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Investigations into the effect of addition of flyash and burnt clay pozzolana on certain engineering properties of cement composites

S.K. Malhotra *, N.G. Dave

Central Building Research Institute, A Constituent Establishment of CSIR, Roorkee 247 667, India

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Abstract

In cementitious binders when used for masonry mortars the requirements for properties of importance during early and later ages are different. Whereas during the early periods the attributes required are water retention, workability, plasticity, adhesion, etc. to allow the mortar to possess good working properties such as the ease of spreading, proper filling of joints and also to provide a water resistant crack free smooth surface, but at later ages strength becomes the main criterion to sustain the imposed load of the structure. Portland cement based mortars though harden rapidly and attain high strength but possesses a relatively poor early age properties. In composite mortars there is a common practice to incorporate lime along with portland cement, whose presence improves upon the early age rehological properties. Once the setting and hardening take place and the role of these early age properties is completed, lime has little role to play, as it harden through the lethargic process of carbonation i.e. by the chemical action of lime with atmospheric carbon dioxide forming insoluble carbonate. The process of carbonation is very slow and takes place from surface inwards. Modified composite mortars have been developed by the replacement of certain part of lime with pozzolana such as burnt clay or flyash and has been found to be of advantage. Laboratory investigations on a series of such mixtures have revealed the possession of good early age properties and at the same time better strength at later ages. Some of the results are reported in this paper.

Keywords: Cement; Lime; Pozzolana; Flyash; Burnt-clay; Composite; Compressive strength; Workability; Water retention; Bond strength

1. Introduction

There are several demands from any cementitious binder [1,2] used for mortars. At the time of application it has to remain in plastic and pliable state so that a good bond can be established between the building units and the mixture of cementitious material, inert material (e.g. sand) and water. The mortar is desired to have good water retention against the forces of suction exerted by the porous building units and maintain moisture in the mortar for the chemical reactions to continue. The mortar also has to possess good workability to allow better spreadability for proper filling of joints. Such a type of mortars results in a more water tight and crack free smooth surface.

Once the chemical reactions have advanced to a sufficient level, setting and hardening takes place. The mass gradually becomes more and more cohesive and stony texture is finally obtained [3]. The early age properties of the hydraulic material now become irrelevant and finally compressive strength becomes the main criterion to with stand the imposed load of the structure.

2. Types of mortars

In building construction a variety of mortars [4] prepared from different binders have been used for plastering and joining purposes. Some of the most commonly used mortars are as follows.

2.1. Lime mortars

Lime has been the principle binder throughout the world since ancient times. Lime based mortars [5] are known to possess high water retention, plasticity, good workability and capability of autogenous healing properties. On the other hand these mortars harden mainly by carbonation i.e. the chemical action of

* Corresponding author. Tel.: +91-01332-72235; fax: +91-01332-72272.

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atmospheric carbon dioxide with lime forming calcium carbonate. The carbonation process is very slow and takes place from the surface inwards [6].

2.2. Cement mortars

Portland cement, which has been available for over a hundred years, has largely replaced lime. Cement based mortars though harden rapidly attain high early strength which leads to high shrinkage cracks in the plaster surface resulting penetration of rain water.

Both the above type of mortars have been found to suffer from certain serious deficiencies in performance either at early ages or at later ages.

2.3. Composite mortars

Composite or gauged mortars [7] contain both portland cement and lime in varying proportion. These mortars have the properties of both lime as well as of portland cement. In these types of mixtures, cement provides early strength, consistency of hardening rate, while the presence of lime improves water retention, plasticity and workability.

On the other hand, certain other properties are absent during the period when the above-mentioned changes are taking place. Their role becomes significant after a certain length of time extending from a few hours to several weeks and probably months and years. Among these, compressive and flexural strengths are the most prominent. Cement–lime [8] composites have over the years produced highly satisfactory results, and it is possible to predict their performance. Composite mixtures exhibit the beneficial counter-balancing properties of both of these materials. More importantly, it is possible to mix them in different proportions such that the properties required by any particular situation are easily obtained. Another trait of these mixes is that some properties perform their role during the process of setting and hardening which are completed in a short period. Once these processes are over, these properties have hardly any role to play.

3. Development of modified composite mortars

The objective of the study is to improve upon the overall properties of the composite mortars. Because in composite mortars the presence of lime improves only the early age properties such as workability, bond strength and plasticity, but its contribution towards strength development is almost negligible. To have the fullest advantage of lime present in the composite mortars, it is suggested to develop modified composite mortars by replacing certain portion of lime with some pozzolanic material such as burnt clay, flyash, etc. Thus, the presence of lime besides contributing towards early age properties may also improve the final strength of the mortar due to the chemical reaction of pozzolanic material with lime and calcium hydroxide released during the process of cement hydration.

4. Materials

4.1. Cement

Two commercial samples of ordinary portland cements were taken for the study. The physical properties of the cement samples were evaluated as per the methods described in the Indian Standard IS:4031-1988 [9]. The properties of the cement samples are reported in Table 1.

4.2. Lime

The lime used should conform the requirements of class 'C' as per Indian Standards IS:712-1984 (Hydrated lime) [10]. The properties of lime are given in Table 2.

4.3. Pozzolanic materials

Pozzolanas have been defined as substances which are not themselves cementitious, but form hydraulic compounds when mixed with lime in presence of water. The reactivity of the pozzolanas depend upon the factors like

Table 1
Properties of cement samples

No.	Property	Sample I	Sample II
1	Fineness (cm^2/g) (Blaine)	3050	3200
2	Setting time (Min)		
	Initial	70	85
	Final	385	410
3	Compressive strength (kg/cm^2) (Mortar)		
	3 day	165	195
	7 day	220	275
	28 day	300	395
4	Soundness (mm)	1.0	1.5

Table 2
Properties of lime sample

Loss on ignition (%)	0.60
SiO_2 (%)	3.80
$Al_2O_3 + Fe_2O_3$ (%)	2.72
CaO (%)	92.01
MgO (%)	0.82
Available lime (%)	85.2
Bulk density (kg/m^3)	680
Specific gravity	2.28

available form of silica and alumina to form hydraulic products with lime as well as on the specific surface of the material to create new surfaces for rapid reaction. The Indian flyashes generally possess moderate pozzolanic activity while the reactive burnt clay pozzolanas can be prepared by calcining suitable soils at optimum temperatures. Meilenz and coworkers [11] studied the effect of temperature of calcination on the pozzolanic activity of various clay minerals. During the calcination of clays there exists a definite relationship between the structural collapse of the lattice and its pozzolanic activity.

5. Method of determination of pozzolanic activity

To evaluate the pozzolanic activity of a pozzolanic material, an accelerated test known as 'lime reactivity test' has been carried out [12]. Stipulated proportions of hydrated lime, pozzolana and sand were mixed and water was added to give a flow of 70 ± 5% determined as per method described in Indian Standard [13]. The mortar was filled in 50 mm size cube moulds and kept covered with greased glass plates for 48 h. After demoulding, the cubes were cured at 50 ± 2°C temperature at 90–100% relative humidity for eight days. At the end of this period, the cubes were tested for compressive strength. Thus, the activity of a pozzolana is represented by its compressive strength. Three commercially available pozzolanic materials were taken for the study.

5.1. Flyash

Flyash is a fine powder obtained as a waste at the thermal power plants after combustion of pulverised coal in boilers and is collected by mechanical collectors or by electro-static precipitators. One commercial sample of fly ash was collected. The properties of the flyash were evaluated as per methods described in Indian Standard IS:3812-1987 [14].

5.2. Reactive burnt clay pozzolana

Reactive burnt clay pozzolana [15] is obtained by calcining a particular type of soil at optimum temperature and then grinding it to a fine powder. The properties of the burnt clay pozzolana should conform to the specifications laid in Indian Standard IS:1344-1984 [16].

5.3. Ordinary burnt clay pozzolana

Ordinary burnt clay pozzolana is obtained by crushing the burnt clay brick bats. This material is used in building construction as a locally available material known as 'Surkhi' [17] and mostly it has a low lime reactivity.

The properties of flyash (F), reactive burnt clay pozzolana (B) and ordinary burnt clay pozzolana (S) are reported in Table 3.

6. Preparation of modified composite mortars

Various cementitious binders and pozzolanic materials have been proposed in the Indian Standards [4] for making masonry mortars.

Out of these, one cement based mortar designated as 'C' and three most commonly used conventional composite mortars designated as N, O and K (Table 4) were selected for these studies.

The composition of the composite mortars was modified by the replacement of certain part of lime with pozzolanic material. The composition of modified composite mortars is tabulated in Table 5.

6.1. Methods of testing

Experiments were, therefore, devised for carrying out necessary tests on conventional as well as on modified composites. Some of the tests performed on various mixtures are as follows.

Table 3
Properties of burnt clay and flyash samples

No.		Reactive clay pozzolana (B)	Ordinary clay pozzolana (S)	Flyash (F)
1	LOI (%)	2.9	0.3	3.4
2	SiO_2 (%)	58.7	74.5	64.4
3	$Al_2O_3 + Fe_2O_3$ (%)	31.7	20.4	23.0
4	CaO (%)	3.9	3.57	6.5
5	MgO (%)	1.16	0.71	0.2
6	Lime reactivity (kg/cm^2)	72	22.5	42.0
7	Bulk density (kg/m^3)	640	1060	840
8	Specific gravity	2.41	2.48	2.27
9	Fineness (Blaine) (cm^2/gm)	3300	–	3150

Table 4
Composition of conventional cement and composite mortars

Mortar designation	Cement	Lime	Sand
C	1	–	6
N	1	1	6
O	1	2	9
K	1	3	12

6.2. Bond strength

The ability of mortar to have a good bond and adhesion with the brick is determined by its bond strength and is measured by the force necessary to separate out the masonry unit from the mortar. According to ASTM C-62-69 ‘specification for building bricks’ having initial rate of absorption not exceeding 20 g per minute per 30 sq inch should be well wetted prior to laying. It is also a common practice to wet the bricks before applying the mortar to them. The bond strength of the mortar was determined as per method suggested by Chopra et al. [18]. Two pieces of half bricks (burnt clay) were saturated with water by soaking for 5 min. A saturated half brick was taken and a half inch thick layer of the stipulated mortar prepared at 110 ± 5% flow was applied. Another saturated half brick was placed over this and 8.0 kg weight was applied for 2 min. The samples were cured for 28 days at 95% relative humidity. Bond strength was determined by the pull out force applied and was determined by the force in kg required to separate out the bricks. The results are reported in Fig. 1(a) and (b).

6.3. Water retention

Water retention is the ability of the mortar to retain the water present in it against suction exerted by the porous building units. It was determined as per standard method [19]. Prepare the mortar and adjust a flow of 110 ± 5% with the help of a flow table [13]. The water retentivity is measured with the apparatus consisting of a perforated dish fixed on the funnel attached to a vacuum assembly [20]. Now fill the mortar in the perforated dish fixed with a wetted Whatman filter paper no. 50 in the bottom, flush off the excess mortar to a plane surface with a straight edge steel spatula. Now adjust the mercury column to maintain a vacuum of 50 mm as measured on the manometer. Turn the stop cock to apply the vacuum to the mortar. After suction for 60 s, close the stop cock and immediately slide out the dish from the funnel. Remove the droplets of water from the bottom with a damp cloth. Now take out the mortar from the dish and determine the flow. Calculate the percent water retention from the readings of flow

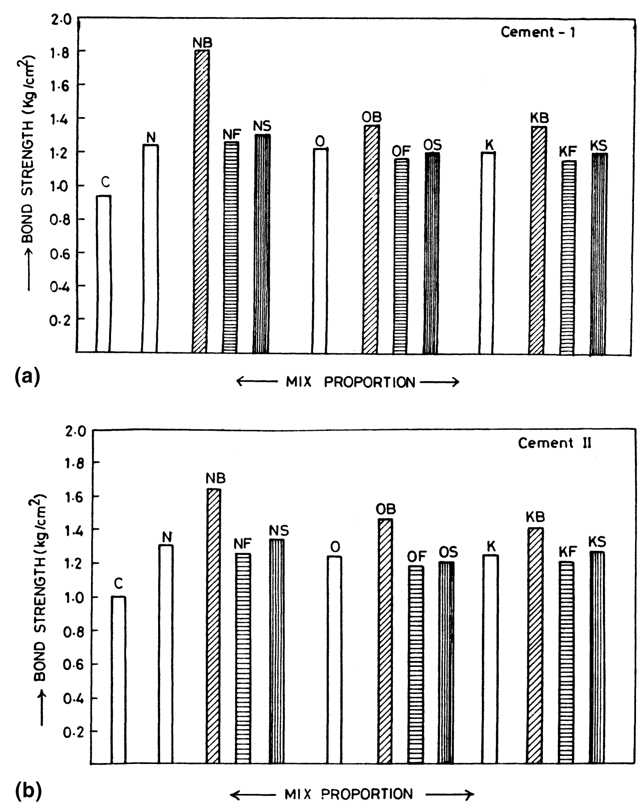

Fig. 1. (a) and (b): Bond strength of mixes.

Table 5
Composition of modified composite mortars

Mortar designation	Cement	Lime	Pozzolana			Sand
			B	S	F	
NB	1	0.5	0.5	–	–	6
NS	1	0.5	–	0.5	–	6
NF	1	0.5	–	–	0.5	6
OB	1	1	1	–	–	9
OS	1	1	–	1	–	9
OF	1	1	–	–	1	9
KB	1	1.5	1.5	–	–	12
KS	1	1.5	–	1.5	–	12
KF	1	1.5	–	–	1.5	12

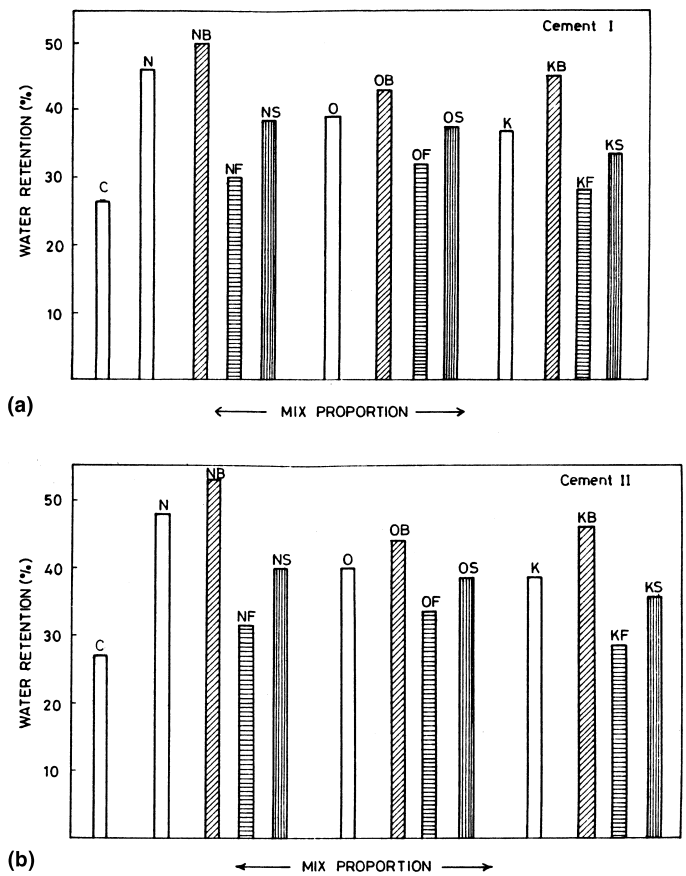

Fig. 2. (a) and (b): Water retention of mixes.

before and after the suction. The results are given in Fig. 2(a) and (b).

6.4. Compressive strength

The compressive strength [21] of the various compositions was determined on 5.0 cm cubes at 110 ± 5% flow [13] as per standard method. The cubes were cured at 27 ± 2°C temperature and 95% relative humidity for 7 days and then in water for upto one year. The results are shown in Fig. 3(a) and (b), Fig. 4(a) and (b), and Fig. 5(a) and (b).

For each property, a set of six specimens were tested and the average of the results were finally taken.

7. Results and discussion

A perusal of the results shows that the trends are very clear. The addition of lime to cement sand mixtures results in an overall improvement in almost all properties; these are manifested in the increase in bond strength as well as water retention and enhancement of compressive strength. This is observed not only in 'N' type but also in 'O' and 'K' types of composite mortars.

The replacement of lime with pozzolanic material affects the results in a curious way. In modified composite mortars (NB, OB, and KB) prepared with reactive clay pozzolana (B), the values of water retention are substantially higher than the conventional composite mortars (N, O and K) as well as straight cement sand mortar (C) Fig. 2(a) and (b). But in mortars (NS, OS and KS) prepared with ordinary clay pozzolana (S) the performance is not very good because of the inferior quality of clay pozzolana. However, these values are better than the straight cement sand mortar (C). On the other hand, modified composite mortars with flyash (NF, OF and KF) show poor results, but even these are better than straight cement sand mortar (C) Fig. 2(a) and (b).

The bond strength values Fig. 1(a) and (b) are not much affected by these replacements. In modified compositions (NB, QB and KB) containing reactive clay pozzolana (B), the bond strength values are better than the conventional composite mortars (N, O and K) and straight cement sand mortar (C). But the modified composites with ordinary clay pozzolana (S) and fly ash

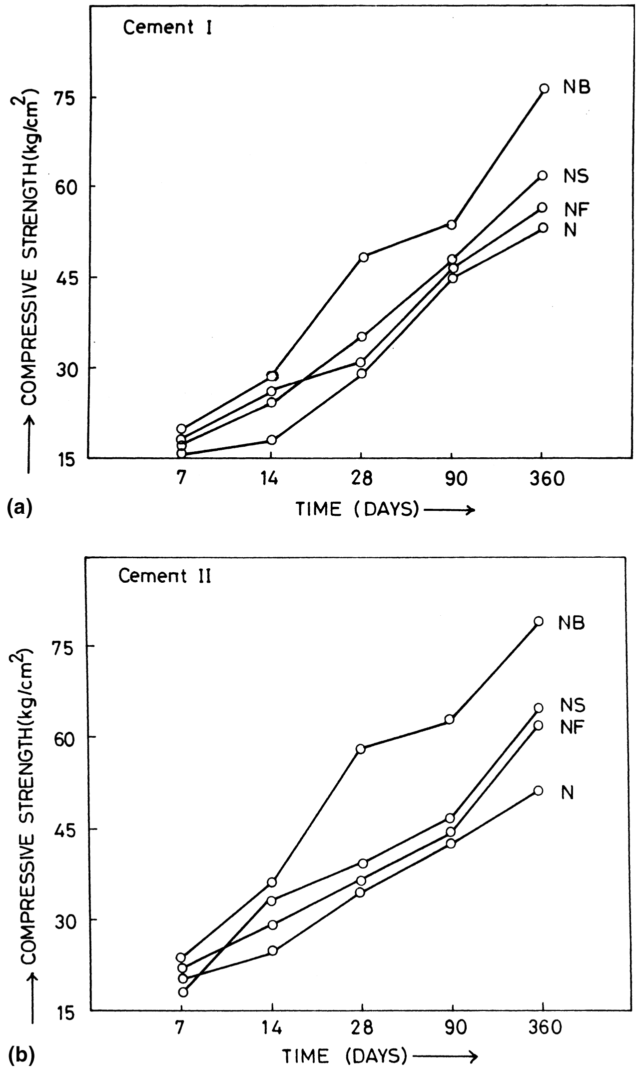

Fig. 3. (a) and (b): Compressive strength of mixes.

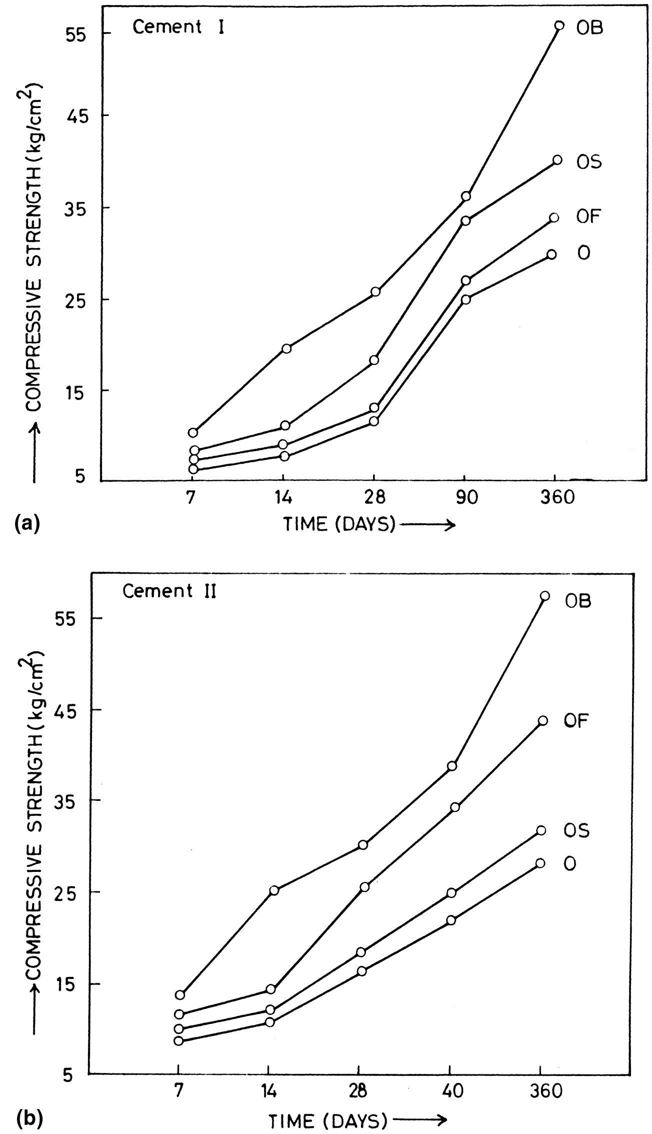

Fig. 4. (a) and (b): Compressive strength of mixes.

(F) maintain almost as high bond strength as the conventional composite mortars (N, O and K).

It is in the results of compressive strength that real advantage is obtained. Higher strengths are achieved in all the cases of modified composite mortars Fig. 3(a) and (b), Fig. 4(a) and (b), and Fig. 5(a) and (b). Even in the seven day strengths, the modified composite mortars show significant increase and the one year strengths are almost double of those of the conventional composite mortars.

8. Conclusions

The investigations reveal that in conventional composite mortars, the replacement of certain portion of lime with suitable pozzolanic material may be advantageous and ultimately improves upon the overall properties of the mortars. The results also show that there exists a definite relationship between the reactivity of pozzolana and the increase in strength, i.e. higher the lime reactivity of the pozzolanic material, higher will be the strength. Thus, in modified composite mortars, the presence of lime on one hand results in the improvement of early age properties, and on the other contributes to the final strength due to the additional lime–pozzolana reactions. Simultaneously with the addition of pozzolanic materials the modified composite mortars are likely to be more economical in cost.

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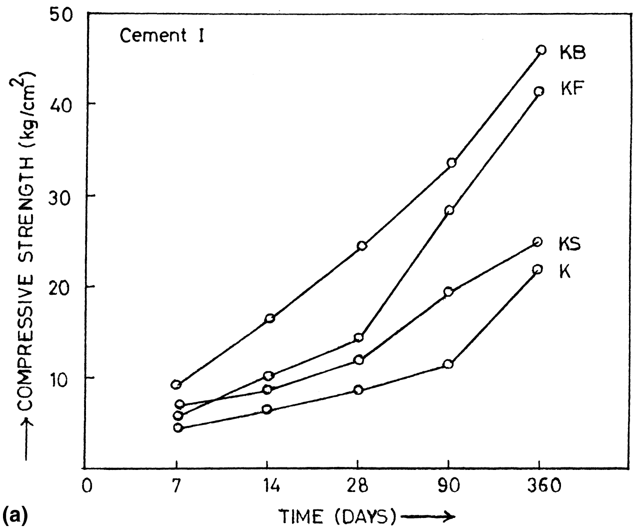
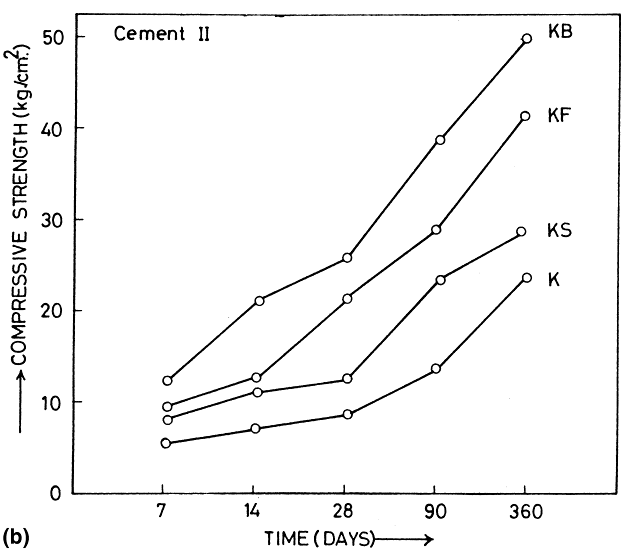


(a)



(b)

Fig. 5. (a) and (b): Compressive strength of mixes.

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References

[1] Beall C. Masonry design and detailing for architects, engineers and builders AIA. Englewood Cliffs (NJ): Prentice-Hall, 1984.

[2] Boyntan RS. Chemistry and technology of lime and limestone. New York: Interscience, 1960.

[3] Lea FM. Chemistry of cement and concrete. London: Edward Arnold, 1956.

[4] Code of practice for preparation and use of masonry mortars, IS:2250-1981. Bureau of Indian Standards, New Delhi.

[5] Mehrotra SP, Dave NG. Lime mortars. Civil Engineering Construction and Public Works Journal, 1973:1–5.

[6] Glasson DR. The reactivity of lime and related oxides IV. Journal of Applied Chemistry, 1960:42–48.

[7] Macedo N. Composite mortars and plasters. Seminar on Lime Manufacture and Uses, New Delhi, 1972.

[8] Voss Walter C. Lime characteristics and their effect on construction. Symposium on Lime. Philadelphia, ASTM: 1939:103–116.

[9] Methods of physical tests for hydraulic cement, IS:4031-1988. Bureau of Indian Standards, New Delhi.

[10] Building lime, IS:712-1984. Bureau of Indian Standards, New Delhi.

[11] Mielenz RC, et al. Symposium on the Use of Pozzolanic Materials in Mortars and Concrete, ASTM;99:1949.

[12] Method of test for pozzolanic materials, IS:1727-1990. Bureau of Indian Standards, New Delhi.

[13] Methods of tests for building limes – Determination of workability, IS:6932(Pt.8)-1991. Bureau of Indian Standards, New Delhi.

[14] Specification for flyash for use as pozzolana and admixture, IS:3812-1987. Bureau of Indian Standards, New Delhi.

[15] Bhatia ML. Manufacture of reactive surkhi and lime surkhi mixture at CRRI. Symposium on Pozzolanas – Their Survey, Manufacture and Utilization, New Delhi, 1964.

[16] Calcined clay pozzolana, IS:1344-1984. Bureau of Indian Standards, New Delhi.

[17] Srinivasan NR. Surkhi as a pozzolana, Road Research Paper No.1, Central Road Research Institute, New Delhi, 1956.

[18] Chopra SK, et al. Tensile bond strength of bricks and mortar. Indian Builder, 1960:55–58.

[19] Measurement of water retentivity of masonry cement, IS:4031 (Pt. 13)-1988. Bureau of Indian Standards, New Delhi.

[20] Specification for apparatus for measurement of water retentivity of masonry cement, IS:10550-1984. Bureau of Indian Standards, New Delhi.

[21] Methods of physical tests for hydraulic cement – Determination of compressive strength of masonry cement, IS:4031 (Pt.7)-1988. Bureau of Indian Standards, New Delhi.