/cm^2]
43 G OPC	310	100	250	360
OPC+10% sand	285	92	200	320
Dhanu fly ash	340	110	220	350
Dhanu fly ash (Fine ground)	360	116	240	380
Dadri fly ash	380	123	250	340
Dadri fly ash (fine ground)	390	126	250	–
Silica fume	380	123	240	400
Fused quartz (<45 μ)	430	139	290	435
Metakaolin	340	110	250	400
RHA (1.2% LOI)				
As received	260	84	140	260
150 μ passing retaining 75 μ	340	110	180	340
45 μ retaining	420	135	240	390
<45 μ	460	148	240	415
RHA (13%) <75 μ	390	126	260	400
RHA (20%) <45 μ	380	123	260	410
Precipitated silica	300	–	240	–
With superplasticizer	400	–	320	–

carbon content does not significantly influence the pozzolanic activity index in terms of compressive strength ratio [16,17]. A similar observation is observed in case of RHA. The particle size analysis and X-ray are shown in Figs. 4 and 7. The X-ray of RHA shows a peak of cristobalite and tridymite. It has been reported [15] that the activity of RHA is reduced. In the present case, we have found increase in activity from 10% to 48%. It is possible that a fraction of RHA present is showing the peaks of cristobalite and tridymite, which, on grinding, has no significant effect on the activity.

In a comparison of accelerated pozzolanic index with 28-day strength of cubes stored in water, there is good correlation between the results. A similar observation has been observed by Watt and Thorne [11] for fly ashes tested as per ASTM311 and CSA A 23.5.

Furthermore, a mix containing 10% of fine sand has given a pozzolanic activity of 92% compared with the control. The ASTM 1240-1998 suggests a pozzolanic activity of 85% when 10% pozzolana is added. Thus, the addition of 10% inert filler passes the activity criteria, which indicates that any inert material may pass this criteria. However, the minimum activity criteria should have been equal to the control because the purpose of adding pozzolana is to get better activity.

4. Conclusions

(1) The RHA collected from paper plant after grinding (<45 μ) has shown accelerated activity better than silica fume did.
(2) Deleterious effect due to high carbon content in RHA on activity has not been found in the present study.
(3) Fine ground fly ash has given pozzolanic activity equivalent to silica fume.
(4) Fused quartz has given better activity when compared with silica fume.
(5) The physical requirement of 85% activity of control with the addition of 10% pozzolana should be more.

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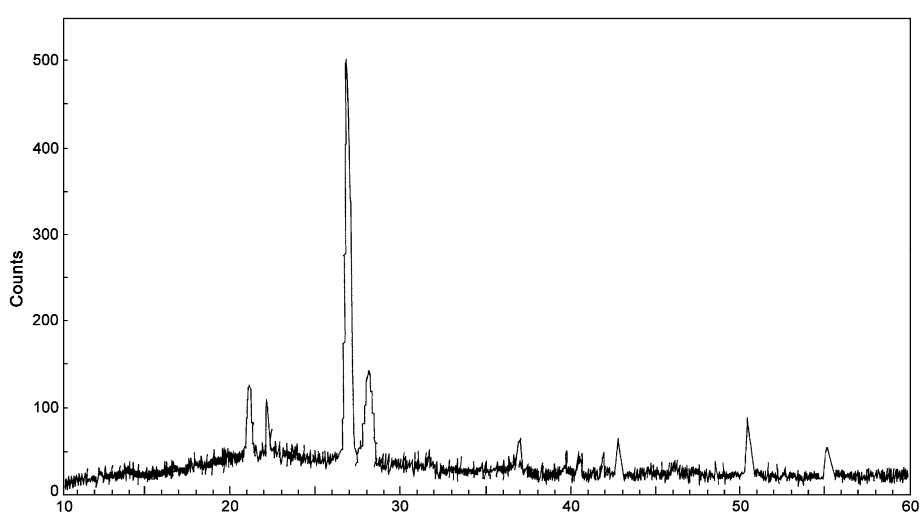

Fig. 7. XRD pattern of RHA.

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