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A New Hydraulic Binder from Waste Lime and Rice Husk : Part II—Typical Applications

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A hydraulic binder with properties comparable to those of natural cement of ASTM designation C-10-54 (1961) has been prepared by burning waste lime sludge with rice husk and grinding the resultant ash. The binder has been found to be suitable for use in making masonry mortar, plaster and concrete for foundations and sub-flooring, load bearing concrete blocks, pressed bricks with sand and soil stabilized bricks. The binder is composed primarily of lime and silica and possesses qualities like improved water retention, workability, water tightness, etc., associated with lime-based compositions. In addition, it has the quick setting characteristics unobtainable with ordinary lime-pozzolana mixtures. Since the binder can be prepared entirely from industrial and agricultural wastes without need for special skill or machinery, it can be produced on a small scale at a reasonably low cost.

A lime-based hydraulic binder developed from waste lime sludge (sugar press mud) and rice husk has been reported earlier[1]. The binder was found to possess hydraulic characteristics comparable to those of ordinary lime-pozzolana mixtures. Its setting characteristics and rate of development of strength were found to be comparable to those of natural cement conforming to ASTM designation C-10-54 (1961) and superior to those of hydraulic lime (class A lime of ISS 712 : 1973). On the basis of these characteristics, this binder was suggested as a substitute for hydraulic lime and portland cement in certain applications in building practice. In this paper, the details of the process for the production of the binder and some typical trials conducted on its use in building practice are given.

Production method

Crushed rice husk and lime sludge were mixed thoroughly in the ratio 1 : 1 (by wt). Sufficient quantity of water was added to the mix, so that it could be formed into balls. The balls were then air dried. The dry balls which had sufficient handling strength were placed in an open trench constructed by arranging fired clay bricks. The balls were put to fire at one end. The fire propagated horizontally without the need for any extra fuel. The height of the walls constituting the trench was 1 m. The width of the trench was also about 1 m. Since sufficient air is needed during the burning of the material, the bottom of the trench was so made as to allow air from below. The fired product obtained after complete burning is in the form of soft ash like that of fire wood. This ash was ground in a ball mill for 1 hr to achieve the desired fineness (~8000 cm²/g).

Typical applications

Masonry mortar and plaster

Mortars based on hydraulic lime and lime-pozzolana mixture possess advantages over those based on cement in being more plastic and cohesive and less harsh. These mortars are capable of taking up the shrinkage and temperature movements in the masonry more evenly[2]. The data presented in Table 1 show that the compressive strengths and water retention values of different binder compositions tested as per IS 4098 : 1967 (Specification for lime-pozzolana mixture) are comparable to those of lime-pozzolana mortars.

On account of the quick-setting nature of the binder, these mortars are suitable for use in plastering. For the above two applications binder-sand (1 : 2 vol./vol.) mixture has been found suitable. The binder-sand and cement-sand compositions are compared in Table 2 in terms of the development of early strength with fine sand (fineness modulus, 0.99). All the mixes were moulded at equal consistency. The cement used was ordinary portland cement conforming to the requirements of IS 269-1967.

Table 1 —Compressive strength and water retention values of binder-sand compositions

(a) Compressive strength

CURING PERIOD days	COMPRESSIVE STRENGTH, kg/cm²		
	BINDER-SAND (1 : 2) MIX	STANDARD REQUIREMENTS FOR LP 20	STANDARD REQUIREMENTS FOR LP 7
14	14.5	10	3
28	23.5	20	7

(b) Water retention

Binder-sand proportion (vol./vol.)	Water reteniton %
1 : 1.5	73
1 : 2	65
1 : 3	60

Table 2— Relative compressive strengths of cement-sand and binder-sand compositions

CURING PERIOD days	COMPRESSIVE STRENGTH, kg/cm²		
	CEMENT-SAND MIXTURE (1 : 6, vol./vol.)	BINDER-SAND MIXTURE 1 : 2 (vol./vol.)	BINDER-SAND MIXTURE 1 : 1.5 (vol./vol.)
7	11.5	11.0	13.5
28	24.0	23.0	29.0

The binder-sand plaster was found to stick over the burnt clay brick walls well and no failure like cracking or separation from the substrate was observed over a period of 1 year.

Concrete blocks

Ordinary concrete can be made from the binder with coarse sand aggregate in the same way as from portland cement. The concrete was found to set within 24 hr after casting and was, therefore, demoulded the next day. The compressive strengths of concrete blocks of 29×19×9 cm size prepared using this binder in different mix proportions are given in Table 3. The blocks were kept in water for curing one day after demoulding. Shrinkage and moisture movement values determined as per IS : 2185-1967 (Specifications for hollow cement concrete blocks) are also given in Table 3.

Pressed bricks

The binder has been tried for making pressed bricks with sand under pressure using semi-dry mix of sand and binder. The compressive strengths of briquettes of binder-sand (20 : 80 wt/wt) mix are given in Table 4. The grading of the sand used conforms to IS 2116 : 1959 (Specifications for sand for masonry mortars). Briquettes of size 100×50×20 mm were made under forming pressures of 150 and 300 kg/cm². Under similar conditions of casting and curing, full size bricks are expected to possess 65-75% of the compressive strength of the briquettes. Considering the minimum specified compressive strength of 150 kg/cm² for sand-lime bricks as per IS 4139 : 1967, the binder can be regarded suitable for making bricks of these types even without autoclaving.

Soil stabilization (stabilized soil bricks)

The binder was also tried as a stabilizer for soil. Full size bricks of two illitic soils were made on CBRI hand operated brick-making machine and tested for various stabilization characteristics. The physical characteristics of the soils used are given in Table 5. The wet compressive strengths and water absorption values of the bricks made using different quantities of the binder are given in Table 6.

Table 3— Characteristics of concrete blocks made using binder-sand-coarse aggregate mix

Binder-sand: coarse aggregate proportions (by vol.)	28 day compressive strength, kg/cm²		Drying shrinkage	Moisture movement %
	Compaction factor = 1	Compaction factor = 0.75		
1 : 1 : 2	85.0	101.8	0.02	0.01
1 : 1.5 : 3	50.1	69.5	0.02	0.02
1 : 2 : 4	19.4	31.2	—	—

Table 4— Performance of pressed bricks made from binder-sand mix

Forming pressure kg/cm²	Compressive strength, kg/cm²		
	Cured under water for 28 days	Steam cured for 72 hr	Autoclaved at 10 kg/cm² for 6 hr
150	127.8	144.0	204.0
300	214.0	243.7	328.5

Table 5— Physical characteristics of the soils

	Soil A	Soil B
Clay, %	20.5	8.35
Silt, %	31.0	13.95
Sand, %	48.5	77.70
Liquid limit	39.6	20.2
Plastic limit	28.3	15.5
Plasticity index	11.3	4.7

Table 6— Characteristics of stabilized bricks

Soil No.	Binder % (by wt)	Dry bulk density	Compressive strength (28 days) kg/cm²	Water absorption %
A	10	1.82	26.2	12.9
	15	1.80	37.5	13.0
B	10	1.87	29.0	12.2
	15	1.84	40.3	12.8

It is seen that bricks made from both the soils, including soil B, which is very sandy and is unsuitable for even moulding and making burnt bricks with 10% binder by weight, pass the compressive strength requirements (18 kg/cm²) as laid down in IS 1725 : 1960 (Specification for soil-cement blocks used in general building construction). Increase in the binder content up to 15% on the weight of soil yields bricks which have compressive strengths falling within the minimum range specified for burnt clay bricks[3] (35 kg/cm²).

Binder-sand mortar can be used in the construction of stabilized soil brick masonry as well as for plastering. This composition is superior to cement-sand mortar in this respect, as it not only matches the properties of the brick but also has the ability to react with the silica of the soil and consequently produce adhesive bond with it. Thus, the use of this material for the dual purpose of acting as a stabilizer for the soil brick and performing the function of jointing and plastering of masonry work is a promising possibility to minimize the differential movements in the composite mass and thus improve its efficiency and durability.

Field trials

The binder compositions have been used as masonry mortars for jointing and plastering purposes on burnt clay brick as well as lime stabilized soil brick walls. At the end of one and a half year, no cracking in or separation of the plaster from the substrate occurred. A wall of 3×3 m surface area made using soil bricks stabilized with 10% binder and the same soil as that in the bricks containing 15% by weight of binder as masonry mortar has so far shown no signs of erosion after the expiry of one rainy season.

Conclusions

(1) A cementitious binder has been prepared by calcining and grinding a mixture of waste lime and rice husk. These wastes are available in huge quantities as industrial and agricultural byproducts.

(2) The binder has some special features because of its typical chemical composition and mode of preparation. Having lime as one of the principal components, it possesses the qualities of lime-based compositions, viz. improved water retention, workability, water tightness, etc., coupled with quick-setting characteristics, unobtainable with ordinary lime-pozzolana mixtures.

(3) The binder can be used for making foundation concrete and concrete for sub-flooring and terracings in place of lime concrete, masonry mortars and plasters, soil stabilization, load bearing concrete blocks and pressed and stabilized bricks.

(4) The binder shows immense promise of use in low cost housing programmes. Since the metho d for its preparation does not involve special skill and machinery, it can be made in the cottage and small scale sectors and used as a partial substitute for cement.

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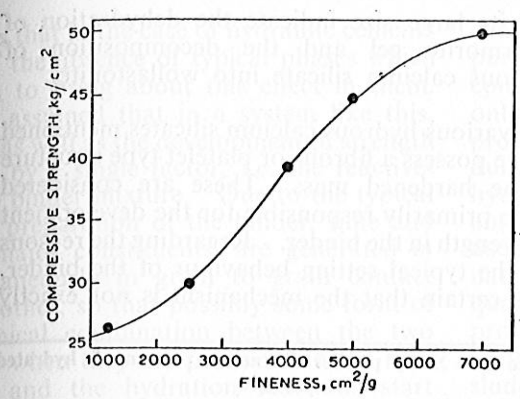

Fig. 1 — Relationship between the fineness and compressive strength of the binder

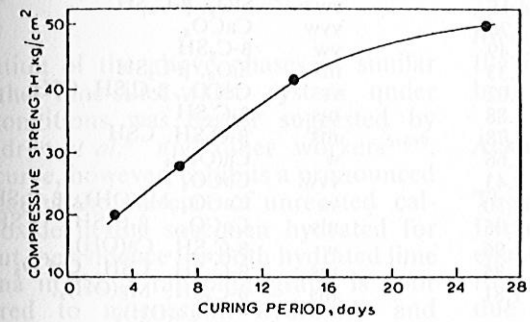

Fig. 2 — Trend of development of strength in the binder with time up to 28 days

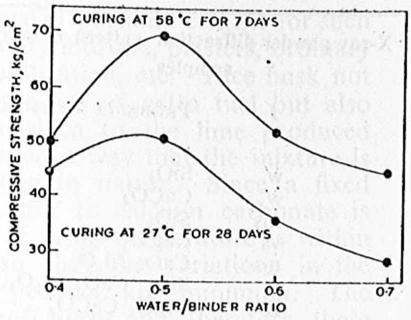

Fig. 3 — Relationship between the compressive strength and water-binder ratio

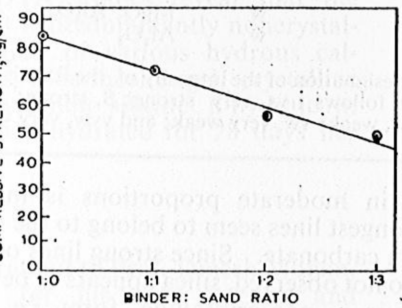

Fig. 4 — Compressive strength vs binder-sand ratio

typical compressive strength of the binder in relation to its fineness and water content is evident from Figs. 1-3. In this respect it is comparable to hydraulic cements. These results show that the maximum benefit in this respect could be derived when the fineness of the material is above 7000 cm^2/g and the water/binder ratio around 0.5.

Since the product has been fired at the temperature commonly used for the burning of lime, i.e. 900–950°C, there appears to be no danger of the product becoming unsound on hydration, i.e. the temperature is low enough to cause over-burning of calcium carbonate or formation of periclase. The bulk density of the product is, therefore, low compared to cement and the ash obtained on firing can be easily ground to the desired fineness in less than 1 hr in a ball mill. Grinding effort which causes in cement clinker a specific surface area of 3000 cm^2/g in 6 hr has been found to produce a fineness of about 9000 cm^2/g in the ash in just 1 hr.

Considering the product from the viewpoint of temperature of formation and the chemical make up, it belongs essentially to the system $CaO\text{-}SiO_2$ when unhydrated and to the system $CaO\text{-}SiO_2\text{-}H_2O$ after hydration. The proportions of the other constituents are too low to be of major significance, although their presence cannot be altogether ignored. Compared to the simple lime-silica-water system, which is characterized by slow setting and strength development at room temperature in the presence of water, this product is hydraulically much more active under similar conditions. Its short-term hydration behaviour is almost analogous to that of hydraulic cements.

To have an insight into its typical properties, a preliminary examination of the binder limited to the unhydrated specimen was carried out by X-ray and differential thermal analysis. X-ray diffraction analysis of the binder was done by exposing the specimen to CuKα radiation for 6 hr at 40 kV and 21 mA. The diffraction pattern obtained for the unhydrated specimen (Table 3) contains only a few lines, which shows that the material is deficient in crystalline compounds. While the presence of individual

Table 3 — X-ray powder diffraction pattern of unhydrated samples

d Å	I	Probable identification
4.16	w	SiO_2
3.81	w	$CaCO_3$
3.35	ms	SiO_2
3.00	vs	$CaCO_3$
2.82	ms	CaO, Al_2O_3
2.46	S	SiO_2, CaO, Al_2O_3, MgO
2.16	S	MgO, $CaCO_3$
2.01	ms	$CaCO_3$, Al_2O_3
1.89	vw	$CaCO_3$
1.83	w	$CaCO_3$, SiO_2
1.71	ms	CaO
1.51	w	MgO, Al_2O_3
1.40	w	Al_2O_3

The designation of the intensity of the lines is arbitrary and is as follows : vs, very strong; S, strong; ms, mild strong; w, weak; vw, very weak; and vvw, very very weak

oxides in moderate proportions is indicated, the strongest lines seem to belong to the residual calcium carbonate. Since strong lines of quartz are also not observed, silica appears to be present mainly in a non-crystalline form, i.e. amorphous state. Evidence of the presence of any of the major phases typical of hydraulic cements is also not convincingly forthcoming. Crystallographic pattern of the specimen of the binder hydrated for 28 days, however, presents interesting information (Table 4). Due to the presence of typical 3.0, 2.8 and 1.8 A lines, the formation of weakly crystalline tobermorites in gel form is indicated. Other lines also show the formation of C_2S-β-hydrate (Hillebrandite) along with $Mg(OH)_2$ and calcite. DTA curve for the same hydrated specimen is given in Fig. 5. Four prominent endothermic peaks corresponding to 100°, 420°, 500° and 820°C show respectively the loss of free water, dehydration of magnesium hydroxide, calcium hydroxide and decarbonation of calcium carbonate. A continuous bend in the curve between 100°C and 200°C is supposed to be due to the desorption of water from the tobermorite gel. A weak endothermic effect at 280°C in the form of a dent in the curve may principally be due to small amounts of crystalline tobermorite which, however, has not been observed in the X-ray pattern of the hydrated specimen. The thermal effect obtained around 560°C may represent the dehydration of dicalcium silicate β-hydrate observed from the X-ray study. An early bend around 600°C in the calcite decarbonation peak and its large size indicate the dehydration of tobermorite gel and the decomposition of hydrous calcium silicate into wollastonite.

The various hydrous calcium silicates mentioned above possess a fibrous or platelet type structure in the hardened mass. These are considered to be primarily responsible for the development of strength in the binder. Regarding the reasons for the typical setting behaviour of the binder, it is certain that the mechanism is not exactly

Table 4 — X-ray powder diffraction pattern of hydrated sample

d Å	I	Probable identification
4.70	ms	$Mg(OH)_2$, β-C_2SH
4.15	vw	SiO_2, β-C_2SH
3.78	vvw	$CaCO_3$
3.49	vw	β-C_2SH
3.33	ms	SiO_2, β-C_2SH
3.02	vs	$CaCO_3$, β-C_2SH, CSH
2.88	ms	β-C_2SH
2.78	ms	β-C_2SH, CSH
2.66	w	$Ca(OH)_2$
2.43	vvw	$CaCO_3$
2.30	vs	$CaCO_3$, $Mg(OH)_2$, β-C_2SH
2.05	ms	$CaCO_3$, β-C_2SH, CSH
1.96	w	β-C_2SH, $Ca(OH)_2$
1.85	ms	β-C_2SH, CSH, $CaCO_3$
1.81	ms	β-C_2SH, $Mg(OH)_2$, $Ca(OH)_2$
1.76	vw	β-C_2SH
1.56	ms	CSH, $Mg(OH)_2$, β-C_2SH
1.41	w	β-C_2SH, CSH
1.36	vw	$(MgOH)_2$
1.28	vw	$Mg(OH)_2$
1.22	vvw	CSH
1.17	vw	$Mg(OH)_2$, CSH
1.14	vvw	CSH
1.03	vvw	$Mg(OH)_2$

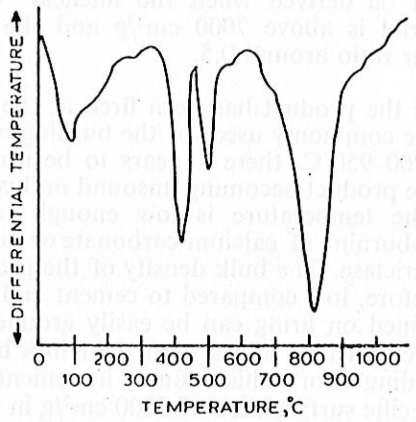

Fig. 5 — DTA curve for the specimen hydrated for 28 days

the same as that in the case of hydraulic cements because of the absence of typical phases which are known to bring about this effect in them. It may be assumed that in a system like this, the setting as well as the development of strength are caused by a single factor, i.e. the reactiveness of the binder mixture. Due to the typical method of preparation of the binder, lime and silica, its major constituents, are generated *in situ* simultaneously in grain to grain contact with each other, so that possibly some form of loose chemical combination between the two takes place when they are produced in the nascent state and the hydration reactions start readily on the addition of water. This typical state of combination could not, however, be detected by X-ray or differential thermal analysis.

The formation of the above phases or similar ones in the lime-silica-water system under different conditions was earlier suggested by Ramachandran *et al.*[8] and other workers[5,6,9]. The DTA curve, however, exhibits a pronounced peak, indicating the presence of unreacted calcium hydroxide in the specimen hydrated for 28 days, but the evidence for both hydrated lime and alumina in the X-ray photograph is poor as compared to magnesium hydroxide and calcium carbonate. The lime may, however, be present in the tobermorite gel in an amorphous form; alumina, on the other hand, may partially substitute the silica in the gel. Under these conditions, reaction of the lime may further continue to form the phases reported above, i.e. dicalcium silicate hydrate and tobermorite. Further studies on the hydration reactions in systems analogous to the above system containing rice husk silica are in progress.

Conclusion

Firing waste lime sludge with rice husk and grinding the ash obtained yields a lime-silica mixture which possesses quick setting and hardening properties. The lime silica binder thus obtained can be used in place of portland cement for such purposes as masonry mortars, plasters, ordinary concrete, soil stabilization, etc. Rice husk not only eliminates the use of extra fuel but also provides reactive silica to the lime produced during firing in such a way that the mixture is hydraulically active in nature. Since a fixed amount of rice husk to calcium carbonate is used, the range of firing temperature is within narrow limits, so that the variations in the quality of the product are minimum. The product is also soft burnt and, therefore, there is no danger of its being unsound even if lime sludge of a magnesian lime is used. X-ray diffraction and DTA studies reveal that the silica present in it is predominantly noncrystalline. The formation of various hydrous calcium silicates, e.g. tobermorite gel, crystalline tobermorite and calcium silicate β-hydrate in the binder specimen hydrated for 28 days has been detected.

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