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POZZOLANA CEMENTS[1]

by

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CHAPTER I. POZZOLANA CEMENTS AND THEIR PROPERTIES

A. Historical

1. Cementing Materials in Antiquity:

1. The earliest cements which could form a plastic paste on the addition of water, bind bricks, stones or stone pieces, and sand etc., and also resist the leaching and aggressive action of water were based either on gypsum or lime. Calcined gypsum was used as a cementitious material in Egypt where subsequently the Romans introduced the use of lime which, according to Lea,1/ appears to have been used still earlier by the Greeks. The durability of the ancient Roman buildings goes to prove that the Romans had developed and mastered the art of making very hard, strong and durable lime-sand mortars.

2. With the passage of time mortars, superior both in strength and durability, seem to have been developed and discovered either by observing the effects of certain additions or accidental use of certain reactive materials or aggregates. The latter seems more probable as both the Greeks and the Romans had hit upon certain volcanic deposits which, if finely ground and mixed with lime and sand, made the mortar stronger and more resistant to the action of fresh or salt water. A volcanic tuff from the island of Santorin (presently known as Santorin earth) was employed by the Greeks for this purpose and similarly a volcanic tuff from from the Bay of Naples was found by the Romans to make superior mortars. The latter seem to have been used in the construction of the several important ancient Roman buildings and structures which have survived to this day.2/ This type of material was called pozzolana after the place called Pozzuoli (Italy) whose neighbourhood was the source of the best variety of tuff. Later the term pozzolana was extended to cover the use of powdered tiles or pottery which the Romans used with success when the volcanic earth was not available.

1/ F.M. Lea, "The Chemistry of Cement and Concrete", Edward ARnold (Publishers) Ltd., London, 1956, p.2.

2/ The Chemistry of Portland Cement, R.H. Bogue, Reinhold Publishing Corporation, New York, 1955, pp. 3-4.

2. Forerunners of Portland Cement:

(a) Hydraulic Limes:

3. For many centuries the Roman mixture of lime and pozzolana continued to be the only suitable cement for civil works and hydraulic structures and in the course of time materials, such as the Rhenish volcanic tuff (trass), scales from a blacksmith's forge, ground brick (surkhi), crushed pot shreds, burnt iron stone etc., were added to the list of pozzolanas. The next important discovery was made by Smeaton about 1756 that limestones containing a considerable proportion of clayey matter yielded lime which resulted in mortars stronger than those produced from pure limestones.3/ However, this so-called hydraulic lime did not get much attention.

(b) Roman Cement:

4. This cement was discovered about 1800 and was obtained as a result of the calcination of nodules of argillaceous limestone (Septaria nodules) of tertiary strata found in some localities along the Kentish Coast.4/ This cement was quick-setting and was in great use till about 1850. In reality the Roman cement is a misnomer as it had no resemblance to the Roman mortar mentioned earlier except perhaps its colour. This type of cement was also produced in France at about the same time. Vicat had prepared an artificial hydraulic lime by calcining an intimate mixture of limestone (chalk) and clay and this process is considered a principal forerunner of the manufacture of portland cement.5/

(c) Natural Cements:

5. A contemporary discovery was the finding of "cement rock" at Rosendale and Louisville in the United States which on calcination yielded a hydraulic cement. The cement rock had composition similar to the artificial mix of limestone and argillaceous material which was used subsequently in the production of portland cement. The calcination temperatures employed were probably lower than the temperature at which sintering takes place. Nevertheless, the natural cement industry in America saw a phenomenal growth and natural cement was much in use even in the early days of portland cement. Though its use has declined in the present times, it merits the inclusion in the American Standards as one of the cements for use

3/ Smeaton, J., "Narrative of the Building of the Eddystone Lighthouse", London, 1791.

4/ (Reference 2), pp. 8-9

5/ (Reference 1), p. 7

(with portland cement) in general concrete constructions.6/ While noteworthy developments had also taken place in the natural cement industry on the Continent, presently its production has either ceased or is very small.

B. Portland Cement

6. Portland cement is a product obtained by intimately mixing together calcareous and argillaceous or other silica, alumina and iron oxide-bearing materials, burning them at a clinkering temperature and grinding the resulting clinker.7/ The history of the portland cement began with the invention of Joseph Aspidin, British Patent 5022, Dec. 18, 1824, and is described in the textbooks on the Chemistry of Cement.1,2/ Suffice to say here that the modern portland cements are a result of very painstaking researches and technological advances over the period of the last 50 years.

C. Pozzolanic Cements

1. Pozzolana:

7. Lea8/ defines pozzolanas as materials which, though not cementitious in themselves, contain constituents which will combine with lime at ordinary temperatures in the presence of water to form stable insoluble compounds possessing cementing properties. The definition given in the ASTM Standard on Portland-Pozzolan Cement, Designation C340-66T is as follows:

> "Pozzolan shall be a siliceous or siliceous aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."

The latter definition is a little more explicit about the nature and physical state of materials and spells out the conditions under which the reaction proceeds; otherwise, the two are the same in substance. The main point to be noted is that the emphasis is on the formation of cementitious compounds which is the end use of pozzolana and not on the extent of combination of lime with pozzolana.

6/ Standard Specification for Natural Cement, ASTM Designation: C-10-64, 1964 Handbook of ASTM Standards, 1964, part 10, American Society for Testing and Materials, Philadelphia, USA.

7/ (Reference 1), p.14.

8/ (Reference 1), p.358.

TABLE 1

Physical Requirements for Portland Cement

	Type I	Type II	Type III	Type IV	Type V
Fineness, specific surface, sq cm per g (alternate methods):					
Turbidimeter test:					
Average value, min.	1600	1600	-	1600	1600
Minimum value, any one sample	1500	1500	-	1500	1500
Air permeability test:					
Average value, min.	2800	2800	-	2800	2800
Minimum value, any one sample	2600	2600	-	2600	2600
Soundness:					
Autoclave expansion, max., per cent	0.50	0.50	0.50	0.50	0.50
Time of setting (alternate methods):					
Gillmore test:					
Initial set, min., not less than	60	60	60	60	60
Final set, hr., not more than	10	10	10	10	10
Vicat test (Method C 191):					
Set, min., not less than	45	45	45	45	45
Air content of mortar, prepared and tested in accordance with Method C 185, max., per cent by volume, less than	12.0	12.0	12.0	12.0	12.0

Table 1 (continued)

Table 1 (continued)

	Type I	Type II	Type III	Type IV	Type V
Compressive strength, psi:					
The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with Method C109, shall be equal to or higher than the values specified for the ages indicated below:					
1 day in moist air	-	-	1700	-	-
1 day in moist air, 2 days in water	1200	1000	3000	-	-
1 day in moist air, 6 days in water	2100	1800	-	800	1500
1 day in moist air, 27 days in water	3500	3500	-	2000	3000
Tensile strength, psi:					
The tensile strength of mortar briquettes composed of 1 part cement and 3 parts standard sand, by weight, prepared and tested in accordance with Method C190, shall be equal to or higher than the values specified for the ages indicated below:					
1 day in moist air	-	-	275	-	-
1 day in moist air, 2 days in water	150	125	375	-	-
1 day in moist air, 6 days in water	275	250	-	175	250
1 day in moist air, 27 days in water	350	325	-	300	325

Standard Specification for Portland Cement, ASTM Designation C 150-64

Source: 1964 Book of ASTM Standards Part 10, American Society for Testing Materials, 1916 Race St., Philadelphia 3, pa.

2. Lime-Pozzolana Cements:

8. Earlier a mention was made of the use of lime-pozzolana mortars since very early times and their excellent service record. Some pozzolanas of high reputations are still being used in combination with lime in many European countries. The important examples being the Italian pozzolanas of volcanic origin, the Rhenish trass, the Bavarian trass, the Rumanian trass and the Santorin Earth etc. Lime-fly ash mixes, though of recent origin, are also in use in some countries.* The lime-pozzolana mixes contain mostly hydrated lime; hydraulic lime is also used sometimes.

9. As against lime-pozzolana mortars of older days, the present day lime-pozzolana mixes may contain small quantities of an additional constituent such as portland cement or gypsum or chemicals in small quantities to accelerate early hardening. Also, the modern lime-pozzolana mixes are being produced in many countries as factory finished product and their production is backed by scientific research instead of traditions. In view of this and to facilitate discussions, the use of the term of pozzolanic cements has been extended to cover the lime-pozzolana mixes. This is considered justified because the latter are also hydraulic in nature and form hydration products of the type obtained on the hydration of portland-pozzolan cement.

3. Portland-Pozzolana Cements:

10. Portland-pozzolan cement is the product obtained by intimately intergrinding a mixture of portland cement clinker and pozzolana, or by blending portland cement with fine pozzolana intimately and uniformly. The amount of pozzolan used is such that the pozzolana constituent makes up between 15 and 40 per cent by weight of portland-pozzolana cement.[9/] This type of cement was first used in Europe. The Italian pozzolana cement, the Trass cement of Germany and the Gaise cement of France are typical examples. Such cements are also in use in Sweden, Rumania, U.S.S.R. and other countries. In fact, some countries produce more than one grade of portland pozzolana cement.

11. A portland pozzolana cement was used in America in the construction of the Los Angeles aqueduct around 1910.[10/] Since 1930 this cement has been used in America

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* Corson & Co., and Pozzolana Products Co., U.S.A., U.S.S.R. & India.

9/ ASTM Designation: C 340-66T on Tentative Specification for Portland-Pozzolan Cement, Book of ASTM Standards, 1964, Part 10, American Society for Testing and Materials, Philadelphia, U.S.A.

10/ R.E. Davis, "A Review of Pozzolanic Materials and Their Use in Concretes", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, American Society for Testing Materials, Special Technical Publication No.99, Philadelphia, U.S.A., 1950, P. 1.

in mass concrete in a big way and is currently being produced with and without an air entraining agent.[9] Many other countries have also followed the American lead in this field, but, in most of these instances, the cement is not a factory product of intergrinding but is the result of partial replacement of portland cement by pozzolana in a concrete mixer.

4. Miscellaneous Pozzolanic Cements:

12. All pozzolana bearing cements which are not covered by the above three types have been put in the category of Miscellanecus Pozzolanic Cements. Though their use is not yet widespread, future holds a good promise for them because of their special properties. In Germany trass-blast furnace cement with 15 and 25 per cent by weight of trass component is a factory made cement which is generally ground very fine. Though there is no standard for this cement, the latter finds particular application for concrete structures which come in contact with aggressive waters.[11]

13. Another cement which deserves a special mention is the Puzzolano-metallurgical cement of France which consists essentially of an interground mixture of portland cement clinker, a pozzolana (fly ash) and granulated blast-furnace slag in certain proportions. This cement is claimed to attain the same strength as ordinary portland cement even in early ages and to surpass the strengths of portland cement at later ages.[12] In short, it is superior to a portland-pozzolana cement. The important characteristics of the two grades of the Fouilloux puzzolano-metallurgical cements are reported in table 2. The two C.P.M.F. grades are 160/330 and 210/375. (The figures represent compressive strength in kg/cm^2 at 7 and 28 days respectively.)

D. Properties of Pozzolanic Cements

1. Pozzolanic Action:

14. In order to understand the properties of pozzolanic cements better, a brief discussion on the pozzolanic action is desirable. According to the definition,

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11/ Heinz Kremser, "The Use of Puzzolana in Germany", Symposium on 'Pozzolanas - Their Survey, Manufacture and Utilization', Central Road Research Institute, New Delhi (INDIA), December, 1964.

12/ "A Note on the Puzzolano-Metallurgical Cements", Société des Materiaux de Construction de la Loisue, France, Symposium on 'Puzzolanas - Their Survey, Manufacture and Utilisation', Central Road Research Institute, New Delhi (INDIA), December, 1964.

TABLE 2

Physical and Mechanical Characteristics of the Fouilloux Puzzolano-metallurgical Cements

		PMP No. 1		PMP No. 2	
Specific surface by Blaine method, cm^2/g		3720		3800	
Specific gravity, g/cm^3		2.76		2.82	
Initial setting		5 hours		3 hours 30 mins.	
Final setting		Between 9 hours and 15 hours		9 hours	
Time for cracking of the pat at 20 to 50 per cent relative humidity		38 hours		22 hours	
		PMP No. 1		**PMP no. 2**	
		R	G	R	G
Shrinkage (R)	2 days	195	0	94	31
Swelling (G)	4 days	313	63	281	63
in microns per metre	7 days	438	94	375	94
on RILEM mortar	14 days	594	94	531	94
	21 days	656	94	594	94
	28 days	750	125	625	94
Compressive strength on RILEM mortar in kg/cm^2	2 days	107		140	
	7 days	232		276	
	28 days	414		452	
	90 days	567		605	

Source: "A Note on the Puzzólano-metallurgical Cements", Société des Materiaux de Construction de la Loisne, France Symposium on Puzzolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec., 1964.

a pozzolana must be in a fine state and its constitutents should react with lime at normal temperature in the presence of moisture and produce cementitious materials of low solubility. As far as lime-pozzolana cements are concerned the occurrence of such a reaction is easily understood but some explanation is required in the case of portland-pozzolan cements.

15. Ordinary portland cement contains a very high percentage of silicates; di- and tricalcium silicates make up more than 70 per cent of the total mineral content. On hydration of these silicates, calcium hydroxide is liberated as indicated by the two equations[13/] given below:

$$2Ca_2SiO_4 + 4H_2O = Ca_{3.3}Si_2O_{7.3}.3.3H_2O + 0.7Ca(OH)_2$$

$$2Ca_3SiO_5 + 6H_2O = Ca_3Si_2O_7.3H_2O + 3Ca(OH)_2$$

16. While the resulting two calcium silicate hydrates, called collectively tobermorite gel,[14/] are insoluble, cementitious and account for most of the strength of hardened cement, calcium hydroxide liberated during the hydration of silicates does not contribute to the strength and, being soluble in water, may be leached out. Pozzolana which is a constituent of portland-pozzolana cement fixes up this lime during its hydration by entering into chemical combination and forming cementitious calcium silicate hydrate of the tobermorite type. Though nothing definite can be said about the nature, composition and morphology and other characteristics of the tobermorite phase formed from portland-pozzolana cement because its chemistry is not fully understood,[15/] it appears, it is probably different from that formed on the hydration of portland cement.[16/]

17. The important point to be borne in mind, however, is that this tobermorite phase is also in the form of gel with low degree of crystallization and fills the

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13/ S. Brunauer and D.L. Kantro, "The Hydration of Tricalcium Silicate and β-Dicalcium Silicate from 5°C to 50°C", The Chemistry of Cements, Edited by H.F.W. Taylor, Academic Press Inc., London & New York, 1964, vol.1, p.289.

14/ H.F.W. Taylor, "The Calcium Silicate Hydrates", The Chemistry of Cements, Edited by H.F.W. Taylor, Academic Press Inc., London & New York, 1964, vol.1, p.199.

15/ G. Malquori, "Portland-Pozzolana Cement", Proceedings of Fourth International Symposium on Chemistry of Cement, Washington 1960, National Bureau of Standards, Washington, Monograph 43, 1962, vol.2, pp.983-995.

16/ S.K. Chopra, "The Hydration and Hardening of Clinker-based Cements - Some Unresolved Problems", The Indian Concrete Journal, vol.40, No.5, May, 1966.

voids and capillary pores in mortars and concretes. Consequently, properties of Portland-pozzolana cement mortars and concretes are modified as discussed below.

2. Properties of Lime-Pozzolana Cements:

18. Properties of lime-pozzolana cements depend entirely on the pozzolanic action unlike portland-pozzolana cement wherein the pozzolanic action only supplements the hydration of portland cement clinker component. Since clinker is a standard material and is generally present in higher proportions, it controls the properties of the pozzolanic cement to such a degree that it is possible to lay down minimum standards about properties such as fineness, consistency, setting time, strength, soundness, shrinkage etc. No wonder National Standard Specifications have been evolved for portland pozzolana cements while lime-pozzolana cements are covered either by standards laid by individual organizations or by a National Code of Practice.

19. The properties of lime-pozzolana cement depend mostly upon the ratio of its constituents, quality and type of lime, and fineness and activity of pozzolana. This type of cement is comparatively slow setting. Setting time is variable; according to Lea 17/ initial set may occur in 1-3 hours and final set in not less than 10-12 hours when determined by the Vicat plunger. Strengths vary with lime to pozzolana ratio and are very much influenced by temperature and storing or curing conditions. Mixes with low lime content (1:4) will give higher early strengths compared to those containing higher lime content (1:3 and 1:2) and the situation may reverse at later ages. Higher temperatures increase the rate of pozzolanic action and consequently strength development is faster. Water curing gives much higher strengths in comparison to air curing.

20. Lime-pozzolana cements do not compare favourably with ordinary portland cement in as much as they do not develop strengths fast and also the ultimate strengths are generally lower. However, pozzolanic action, though slower, can go on for a much longer period and make its mortar and concrete as watertight as that of portland cement. Similarly, mortars and concretes of some cements of this type could be as resistant to the action of fresh and salt water as those of portland cement. This is evident from the long term performance of marine structures

17/ (Reference 1), p.376.

built in Italy and Germany with mixtures of lime and pozzolana with or without portland cement.[18,19]

3. Properties of Portland-Pozzolana Cements

(a) General Properties:

21. The properties of portland-pozzolana cements (PP cements) are, in general, similar to those of ordinary portland cement; however, an understanding of differences in the properties is important from the point of view of application. Information on the important properties of portland-pozzolana cements is available in the National Standards of ten countries (Appendix).

22. The chemical composition of some American Pozzolanic Cements, based on Kalousek and Jumper's data,[20] is reported in table 3. Specific gravity of portland-pozzolana cements is comparatively lower as the specific gravities of pozzolanas vary from about 2.0 to 2.7 against 3.15 of clinker. PP cements generally lower the workability of concrete (slump) at the same water content, however, there are some exceptions such as fly ashes with low carbon content and high fineness which improve the workability of concrete. On the other hand, PP cements improve the plasticity of concrete, reduce bleeding and segregation. These effects are more pronounced in lean mixes.[10,21]

23. Setting times are nearly the same for the two cements. Portland-pozzolana cements made from type I and II portland cement clinker and having 15 to 30 parts of pozzolana by weight have nearly equal tensile strengths at early ages; later on tensil strengths may be even 50 per cent higher. Also, under moist curing conditions, mortars containing pozzolanas do not show the regression in tensile strength at later ages which straight portland cement mortars may show. Pozzolana-cements usually attain their ultimate strengths at one year of age.

24. Compressive strengths of mortars and concretes prepared with PP cement are comparatively lower than those of portland cement at early ages; the greater the percentage replacement, the lower the early-age strength. Later-age strengths

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18/ (Reference 1), P.368.

19/ G. Malquori, "Natural Italian Pozzolanas", Paper Presented at the Symposium on 'Pozzolanas - Their Survey, Manufacture and Utilization', Central Road Research Institute, New Delhi (INDIA), Dec., 1964.

20/ G.L. Kalousek and C,H. Jumper, "Some Properties of Portland Pozzolana Cements", Journal American Concrete Institute, Nov., 1943.

21/ B. Mather, "The Partial Replacement of Portland Cement in Concrete", Cement & Concrete, Special Technical Publication No. 205, American Society for Testing Materials, Philadelphia, U.S.A., 1958, pp.52-55.

TABLE 3

Chemical Composition of American Pozzolanic Cements

(After Kalousek and Jumper)[a]

Chemical constituent %	Pozzolanic cements				
SiO_2	28.2	28.1	33.3	31.2	26.4
Fe_2O_3	3.7	0.9*	5.3	5.3	3.3
Al_2O_3	8.2	10.7	13.3	7.1	7.3
CaO	48.6	55.6	39.7	49.8	57.5
MgO	3.5	2.2	2.1	2.0	1.6
SO_3	1.8	0.8	1.9	1.5	1.8
Ign. loss (-)	5.8	+	2.7	0.8	+
Na_2O	n.d.**	n.d.	0.04	1.61	0.22
K_2O	n.d.	n.d.	1.24	0.93	0.93
Insoluble	16.5	0.3	35.5	19.7	0.5
Free CaO	0.7	0.4	0.1	0.4	0.1

* Also 0.9 per cent FeO n.d.** not determined

a/ G.L.Kalousek & C.H. Jumper, "Some Properties of Portland Pozzolana Cements", Journal American Concrete Institute, Nov., 1943.

of richer concrete mixes prepared with PP cement are generally lower than that of portland cement. However, later-age strengths of PP cements may equal or exceed those of portland cement in lean mixes. But all this is valid under continuous moist curing conditions. Dry curing conditions and low temperatures affect the strengths of PP cements more adversely than that of portland cement.

25. Moisture movements of concretes prepared with PP cement are not significantly different from those of Portland cement, but initial drying shrinkage is greater in the former cement. Creep of pozzolana concrete is comparatively greater both in tension and compression. Other things being equal, the magnitude of creep increases with the magnitude of replacement of cement by pozzolana. One good consequence of this increased ability to creep is that PP cements show lesser tendency to cracking.

26. Freezing and thawing tests reveal that frost resistance of PP cements is lower when evaluation is carried out on 28 days old specimens. This is because of lower strength development compared to that of portland cement at the same age. If, however, the former cement is cured for longer periods, say six months, there is no difference in the performance of the two cements. The abrasion resistance of concrete prepared with PP cement is generally lower except at later ages when the differences are neglegible.

(b) Special Properties:

27. Portland pozzolana cements possess some special properties which make them more suitable for certain applications discussed in Chapter V. PP cements evolve lower heat of hydration per unit weight, and are preferred for use in mass concrete constructions on that account. However, the total heat liberated by PP cement is substantially greater than that which can be accounted for by the portland cement component only, showing thereby that pozzolanic reaction does contribute towards heat. As a rough indication the percentage reduction in heat evolution at 7 and 28 days may be about one half the percentage substitution.[22/] The advantage of reduced heat of hydration is nullified to great extent if a pozzolana is much finer than cement. For example, Venuat[23/] found that 7 days heat of hydration of cement wherein 25 per cent cement had been replaced by fly ash of a fineness of 10,000 square centimetre per gram was nearly equal to that of plain cement.

22/ (Reference 1), p.383.

23/ Michael Venuat, "A Study of Properties of Fly Ash Cements", Revue des Materiaux de Construction No. 506, pp. 309-317, Nov., 1957 (In French).

28. Permeability of concrete prepared with PP cement may or may not be lower than that of portland cement concrete as it depends on the activity and fineness of pozzolana, and water requirements of concrete for the same workability. Incorporation of pozzolanas which reduce water requirements will lead to reduced permeability even at early stages; otherwise under wet curing conditions permeability of pozzolana concrete is definitely lower at later ages because of formation of pseudogelatinous, expanded products which fill pores and voids and reduce permeability.24/ That is why use of PP cement is recommended in the construction of dams where lean mixes are customary as it leads to a degree of water tightness which is not attainable otherwise.

29. Portland pozzolana cements generally increase resistance to aggressive waters (soft and sulphate bearing waters) because of formation of pseudogelatinous products which seal the pores. Also calcium hydroxide, liberated on hydration of Portland cement in concrete and which is vulnerable to leaching and attack of aggressive water, is consumed in portland pozzolana cement concrete due to the pozzolanic action. All this may lead to increased resistance of PP cements.25-28/ But the effects may be offset if pozzolanas contain reactive alumina.24/

30. A good deal of evidence24,29-31/ shows that use of PP cement in concrete

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24/ (Reference 15), p.996.

25/ R.E. Davis, Wilson C. Hanna and E.H. Brown, "Strength, Volume Changes and Sulfate Resistance of Mortars containing Portland-Pozzolan Cements", The American Society for Testing Materials, Special Technical Publication No.99, ASTM, Philadelphia, U.S.A., 1950, pp.131-152.

26/ Milos Polivka and Elwood H. Brown, "Influence of Various Factors on Sulfate Resistance of Concretes Containing Pozzolan". Proceedings, American Society for Testing Materials, vol.58, pp.1077-1100, 1958.

27/ P. Fouilloux, "Pozzolanic Slag Cements of High Chemical Resistance and Normal Strength Gain", Revue des Materiaux de Construction, No.502, pp.191-196 July 1957 (In French).

28/ Standard Method of Test for Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar Bar Method), ASTM Designation C227-64, 1964 Handbook of ASTM Standards, Part 10, American Society for Testing & Materials, Philadelphia U.S.A.

29/ T.E Stanton, "Studies of Use of Pozzolanas for Counteracting Excessive Concrete Expansions Resulting from Reaction between Aggregates and the Alkalis in Cement", ASTM Special Technical Publication No.99, pp.178-201.

30/ George E. Troxell and Harmer E. Davis, "Composition and Properties of Concrete" McGraw-Hill, pp.72-73, 1956.

31/ J.A. Hester and O.F. Smith, "The Alkali-Aggregate Phase of Chemical Reactivity in Concrete - Part II", American Society for Testing Materials, Special Technical Publication No.205, pp.74-90, 1956.

will check alkali-aggregate reaction which results in delayed expansion.[32/] Pozzolanas have been found generally effective in checking alkali-aggregate reactions where the aggregates are potentially dangerous and alkali content of portland cement is higher than the recommended limit of 0.60 per cent as Na_2O.[33/] Pozzolanas should be used in sufficient quantities as presence of small amounts may induce deleterious alkali-aggregate reaction.[34,35/] However, presence of calcium chloride could reduce the effectiveness of pozzolanas.[35/]

31. The data on the resistance of concretes containing pozzolana replacements to freezing and thawing is conflicting and not conclusive. This appears to result primarily from lack of uniform testing conditions and procedures employed by different workers.[36/] Steopoe[37/] found reduced resistance with pozzolana replacements more than 10 per cent because of the presence of micro- and macro-fissures on account of air slaking. Most of the investigations relate to portland fly ash cement and, according to Abdun Nur,[38/] fly ash concrete has to be wet cured for about 80 days if it has to equal or exceed normal air-entrained concrete in durability. Since drying of pozzolana concrete at early ages will affect the resistance to freezing and thawing much more than in portland cement concrete, curing of pozzolana concrete should not be carried out at a relative humidity of less than 50 per cent.

E. Standard Specifications

32. American Specifications for Raw or Calcined Natural Pozzolanas are reported in table 4. A pozzolana is required to have a minimum content of 70 per cent of the oxides of silicon, aluminium and iron of which a pozzolana is mainly constituted.

32/ R.H. Bogue, "The Chemistry of Portland Cement", Reinhold Publishing Corporation, New York, Second Edition, 1955, pp.699-711.

33/ (Reference 2), p.704.

34/ Russel H. Brink and Woodrow J. Halstead, "Studies Relating to the Testing of Fly Ash for Use in Concrete", Proceedings, American Society for Testing Materials, vol.56, pp.1161-1214, 1956.

35/ U.S. Bureau of Reclamation, "Concrete Manual", 6th. Edition, pp.47-46, 1955.

36/ H.L. Flack, "The Freeze-Thaw Resistance of Concrete as Affected by Method of Test". Proceedings American Society for Testing Materials, vol.57, pp.1077-1095, 1957.

37/ A. Steopoe, "The Action of Pozzolanas and its Influence on the Structure of Hardened Binders and on the Properties of Concrete", Paper R.35, (Roumania), Sixth International Congress on Large Dams, New York, September, 1958.

38/ Edward A. Abdun-Nur, "Fly Ash in Concrete - An Evaluation", Highway Research Board Bulletin 284, Highway Research Board, Washington D.C., 1961, p.31.

TABLE 4

Raw or Calcined Natural Pozzolans for Use as Admixtures in Portland Cement Concrete

CHEMICAL REQUIREMENTS	
Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min., per cent	70.0
Magnesium oxide (MgO), max., per cent	5.0
Sulphur trioxide (SO_3), max., per cent	3.0
Loss on ignition, max., per cent	10.0
Moisture content, max., per cent	3.0
PHYSICAL REQUIREMENTS	
Fineness:	
Mean particle diameter, microns, max.	9.0
Amount retained when wet-sieved on No. 325 (44-micron) sieve, max., per cent	12.0
Pozzolanic activity index:[a]	
With Portland Cement, at 28 days, min., percentage of control	75.0
With lime, at 7 days , min., psi	800.0
Water requirement, max., percentage of control	115.0
Change of drying shrinkage of mortar bars at 28 days, max., per cent	0.03
Soundness:[b]	
Autoclave expansion or contraction, max., per cent	0.50
Amount of air-entraining admixture in concrete,[c] ratio to control, max.,	2.0[d]

Table 4 (continued)

Uniformity requirements:	
The specific gravity of individual samples will not vary more than 15 per cent from the average established by the ten preceding samples, or by all preceding samples if the number is less than ten, by more than, per cent	3.0
In addition, when air entrainment is specified for the concrete, the quantity of air-entraining admixture required to produce an air content of 18.0 per cent by volume of mortar will not vary from the average established by the ten preceding tests, or by all preceding tests if less than ten, by more than, per cent	20.0
Reactivity with cement alkalis:[e]	
Reduction of mortar expansion at 14 days, min., per cent	75.0
Mortar expansion at 14 days, max., per cent	0.020

Regarding a, b, c, d and e, original standard may be consulted.

Source: Tentative Specifications for Raw or Calcined Natural Pozzolans for Use as Admixtures in Portland Cement Concrete, ASTM Designation C 402-63 T, 1967 Book of ASTM Standards, Part 10, American Society for Testing Materials, 1916 Race St., Philadelphia, 3, pa.

ASTM Designation C 402-63 T has now (1968) been replaced by C 402-65, 1967.

The stability and durability aspects of pozzolana are controlled through limits placed on the contents of magnesium oxide (MgO), sulfur-trioxide (SO_3) and loss on ignition. The most important physical requirements are the fineness, pozzolanic activity index and soundness. Limits have therefore been specified for all the three properties (table 4). The other physical requirements in this table pertain to the use of pozzolana for special purposes. The uniformity requirement which is important from the point of view of quality control of pozzolana has also been taken care of (table 4).

33. Most of the chemical and physical requirements for the natural pozzolanas are also applicable for artificial pozzolanas, however, specifications for artificial pozzolana generally are specific in nature and may have to be drawn for each pozzolana separately. In fact, more than one specification may be in use for one artificial pozzolana in a particular country. For example, fly ash in U.S.A.

34. The ASTM Specification for Natural Cements and Portland-Pozzolana Cement are reported in table 5 and 6 respectively. It may be noted that while the specified fineness of the natural cement in terms of sqcm/g is about two times of that of portland cement (table 1), the strength requirements are much lower. The limit on the autoclave expansion is also lower compared to that of portland cement (Type I in table 1).

35. The fineness of portland pozzolana cement was specified earlier in terms of residues on ASTM sieve No. 100 and 325. As against fineness in terms of sieve residue, now a few of the National Standards also control the fineness in terms of specific surface (sqcm/g) as determined by Air Permeability Method. This is evident from the specifications of Portland-pozzolana cements in use in different countries (Appendix); many countries produce more than one quality of this type of cement. The important difference to note is that strength requirements for portland pozzolana cements at early ages are generally slightly lower than those for ordinary portland cement (Type I). The difference in strength is, however, reduced with age. The other differences in the specifications for Portland-Pozzolana Cements probably arise from differences in the nature of the local pozzolanas or practices of use of cements.

36. Since the formulation of National Standards takes time and requires to be backed by research and adequate experience, it may be profitable in the beginning for the developing countries to make use of the current specifications (Appendix) for testing and evaluating pozzolanas and pozzolanic cements. When sufficient research

TABLE 5

Standard Specifications for Natural Cement

Chemical Requirements

Test	Limits
Ignition loss	not greater than 12 per cent
Insoluble residue	not less than 2 per cent

Physical Requirements

	Type N	Type NA
Fineness, specific surface, sq. cm. per g:		
Air permeability apparatus	-	-
Average value, min.	6000	6000
Minimum value, any one sample	5500	5500
Soundness:		
Autoclave expansion, max. per cent	0.80	0.80
Time of setting, Gillmore Test:		
Initial time in minutes, min.	60	60
Final time in hours, max.	12	12
Air-entrainment:		
No agent used, max., per cent by volume	12	-
Using air-entraining agent, per cent by volume	-	19 ± 3
Compressive strength, psi, min.		
1 day in moist air, 6 days in water, psi.	1500	1200
1 day in moist air, 27 days in water, psi.	3000	2400

Source: Standard Specifications for Natural Cement, ASTM Designation C 10-64, 1964 Handbook of ASTM Standards, Part 10, American Society for Testing and Materials, 1916 Race St., Philadelphia, U.S.A.

ABLE 6

rtland-Pozzolan Cements

Chemical Requirements		Physical Requirements	
Magnesium Oxide (MgO), max., per cent	5.0	Fineness:	
Sulphur trioxide (SO_3), max., per cent	3.0	Amount retained when wet sieved on No. 325 (44-micron) sieve, max., per cent	12.0
Loss on ignition, max., per cent	3.0	Pozzolanic activity test:	
		Pozzolanic strength, min., psi.	600

Physical Requirements

	Type IP	Type IP-A
Fineness:		
Amount retained when wet sieved on:		
No.100 (149-micron) sieve, max., per cent	1.0	1.0
No.325 (44-micron) sieve, max., per cent	12.0	12.0
Specific surface by air permeability apparatus squ. cm. g[a]		
Average value, min.	2800	2800
Minimum value, any one sample	2600	2600
Soundness:		
Autoclave expansion or contraction, max., per cent[a]	0.50	0.50
Time of setting (alternate methods):[b]		
Gillmore test:		
Initial set, min., not less than	60	60
Final set, hr., not more than	10	12
Vicat test (Method C 191):		
Set, min., not less than	45	45
Air content of mortar prepared and tested in accordance with Method C 185, per cent by volume	12.0 max.	19 ± 3
Compressive strength, psi:		
The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with Method C 109, will be equal to or higher than the values specified for the ages indicated below:		
1 day in moist air, 6 days in water	1500	1250
1 day in moist air, 27 days in water	3000	2500
Water requirement, max., per cent by weight of the cement	64	56

Water requirement, max., per cent by weight of the cement

Table 6 (continued)

	Type IP	Type IP-A
Drying, shrinkage, max., per cent	0.15	0.15
Mortar expansions[c]		
At age of 14 days, max., per cent	0.020	0.020
At age of 8 weeks, max., per cent	0.060	0.060

Reg: a, b, and c, the original Standard book may be consulted.

Source: Tentative Specification for Portland-Pozzolan Cement, ASTM Designation C 340-64T, 1964 Handbook of ASTM Standards, Part 10, American Society for Testing and Materials, Philadelphia, U.S.A.

ASTM Designation C 340-64T, 1966 has been replaced by C 595, page 387, ASTM Standards Part 10.

data and field experience have been gathered, modification in the existing specifications or drawing up of National Standards could be taken up in the interest of greater utilization of natural resources and better use of finished products to suit prevailing climatic conditions or construction practices.

CHAPTER II. POZZOLANAS - THEIR CLASSIFICATION AND MANUFACTURE

A. Classification

37. Pozzolanas can be classified into two groups, i.e. natural and artificial pozzolanas. Naturally occurring products possessing pozzolanic properties are classified as natural pozzolanas and industrial products are termed as artificial[*] pozzolanas. While there is a general agreement about the two classes of pozzolanas, there are some differences about the placement of natural materials such as clays, shales and certain siliceous rocks which act as pozzolanas only after heat treatment in one or the other group. For example, Lea[1] and Malquori[2] have listed the latter under artificial pozzolanas, while Davis,[3] Mielenz and his co-authors,[4] and Orchard[5] call calcined clays and shales etc. as natural pozzolanas. Since, besides heat treatment, other treatments or processes may also turn a non-pozzolana into a pozzolana,[6,7] classification based on the source of the material rather than the treatment or process is considered more realistic and has, therefore, been adopted in this report.

1. **Natural Pozzolanas:**

38. According to Malquori[2] the true natural pozzolanas are pyroclastic, incoherent materials that originate from prevailing explosive types of volcanic eruption through quenching. These are in a state of special instability, rich

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*/ Also known as Synthetic Pozzolanas.

1/ F. M. Lea, "The Chemistry of Cement and Concrete", Edward Arnold (Publishers) Ltd., London, 1956, p. 358.

2/ G. Malquori, "Portland-Pozzolan Cement", Chemistry of Cement, Proceedings of the Fourth International Symposium, Washington, U.S. Department of Commerce, National Bureau of Standards, Monograph 43, vol. II, pp. 985-987.

3/ R. E. Davis, "Pozzolanic Materials and Their Use in Concrete", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia, 1950, p. 5.

4/ Richard C. Mielenz, Leslie P. Witte and Omar J. Glantz, "Effect of Calcination on Natural Pozzolanas", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia, 1950, p. 43.

5/ D. F. Orchard, "Concrete Technology", Asia Publishing House, New Delhi, 1963, vol. 1, pp. 110-111.

6/ K. M. Alexander, "Reactivity of Ultrafine Powders Produced from Siliceous Rocks", Journal of the American Concrete Institute, vol. 32, No. 5, November, 1960.

7/ K. M. Alexander, "Activation of Pozzolanas by Treatment with Acid", Australian J. Applied Science, 69, 327 (1955).

in glassy substances and possess special reactivity towards calcium hydroxide. The examples are the Italian volcanic pozzolans from the Phlegraean (Pozzuoli) and the Latium (Rome) regions. Compact volcanic tuffs, though originating from the same pyroclastic materials, involve a transformation process and therefore are different from the true natural pozzolanas. The Rhenish trass obtained by grinding the very soft tufaceous rock from the Eifel quarries is an example of this group. Between the true pozzolanas, incoherent and rich in glass component and the compact tuffs which originated from the cementation of pyroclastic materials, Malquori recognises a series with intermediate characteristics according to the type and extent of alteration that has occurred. Altered rhyolitic volcanic tuffs, no longer containing any glass because they are deeply zeolitised, belong to the intermediate series. Products resulting from extensive alteration of different types of valcanic rocks due to numerous causes are also good pozzolanas. Examples are opaline silica, clays which have been naturally roasted by incandescent lava flowing over them. Natural pozzolanas are also derived from rocks or earths for which the silica constituent contains opal, either from precipitation of silica from solution or from the remains of organisms. Diatomaceous earths belong to this category. According to Turrisiani 8/ natural pozzolanas could be classified as (i) volcanic glasses, (ii) pozzolana tuffs and (iii) high-silica pozzolanas. Table 1 gives a comprehensive list of natural pozzolanas which has been prepared from the available information. Natural materials which need calcination for developing pozzolanic activity are grouped together. Examples are "Moler" of Denmark and "Giase" of France. Besides listing the well known pozzolanas and the country or countries of their sources, the data on rock type, physical state of the natural material and petrographic description have also been included in Table 1. This information will be helpful in surveying and prospecting for pozzolanas.

2. <u>Artificial Pozzolanas</u>

(a) <u>Fly Ash</u>:

39. Of the different artificial pozzolanas given in Table 1, fly ash (or pulverised fuel ash) is the most important as this is an industrial waste of thermal power stations using pulverised coal for raising steam in their boilers and is available in huge quantities for disposal. It consists of fine particles

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8/ R. Turrisiana, "Aspects of the Chemistry of Pozzolanas", The Chemistry of Cements by H. F. W. Taylor, Academic Press, London and New York, 1964, pp. 70-75.

TABLE 1

Petrographic Characteristics of Natural and Artificial Pozzolanas

Pozzolana 1	Petrographic type 2	Physical state of material 3	Petrographic description 4	Source/country of use 5
Natural				
Volcanic Tuffs	Rhenish Trass	Consolidated rock-like	Trachytic (alkali feldspar) tuff	Germany
	Volcanic pozzolana from phlegraean (Pozzuoli)	Fragmentary, pyroclastic, rich in glass	Alkalitrachytic type more acid bubbled glass with a few inclusions of sanidine crystals, plagioclases and pyroxenes.	Italy
	Volcanic pozzolana from laticum (Rome) region	Fragmentary, pyroclastic	Leucititic type, more basic consisting of leucite dendrites and some parts of augrite in the ground mass of altered glass.	Italy
	Neapolitan yellow tuff	Consolidated, needs pulverization	Alkali trachytic type, isotropic groundmass with fragments of pumice and minerals like sanidine, augite, hornblende, biotite etc.	Italy
	Santorin earth	Pyroclastic, incoherent, granular	Isotropic, mixed with pumice, obsidian, and fragments of crystalline feldspars, pyroxenes, quartz etc.	Grecian

Table 1 continued

1	2	3	4	5
	Bavarian trass	Tuffaceous, compact rocks, originated from cementation of pyro-clastic materials and zeolitization		Bavaria
	Rumanian			Rumania
	Crimean trass			Crimea
	Tosca, volcanic ash	-	-	Canary Islands
	Tetina	-	-	Azore
	Altered rhyolitic volcanic tuffs	White to mottled, firm compact and massive	Zeolitized to clinoptilolite (high calcium heulandite), beidellite and some rock fragments.	Monolith California U.S.A.
	Rhyolitic tuffs	Varying from loose to pulverulent and also firm and massive	Rhylolitic glass more than 50% together with quartz, feldspars, biotite, hornblends, sanidine, opal and clay minerals.	Washington California U.S.A.
	Rhyolite pumicite	Fine to very fine; pulverent and laminated	Glass content in general vary from 75 to 90% together with opal, montmorillonite, clay, quartz, feldspar etc.	-
2. Diatomaceous earths	Diatomite (known by different trade names)	White to cream, fine to very fine, massive pulverulent - wide variations but essentially composed of siliceous skeletons of diatomes deposited	Opal (main constituent) above 80%, clay minerals, silt	California, U.S.A. Canada, Algeria

Table 1 continued

1	2	3	4	5
		from either fresh or sea war; deposits mixed with clay and sand		Germany U.K. Denmark
3. Clays	Clays	Clays naturally roasted by incandascent lava flowing over them	Products of calcination of clay minerals	
	Pumiceous loess	Friable, porous	Glass, montmorillonite-type clay mineral, quartz, feldspar etc.	Washington, U.S.A.
	Clayey silt	Laminated from pulverulent to compact stage	Mixed clay minerals, quartz, feldspars, calcite etc.	U.S.A. and other countries
Calcined Natural Pozzolanas	Molar	Deposit of Tertiary age of diatomaceous earth	Calcined diatomaceous earth containing considerable portion of clay	Denmark
	Gaise	Soft, porous sedimentary rock calcined at about 900°C	Silica in a gelatinous condition with a density of about 1.4 after drying	France
	Burnt bauxite	Naturally occuring bauxite has generally pisolitic concretionary and amorphous structure	$Al_2O_3.nH_2O$ which dehydrates on heating and can be present in different forms of Al_2O_3	France Italy

Table 1 continued

1	2	3	4	5
	Burnt clays and shales	In all possible forms i.e., friable, soft, massive, laminated, stratified, compact, containing sand and silt etc.	Composed of clay containing minerals such as kaolinite, montmorillonite, illite, nontronite, beidellite, vermiculite etc. in the raw state, together with accessory minerals normally occurring in such deposits e.g., quartz, feldspars, calcite, mica, gypsum, dolomite, iron oxides. On calcination clay minerals undergo dehydroxylation; the other minerals also undergo dehydration, decomposition and phase changes - in short active products are formed.	India Egypt Sweden Gt. Britain France U.S.A. U.S.S.R. etc.
<u>Artificial Pozzolanas</u>	Fly Ash (Pulverised fuel ash)	By-product of thermal power stations using pulverized coal as fuel.	Dark grey to blackish powder of fineness near about that of cement and containing glass predominantly. Other minerals are quartz, alumina, haematite, magnetite, mullite; unburnt carbon in small amount	U.S.A. U.S.S.R. U.K. & continental Countries, Japan, India

Table 1 continued

Surkhi	By-product of brick industry, rejected bricks are crushed and ground generally at the kiln site	Reddish or red powder of wide range of fineness	India
Coal ash	Waste product from burning of lump coal	Black in colour unburnt fuel and fused matter	India
Spent oil shales	Natural oil shale. Hard, compact and laminated.	Consist of organic rich laminations and much carbonates. A very little detrital quartz and other minerals.	
Si-stoff	Waste product obtained in the manufacture of alum	Siliceous material containing high sulphur trioxide content	Germany

collected in the stack of power plants by mechanical means or by electrical precipitators or a combination of the two. According to Abdun Nur,9/ fly ash consists for the large part of solid or hollow spherical particles of siliceous and aluminous glass, with small proportions of thin-walled, multi-faced polyhedrons called "cenospheres", of reddish particles high in iron, and of irregularly shaped, relatively porous carbon or carbon-coated particles. Obviously, this condition of fly ash particles is the result of their having been subjected to high temperatures before collection. This, coupled with the fineness of fly ash, which is of the same magnitude as that of portland cement, are the two attributes which make the use of fly ash a very attractive proposition as either no or very little processing is required. Moreover, the use of fly ash will turn the liabilities of disposal into profits. In America, where approximately 160 to 280 pounds of fly ash are produced for each ton of coal burned, the estimated expenditure on disposal of fly ash was about $ 17,500,000 per year about five years ago.9/ The disposal of fly ash poses a serious problem for many producer countries In the United Kingdom, about 8 million tons of fly ash is available and cost of disposal is about 4 shillings per ton. Even in a developing country like India, where fly ash became available only a few years ago, about 3 million tons of fly ash is available every year for disposal. Fly ash should be a valuable industrial by-product for the developing countries which are short of cements.

(b) Coal Ash:

40. Ashes which arise from the combustion of lump coal in large furnaces, such as those used for steam raising at thermal power stations [illegible] or fused together and the product is termed clinker in the United Kingdom and cinder in the United States. This industrial waste finds use as a lightweight aggregate and its quality is controlled through National Standards.10,11/ Finely crushed clinker shows some pozzolanic properties and on grinding with lime in a mill yields a mortar for brick or stone masonry.12/ Though such mortars gain strength slowly,

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9/ Edward A. Abdun Nur, "Fly Ash in Concrete - an Evaluation", Bulletin 284, Highway Research Board, Washington, D.C., 1961, p. 4, 42.

10/ Tentative Specifications for Lightweight Aggregate Concrete Masonry Units, ASTM Designation C331-64T, 1964 Handbook of ASTM Standards, Part 10, American Society for Testing and Materials, Philadelphia, United States of America.

11/ BS 1165-1957 "Clinker Aggregate for Plain and Precast Concrete", British Standards Institution, London, W.1.

12/ F. M. Lea, "The Chemistry of Cement and Concrete", Edward Arnold (Publishers) Ltd., London, 1956, p. 505.

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ultimately they become very hard. In India, ash resulting from the burning of coal in locomotives is collected and finer grades are used for making mortars.[13] More than one million tons of loco coal ash are available every year and ground locomotive ash is recommended for use as pozzolana by some.[14]

(c) Surkhi:

41. Surkhi, which is prepared by powdering brickbats or rejects of a brick kiln, is an industrial waste and consequently has been included in the list of artificial pozzolanas. The reactive surkhi or burnt clay pozzolana which has been included in the list of calcined natural pozzolanas is characterized by high pozzolanic activity and differs in having been produced as an industrial product from carefully selected clays.

(d) Si-Stoff:

42. Si-Stoff[15] is a siliceous waste product of alum manufacture. It can show good pozzolanic activity but is very variable in its composition. The sulphur trioxide content is often high.

B. Pozzolanic Activity and its Estimation

43. According to the definition of a pozzolana, pozzolanic activity implies its ability to combine with lime and form cementitious compounds. Attempts have been made in the past to measure pozzolanic activity in terms of its chemical composition, the amount of material soluble in some medium (solubility tests), absorption of lime by pozzolana from lime solution (lime absorption tests), and reduction in alkalinity of a 0.5 N sodium hydroxide solution by a pozzolana in the presence of calcium hydroxide[16] etc.

44. Since no definite relationships could be established between the activity of the different pozzolanas as determined by any of the above tests and their strength imparting characteristics as revealed in the strength development in either

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13/ P. M. Abdul Rahman, S. S. Rehsi and S. K. Chopra, "Strength of Brick Masonry", NBO Project Report, Journal National Buildings Organisation, October, 1961, vol. 6, pp. 49-61.

14/ "Loco Coal Ash as Pozzolanic Replacement of Cement", Indian Railway Technical Bulletin, vol. 17, No. 139, November, 1960.

15/ F. M. Lea, "The Chemistry of Cement and Concrete, Edward Arnold (Publishers) Ltd., London, 1956, p. 366.

16/ W. T. Moran and J. L. Gilliland, "Summary of Methods for Determining Pozzolanic Activity", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, 1950, pp. 110-120.

lime-pozzolana or portland pozzolana cement mortars or concretes,[17,18,19] none of the above tests can be considered entirely satisfactory. However, these tests may be considered of some value in the selection and evaluation of pozzolanas.

1. **Setting Times of Lime-Pozzolana Mixes:**

45. Pozzolanas are also tested for their activity by determining setting times and strengths of lime-pozzolana mixes or mortars.[16,20] These tests are based on the interaction of active silicates and aluminates present in pozzolanas with lime and formation of insoluble calcium silicate and aluminate hydrates. Initial and final setting times of pastes of 1:4 lime-pozzolana mixes (by weight) are determined at normal consistency of the paste. Materials which are inactive will not set under the conditions of this test procedure while active materials will show on the average an initial set of less than 50 hours and a final set of less than 100 hours. Materials with moderate activity either get set in this range or may not set at all. Experience shows that this method is suitable only for estimating the activity of different materials qualitatively.

2. **Strength Tests**

46. Tensile and compressive strength tests, employed in the past, measured the strengths of lime-pozzolana mixtures or lime-pozzolana-sand mortars. The specifications of the test procedures employed by different workers differed in the ratio of ingredients, size and shape of specimens, consistency of paste or mortar, and curing conditions etc. resulting in different standards to judge pozzolanic activity. Determination of tensile strength is no longer in vogue now.

16/ W. T. Moran and J. L. Gilliland, *op. cit.*

17/ F. M. Lea, "The Chemistry of Pozzolana", Proceedings Symposium, Chemistry of Cements, Stockholm, 1938, pp. 460-90.

18/ Robert D. Vincent, Mateos Manuel and D. T. Davidson, "Variation in Pozzolanic Behaviour of Fly Ashes", Proc. ASTM, vol. 61, 1961.

19/ G. Malquori, "Portland-Pozzolan Cement", Chemistry of Cement, Proceedings of the Fourth International Symposium, Washington, U.S. Department of Commerce, National Bureau of Standards, Monograph 43, vol. II, p. 994.

20/ F. M. Lea, "Pozzolanas and Lime-Pozzolana Mixes", Department of Scientific and Industrial Research, Building Research Station, Building Research Technical Paper No. 27, Her Majesty's Stationery Office, London, 1940.

3. Lime Reactivity Test:

47. Currently an accelerated test has replaced the old compressive strength test for testing pozzolanic activity; for example the lime-pozzolana strength development test in America and the lime-reactivity test in India. According to the Tentative Specifications of the American Society for Testing Materials for Pozzolanas for Use with Lime,21/ the mortar mix consists of 1:2:8 parts of hydrated lime:dry pozzolan:graded standard sand on weight basis. The mortar having plastic consistency is cast in 2 in. cube moulds and when moulding is completed, the filled moulds are placed in the vapour oven with the top surface protected from drip. The specimens remain in the moulds in this condition for 48 hours, after which they are removed from moulds and immersed in the 130 ± 3°F water until they are seven days old. The specimens are then removed, cooled and tested. The minimum compressive strength should be 600 p.s.i.

48. Lime reactivity test in the Indian Standard22/ which is similar to the Pozzolanic Activity Test in the ASTM Specifications,23/ requires 2.78 in. cubes to be prepared from 185 g of the lime:pozzolana mix in 1:2 ratio by weight with 555 g of the standard sand. The stiff mortar is filled in cubes by using standard mortar vibrator. The top and bottom of the specimen in the mould are covered and sealed so that no moisture loss can take place from the specimen. The specimens in moulds are first kept at 27 ± 2.0°C for 24 hours and then at 55 ± 2.5°C in an incubator for six days. The specimens are tested after cooling and should have a minimum strength of 600 p.s.i.24/ If a pozzolana tested in this manner has a strength of 800 p.s.i., a pozzolana may be said to have L.R. value of 800. The L.R. values can be employed for classifying pozzolanas.

21/ Tentative Specifications for Pozzolanas for Use with Lime, ASTM Designation: C 432-59T, 1964, Handbook of ASTM Standards, Part 9, American Society for Testing and Materials, Philadelphia, United States of America.*/

22/ The Indian Standard Methods of Test for Pozzolanic Materials, IS:1727-1960, Indian Standards Institution, New Delhi.

23/ Tentative Specifications for Portland-Pozzolan Cement, ASTM Designation: C 340-647, 1964, Handbook of ASTM Standards, Part 10, American Society for Testing and Materials, Philadelphia, United States of America.**/

24/ Indian Standard Specification for Surkhi for Use in Mortar and Concrete, IS:1344-1959, Indian Standards Institution, New Delhi.

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*/ Editorial Note: ASTM Designation C 432-59T, 1964, has been replaced (1968) by C 593-66T, 1966.

**/ ASTM Designation C 340-647, 1964, has been replaced (1968) by C 595-67T.

49. The accelerated tests mentioned above are not above criticism. First, these tests will not show how pozzolana will behave in portland-pozzolana cement; the correlation between strengths of pozzolanas of different types and the strengths of the corresponding portland-pozzolana cement concrete at an age of one year is poor. Secondly, the hydration characteristics in the lime reactivity test are somewhat different from those of portland-pozzolana cement. Nevertheless, the lime reactivity test is very valuable in evaluating pozzolanas as it is quicker, reliable and reproducible and quite suitable for predicting strength of lime-pozzolana mixes.

4. Strengths of Portland-Pozzolana Cement Mortars

50. Strength tests on portland-pozzolana blends or cements are generally preferred over other methods for evaluating pozzolanic activity because of their simplicity and direct application. The basic approach in strength tests is the determination of strength of mortars prepared with mixtures of portland cement and pozzolana under some specified conditions and its comparison with strength of mortars prepared with straight portland cement cured under identical conditions. Sometimes the strength of mortar prepared with mixtures of known inert substance (in quantity equal to that of pozzolanic material under test) and portland cement cured under similar conditions is also determined. These strengths are utilized in calculating the indices or establishing relationships for purposes of comparison. Though the behaviour of a pozzolana in the blends depends on the richness of the mix, condition of curing, age and quantity of pozzolana, etc., the test gives very satisfactory performance under one single set of test specifications.

5. Drying Shrinkage of Pozzolanic Mortars:

51. The test consists of casting mortar bars; the composition of mortar being 1 part of portland-pozzolana cement to about 3 to 4 parts of standard sand. The American Society for Testing Materials specifies the same mortar mix as for compressive strength test in the Specifications for Portland Pozzolan Cement.23/ The moulds are filled and placed in moist room for 24 hours. The specimens are then cured in water for six days. The initial length of mortar bars is measured and the specimens are then stored under specified conditions. The lengths of the specimens are measured from time to time and percentage shrinkage is calculated after various time intervals.

23/ op. cit.

6. <u>Fratini Test</u>:

52. In this test[25] 20 gm of the cement containing pozzolana is stirred with 100 ml of water for the first few hours and then maintained at 40°C for eight days. The solution is then filtered and titrated for alkalinity. Lime is also estimated. By comparing the results with a curve showing the solubility of lime at 40°C in solutions of varying total alkalinity, it can be seen if the solution is saturated with lime or not. For good pozzolanic cements, calcium hydroxide in solution should be below saturation.[26]

7. <u>Chemical Resistance Tests</u>:

53. Since pozzolanas are known to increase the resistance of concrete to leaching action of sulphate waters, attempts have been made to correlate pozzolanic activity of materials with the resistance to sulphate solutions of mixtures of portland cement and materials under investigation; but these have not yielded any suitable test procedure as the effects produced by other variables are too many to permit a reproducible evaluation. However, the Anstett test, which consists in measuring the expansion of a cylindrical specimen composed of 50 per cent gypsum and 50 per cent hydrated cement paste is considered adequate for comparison purposes by Turriziani.[27]

54. For testing the pozzolanic activity from the point of view of the use of a pozzolana for reducing expansions arising from alkali-aggregate reaction, a mortar bar test[28] is employed. This test is not a general purpose test but is intended to test the special property of a pozzolana. It has proved successful for evaluating a pozzolana for its ability to counteract alkali-aggregate expansions and has therefore been adopted as a standard test.[23]

23/ <u>op. cit</u>.

25/ N. Fratini, "Chemical Control of Pozzolanic Cements" (in Italian), Ann. Chim. 44, 709 (1954).

26/ F. M. Lea, "The Chemistry of Cement and Concrete", Edward Arnold (Publishers) Ltd., London, 1956, p. 393.

27/ R. Turriziani, "Aspects of the Chemistry of Pozzolanas", The Chemistry of Cements, edited by H. F. W. Taylor, Academic Press, London and New York, 1964, vol. 2, p. 83.

28/ Standard Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar Bar Method), ASTM Designation C 227-64T, 1964, Handbook of ASTM Standard, Part 10, American Society for Testing and Materials, Philadelphia, United States of America.*/

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*/ Editorial Note: ASTM Designation C 227-64T, 1964, has been replaced (1968) by C 227-67.

8. **Modern Test Methods:**

55. In addition to the above standard test methods, research methods[29,30] such as determination of insoluble residue (after contact with lime) or the uncombined lime in a mortar have also been applied to lime-pozzolana or portland cement-pozzolana mixtures. Examination of set cement products with the help of a light microscope, X-ray powder diffraction techniques, differential thermal analysis, thermogravimetric analysis and electron microscopy, are the modern tools employed in evaluating pozzolanic activity by indirect methods. Fuller account of techniques[31] and results of important investigations are given in the literature.[29,30]

C. Activity Type

1. **Natural Pozzolanas:**

56. Very extensive laboratory investigations have been carried out on the subject of pozzolanas during the last three decades. The results of investigations on naturally occurring Italian pozzolanas of repute have been published from time to time since 1935 and active constituents responsible for pozzolanic activity are now well recognized.[32,33] Studies on the American pozzolanas had their beginning in 1912 and since then the most productive work has been done in the laboratories of the United States Bureau of Reclamation, Denver, Colorado. The search for

29/ G. Malquori, "Portland-Pozzolan Cement", Chemistry of Cement, Proceedings Fourth International Symposium, Washington, National Bureau of Standards, U.S. Department of Commerce, Monograph 43, vol. 2, pp. 987-994.

30/ R. Turriziani, "Aspects of the Chemistry of Pozzolanas", The Chemistry of Cements, edited by H. F. W. Taylor, Academic Press, London and New York, 1964, vol. 2, pp. 75-82.

31/ Experimental Methods, Part V, The Chemistry of Cements, edited by H. F. W. Taylor, Academic Press, London and New York, 1964, vol. 2, pp. 191-323.

32/ G. Malquori, "Portland-Pozzolan Cement", Chemistry of Cement, Proceedings Fourth International Symposium, Washington, National Bureau of Standards, U.S. Department of Commerce, Monograph 43, vol. 2, pp. 984-986.

33/ R. Turriziani, "Aspects of Chemistry of Pozzolanas", The Chemistry of Cements, edited by H. F. W. Taylor, Academic Press, London and New York, 1964, vol. 2, pp. 70-75.

suitable pozzolanas for use in mass concrete for the construction of San Francisco Bridges, Arrowrock Bonneville, Friant, Altus and Davis Dams led to a very thorough testing and research programme on more than 200 prospective pozzolanas. These studies have brought out clearly that for comparing the properties of pozzolanic materials, petrographic classification as given in Table 1 can be quite misleading and that activity type based on the active constituents in a pozzolana is more rational and fruitful. According to Mielens, Witte and Glantz,[34] pozzolanic properties in natural pozzolanas, in the raw or calcined form, owe their activity to one or more of five substances, namely (1) volcanic glass, (2) opal, (3) clays, (4) zeolites, and (5) hydrated oxides of aluminium. In other words, prospective pozzolanas can be classified into six activity types, which are

Activity Type 1 - Volcanic glass
Activity Type 2 - Opal
Activity Type 3 - Clay
Activity Type 3a - Kaolinite-type clay
Activity Type 3b - Montmorillonite-type clays
Activity Type 3c - Illite-type clay
Activity Type 3d - Mixed clay with vermiculite
Activity Type 4 - Zeolite
Activity Type 5 - Hydrated oxides of aluminium
Activity Type 6 — Non-pozzolana

The above activity types are very helpful in prospecting for natural pozzolanas and their classification when a very large number of samples is involved.

2. Activity of Fly Ash:

57. A good deal has been published on the activity of fly ash which is the most important artificial pozzolana. Generally it is held that unburnt fuel or carbon content of fly ash reduce its activity. The explanations can be its diluent effect on active pozzolanic constituents in fly ash, its coarser particle size, its adverse effects on strengths due to its organic nature and lesser resistance to crushing, comparatively higher water requirements for a particular level of workability in mortar and concrete mixes and organic matter breaking the continuity of contacts of the cementitious reaction products. Consequently, the specifications place limits on the carbon content of fly ashes, usually from 5 to 12 per cent.

34/ R. C. Mielens, L. P. Witte and O. J. Glantz, "Effect of Calcination on Natural Pozzolanas", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia, pp. 43-53.

58. Fly ash is also known to consist of small spheres of glass of complex chemical composition and crystalline constituents which are mainly quartz (SiO_2), mullite ($3Al_2O_3.2SiO_2$), magnetite (Fe_3O_4) and haematite (Fe_2O_3). Quantitative estimation of glass and crystalline phases has been made for the British and American fly ashes.35,36/ The British fly ashes contained 1-6.5 per cent quartz, 9-35 per cent mullite and 5 per cent or less of magnetite and haematite. The American samples contained 0-4 per cent quartz, 0-16 per cent mullite, 0-30 per cent magnetite and 1-8 per cent haematite. The proportion of glass in the ashes varied from 50 to 90 per cent. The activity of fly ash appears to reside mostly in the glassy fraction. For example, the Indian fly ashes, which are not rich in glassy phase, do not show very high activities.37/

D. Unit Operations in Pozzolana Manufacture

1. General:

59. A chemical plant can be broken down into a number of single steps either physical or chemical in nature. The physical steps are called "unit operations" and the chemical ones "unit processes". These are the first basics necessary for the layout of a chemical plant. Although the information on unit operations38/ provides valuable guidance to the design of an industrial plant, there is no assurance that, when operated, the plant will be a total success. Therefore, it is essential that during the selection of the standard units chosen to carry out the respective unit operations or processes, the proper stress be given to their economics and satisfactory operation, and their suitability to the particular plant. The technology of pozzolana is comparatively simple and consists mainly of unit operations; as such, the laying out of an efficient plant for such purpose should not offer much difficulty.

35/ H. S. Simons and J. W. Jeffery, "An X-ray Study of Pulverised Fuel Ash", Jour. Appl. Chem., vol. 10, Part 8, Aug. 1960.

36/ L. J. Minnick, "Fundamental Characteristics of Pulverised Coal Fly Ashes", Proceedings American Society for Testing Materials, vol. 59, pp. 1155-1177, 1959.

37/ S. K. Chopra, S. S. Rehsi and S. K. Garg, "Use of Fly Ash as a Pozzolana", Symposium on "Pozzolanas - Their Survey, Manufacture and Utilisation", Central Road Research Institute, New Delhi, Dec. 1964.

38/ G. G. Brown, "Unit Operations", Asia Publishing House, New Delhi, 1959, p. 2.

60. The main unit operations in the manufacture of pozzolanas are crushing, calcining and grinding; drying becomes essential when the raw material is wet or the pozzolanic material is very fine and consequently has adsorbed a good deal of moisture. The unit operations described below will cover the manufacture of pozzolanas from the majority of the materials given in Table 1. Some of the natural pozzolanas in the first group of Table 1 require crushing and grinding, others which are already available in the pulverized state in nature need only grinding for their use. Calcined natural pozzolanas need calcination besides crushing and grinding. Pozzolanas like diatomaceous earths may require drying or drying combined with pulverisation.

2. Crushing and Grinding

(a) Primary Crushing:

61. The raw materials for pozzolana manufacture are generally not much harder than cement raw materials. The hardness of most of the pozzolanic materials may seldom increase over that of siliceous shales. For making selection[39] of a primary crushers the hardness of material to be crushed and its size should be known. The other important poins to be borne in mind are that a crusher should be able to break down the largest stone delivered by the quarry; it should not pack or jam if stone has fines or wet clay and it should have a high ratio of reduction so that secondary crushing is either not required or minimised. Also, the crusher should not involve high capital investment and energy consumption per ton should be low. Jaw crushers suggest themselves if the capacities are not high and machines with receiving openings to match the capacity are available. The Ehrsam jaw crushers are considered especially suitable for crushing soft materials.[40] For higher capacities gyratory crushers are available. Gyratory crusher is simply a continuous jaw crusher and its choice against a jaw crusher should be made after a careful study.

62. Certain soft rocks are not suited for crushing in jaw and gyratory crushers because of their packing tendency. For soft materials of hardness 4 or less on Moh's scale and for size reduction excluding very fine ranges, single roll crusher

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39/ J. H. Perry, Chemical Engineer's Handbook, Table 2, page 1117, A guide to the selection of Crushing and Grinding Equipment, McGraw-Hill Book Company Inc., 1950.

40/ Crushing, Grinding and Separating, Pit and Quarry Handbook, 1960, Section B, Chapter I, p. B.12.

can be used. In these machines tearing or shearing forces are applied through a greater distance with the help of the knobs or teeth on the roll. The knobbed roll length is about twice the diameter and the knobs or sluggers extend about 3 to 4 inches beyond the surface of the roll. The stone is caught between the roll and the breaking plate, sledged and pushed again and again. On this account single roll crusher does not require a feeder. This crusher is best for crushing laminated rocks or to reduce rocks having a high percentage of sticky clay.

63. Since hammer mills are characterized by extremely high ratio of size reduction, production of relatively more fines and low operating costs, this type of machine is more suitable for softer and less abrasive rocks, such as clays, shales less siliceous, limestones and gypsum etc. High silica content will, however, wear the hammer quickly and therefore crushing of highly siliceous materials with hammer-mill may not be advantageous. Use of hammer-mills may be preferable for wet sticky clays provided the breaker plate is self-cleaning.

(b) Secondary Crushing:

64. Hammer-mills are probably more suitable for secondary crushing of soft pozzolanic materials. Secondary hammer mills are characterised by higher peripheral speeds and provision of a cage which prevents oversize material from discharging. The cage controls size of discharged material through the spacing of grate bars, the smallest practical spacing being about one eighth of an inch. Cone crushers may be used for secondary crushing of relatively hard and abrasive materials.

(c) Tertiary Grinding:

65. For tertiary grinding crushing rolls may be used. Two heavy cylinders revolve about their axis towards each other, the feed being nipped and pulled downwards through the rolls by friction. The main feature is their flexibility because diameter and spacing of rolls may be varied over rather wide ranges permitting considerable variation in size of feed and product. It can crush a product of ¼ in. or even as fine as 10 mesh. Initial cost of crushing rolls is also low.

66. The technology of pozzolana manufacture is relatively new and it is very difficult to make specific recommendations about the suitability of one or the other crusher. Pilot plant trials are recommended for any new venture or new material, except for the typical plants and materials described later in this report.

3. Calcination

67. A rotary kiln in the cement industry may range in size from 5 to 18 feet in diameter and from 25 to over 500 feet in length. It is made of boiler plate with refractory lining inside the supporting structure and the driving mechanism; the drive is usually of variable speed. The kiln shell has a slope of $\frac{1}{2}$ in. per foot or more. The feed end of the rotary is higher than the discharge end so that the feed, which may be in the form of a dry powder, a filter cake, a slurry, crushed stone or ore or nodules etc., moves downwards as the kiln rotates. Heating is done from the lower end of the kiln with the help of a burner and finished product is also discharged from this end. Fuel for the burner may be oil or pulverised coal.

68. It is difficult to estimate capacity of a rotary kiln as it depends on nature of raw materials, their fineness, the rate of firing and the speed and slope of the kiln. According to the most common formulae, capacity is between $\frac{D^2L}{8}$ and $\frac{D^2L}{12}$ where D is the diameter of discharge end, i.e. the inner diameter of the lining in feet and L the length of the kiln.41/ The capacity is given in barrels per 24-hour day. For calculating the capacity in tons per day, $\frac{KLD^2}{100}$ is used where K is a constant having a value 1.15 for calculating capacity of cement clinker. A more complex equation for calculating kiln output (C), in metric tons/hour is from Witt42/

$$C = 0.04552\ kVe^{-0.00045V}$$ where

V = volume of kiln, in cubic metres

k = 1.00, for dry process kilns

k = 0.96, for wet process kilns

e = base of Napierian logarithm

69. The above formulae give capacity of a rotary kiln only approximately. Calculation of the amount of fuel consumed for pyro-processing a unit of product is far more difficult, as too many variables are involved; important ones are the moisture in raw feed, the rate of feeding, and kind of fuel etc. Provision of waste-heat boilers, insulation between lining and shell, devices for preheating kiln feed and combustion air etc. make the theoretical estimation impossible.

41/ "Burning, Cooling, Drying and Hydrating", Pit and Quarry Handbook, 1960, Section B, Chapter III, p. B.213.

42/ J. C. Witt, "Portland Cement Technology", Chemical Publishing Company, Inc., New York, 1966, p. 85.

70. Rotary kilns can be used for calcining pozzolanas. Both the design and kiln operation are simpler in this process as temperatures of calcination are seldom higher than 1200°C and refractory can be also of a lower grade. Moreover, rotary kilns for pozzolana manufacture are comparatively shorter, with lower outputs compared to rotary kilns for cement manufacture. The former are more comparable with those used in lime manufacture.

4. Pulverizing and Grinding

(a) General:

71. Some natural pozzolanas need only be crushed and pulverised for their use in mortars, while others need to be ground and pulverised before they are ready for use in pozzolanic cement manufacture (pozzolanic materials are normally supposed to be in dry condition before pulverisation or grinding). Before selecting a grinding machine, grindability of the material may be tested on a grindability machine as per ASTM Designation D 409-51, which recommends the Hardgrove Machine for this purpose.43/

(b) Pan Grinder:

72. The dry pan is of particular interest in disintegrating shales and clays, volcanic tuffs, tufaceous limestone, pumice and other similar pozzolanic materials. The dry pan is 8 or 10 feet in diameter and its bottom consists of a centre of solid plates surrounded by others that are perforated. Two heavy rolls rest on the solid plates and revolve by friction as the pan rotates under them. (In edge-runner, which also consists of a pan, it is the rollers which revolve.). The material is continuously swept under the rolls with the help of scrapers until it is fine enough to pass through the perforated plates. Dry pan, if run wet, will perform the double function of coarse grinding and mixing. This type of grinding for the raw materials may be suitable in the manufacture of surkhi by burning moulded clay bricks in a conventional brick kiln. For that matter, it may be advantageous to run the pan wet even if clay happens to be dry. Otherwise, dry pan will grind material to a fineness that it can be fed directly to a ball- or compartment mill or in exceptional cases to tube mills. Sometimes, for its use in making mortar, a natural or calcined pozzolana need only be coarse ground and a dry pan will serve the purpose well.

43/ Standard Method of Test for Grindability of Coal by the Hardgrove-Machine Method. ASTM Designation D 409-51 (1961), Handbook of ASTM Standards, 1967, Part 19, American Society for Testing and Materials, Philadelphia, United States of America.

(c) Raymond Mill:

73. A Raymond roller mill[44] with integral whizzer separator can be used to grind material to pass (99.9 per cent) through 325 mesh and finer. It has means for size classification and is economical. The machine can grind almost all non-metallic minerals and is useful in handling moderately sticky substances. The Raymond flash drying system can be applied here as well as the Raymond hammer-type Imp mill as both the mills are equipped with air separation. The flash drying system permits the introduction of heated air or products of combustion from a furnace or any other source. The heat required can also be waste heat taken from a boiler, rotary kiln etc. The hot gases remove the moisture from finely divided moist particles in suspension and the dried, pulverized product is collected at the bottom of a cyclone collector. Drying of porous materials, like diatomaceous earth with simultaneous pulverization can be achieved in this type of machine. Diatomaceous earth is an important pozzolana.

(d) Grinding Mills:

74. For most natural or calcined pozzolanic materials open circuit grinding mill would suffice. Furthermore, one-stage grinding, i.e. reduction of a rock less than 1½ in. size to a fine powder, may be done in a single mill in one operation for a large majority of pozzolanas. Here the material remains in the grinding zone until it is sufficiently fine. A grinding mill is a cylindrical drum with a metallic or abrasive lining, supported on its cylindrical axis in a horizontal position and rotates about this axis. It contains steel balls, suitable stone or other units which act as grinding media. The mills and balls can be in different shapes, but their over-all value is rated on characteristics such as capital cost, maintenance cost, power requirement, lubrication requirement, output, particle-size distribution of product, vibration, noise, dust production etc. Witt[45] classifies the mills as (1) preliminary mills: ball mill, roll and ring mill; (2) finishing mills: tube mill; and (3) combination mills: compartment mill. A brief description is given below.

44/ "Crushing, Grinding and Separating", Pit and Quarry Handbook, 1960, Section B, Chapter I, pp. B.50.

45/ J. C. Witt, "Portland Cement Technology", Chemical Publishing Company, Inc., New York, 1966, pp. 117-119.

75. Ball Mill. It is a steel cylinder which is lined with iron or steel plates. It rotates horizontally at low speed. Iron or steel balls, usually not less than two inches nor more than four inches in diameter, are used as grinding media. Mills are available in 3 to 10 ft. diameters with lengths to suit (6 to 28 feet). It is used for preliminary grinding purposes. Sometimes a "ballpeb" mill[46/] can be operated in series with a preliminator mill for extra fine grinding. It has diameters from 5 to 11 feet and lengths up to 40 feet and takes in relatively fine feed.

76. Tube Mill. It is generally the second unit in two-stage grinding in a cement plant. It is a cylindrical steel shell with heavy cast steel ends. The diameter varies from 5 to 8 feet and the length from 20 to 27 feet. The lining is no different from that of ball mill. The iron or steel balls not exceeding 1.25 in. diameter are the grinding media. For dry grinding the feed must be free of moisture. General recommendation for feed size is a material passing 16 or 20 mesh sieve. Such a feed may have about 60 per cent passing 100 mesh and 40 per cent passing the 200 mesh sieve.[46/] A tube mill is used for finish grinding.

77. Compartment mill combines a ball and a tube mill in one shell. It may have more than two compartments containing grinding media of different sizes. Compartment mills have screening sections in between the compartment and as such do away with intermediate feeding and conveying which is required in two-stage grinding combination. These mills have diameters ranging from 5 to 9 feet and lengths between heads from 22 to 50 feet. The mill is usually driven by slow speed synchronous motor coupled directly to the pinion shaft. There are two weaknesses in these mills. First, the material retains most of its heat in passing from one compartment to another. Secondly, it is not adaptable to materiel of varying hardness supplied to it with short intervals. The latter could be a disadvantage in grinding a pozzolanic material of varying hardness.

5. Drying and Blending

(a) Rotary Dryer:

78. Essentially rotary dryers are similar to rotary kilns. The dryers are either direct or indirect heating types. Drying may be achieved by hot air or exhaust gases from other operations. When the drying gas has a deleterious effect on the

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46/ "Crushing, Grinding and Separating", Pit and Quarry Handbook, 1960, Section B, Chapter I, pp. B.54, B.57.

product, an indirect-type dryer is used. The direct type is recommended for products which can come in contact with the material to be dried. Partition plates are provided to increase heating surface and lifters are provided to shower the materials through the hot medium, provided the material can withstand this handling.

(b) Blending:

79. In the production of pozzolanic cements, blending of finely ground pozzolana with portland cement or lime or both may have to be done. Blending systems normally used in the cement industry for the blending of raw meal can be adopted for the former purpose. The requirements for such a system would be reinforced concrete or steel silos with the necessary equipment for stirring the charge by compressed air and mechanical means, or both. The auxiliary equipment would be valves, pumps, high pressure fan, etc.

6. Storing and Packing

80. Cylindrical reinforced concrete silos with conical or hopper bottoms are generally used for storing cement. Such silos are also required for storing fine pozzolanas. The height, diameter and capacity of the silo, however, should be chosen to suit the particular situation. The weight of a cubic foot or cement is known to increase as the depth of cement in a silo increases.47/ This will also be true of fine pozzolanas; capacity therefore may be calculated in terms of linear foot of depth.

81. Pozzolana and pozzolanic cements may be packed in wooden barrels, steel drums or bags of various types. Bags made of jute, paper, cloth, woven fibre, laminated textile or rubberised fabric can be used; jute and paper bags are most common. Multi-wall paper bags are made of two to six walls of strongest type of Kraft paper combining flexibility and strength. For protecting the product against moisture, bags may be fitted with a special lining, for example polyethylene.

82. Bag filling and sealing can be done with the help of packing and sewing machines. These machines can be semi- or fully-automatic. Literature may be consulted for their description and job performance.

47/ J. C. Witt, "Portland Cement Technology", Chemical Publishing Company, Inc., New York, 1966, pp. 131-132.

E. Plant Design

1. General Considerations

83. The general considerations for plant design are well known. Since a variety of naturally occurring raw materials can be turned into pozzolanas by either grinding alone or by crushing followed by grinding or by crushing, followed by calcination and grinding. It is not possible to treat the plant design for pozzolana manufacture very precisely. Fly ash pozzolana, normally available in powder form, does not require any processing except drying and that only if it contains moisture. (In some situations a marginal fly ash showing activity somewhat lower than the specified minimum may have to be ground to pass the minimum specifications.) Naturally-occurring materials which are compact, for example tufaceous limestone of Germany and Neapolitan Yellow tuff of Italy, require to be crushed, dried and ground. Some naturally-occurring materials may be available in loose pulverised state, and the crushing operation can be omitted, only pulverising and grinding being required. Others, like diatomites, may require no elaborate processing except drying, which has to be of a special type as driving out of moisture from this very fine powder in ordinary dryers is not easy.

84. Calcination is an additional operation in the manufacture of pozzolanas from natural materials such as clays, shales and other sedimentary products. Calcination is carried out usually in a rotary kiln where drying of the raw material can also take place, i.e. a separate dryer is not needed in this particular manufacturing plant.

2. Scale of Production Unit

85. On the basis of a market survey, Witt[48] opines that commercial conditions in or near a big town are favourable for the construction of a cement plant having an annual capacity of 1.5 million barrels and recommends a unit rotary kiln of dimensions 10 x 250 ft. for production of cement by dry process. The production of clinker would be about 450 tons a day. In India, a rotary kiln with a daily capacity of 600 tons has been adopted as a unit by the cement machinery manufacturers. On this basis, a rotary kiln with a capacity of about 150 tons per day of pozzolana could be considered a suitable unit as the pozzolana component in the portland pozzolana cement is usually about 20-25 per cent and its density is

48/ J. C. Witt, "Portland Cement Technology", Chemical Publishing Company, Inc. New York, 1966, p. 143.

considerably lower than that of clinker. In relation to production of clinker from a large rotary kiln, a unit rotary kiln producing 150 tons of pozzolana could be called medium and the one with a capacity of about 60 tons a day could be considered a small production unit. The nomenclature "large", "medium" and "small" has been used here to denote production from a single unit and not total production achieved by setting up multiples of units.

3. Choice of Process

86. Once a decision has been made regarding the production capacity of the unit, alternative processes of manufacture of a pozzolana should be considered and the one more economical, commensurate with quality, be preferred. For this purpose, selection of major plant equipment discussed under "Unit Operations" and accessory equipment such as feeders, materials-handling equipment, storage, conveyors, etc. alone is not sufficient; preparation of a flow sheet and calculation of the cost per unit of each product by alternative methods is necessary. Then only a realistic choice can be made between alternatives.

4. Level of Technology and Availability of Machinery

87. The two other considerations in the plant design could be the existing level of technology in a particular country and availability of machines. The yardstick for both could be the current level of portland cement technology in a country. A country producing cement by the modern methods and also having facilities for the production of cement manufacturing machinery, could also design and build plants for the manufacture of pozzolanas. But if cement machinery is being imported, it may be desirable to produce pozzolana by processes which do not require much of heavy machinery. The countries where cement production itself is lagging behind demands may seriously consider production of calcined natural pozzolanas by traditional methods so as not to divert efforts and funds from cement to pozzolana manufacture as, unlike pozzolana, the former cannot be produced by traditional methods. Moreover, the object of countries facing cement shortage should be to augment the supply of cement with pozzolana by producing portland pozzolana cement or by reducing the pressure on cement by producing lime-pozzolana cement. These considerations are worthy of attention of planners and designers in developing countries where materials and funds are not adequate and labour is plentiful and cheap. Manufacture of pozzolana by modern methods, however, is essential when it is to be used for special purposes, say in mass concrete for constructing dams and other irrigation and power works In such cases the plant should be mechanised to an extent that it is efficient and permits quality control.

18. 5. 73

APPENDIX

LIST OF TABLES

List of figures

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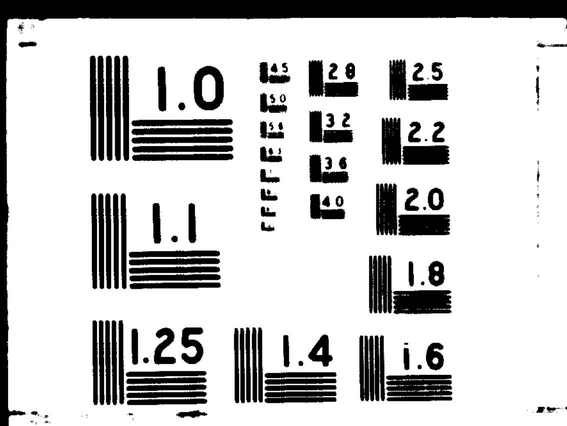

88. Calcination of pozzolana is the most expensive operation in the manufacture of pozzolana both from the point of view of capital cost of equipment and cost of calcination as a unit process. From this point of view, manufacture of pozzolanas which need no calcination but only crushing and grinding is simpler and within the reach of many developing countries as it does not involve a high level of technological development. Also there is a much wider choice for the crushing and grinding machinery and in the absence of the most suitable machine, a second best can be used to produce a finished product suitable for a large majority of purposes, if not for all.

F. Manufacture of Calcined Shale at the Bhakra Dam

89. About 700,000 tons of portland cement was required for producing over five million cubic yards of concrete for the construction of the Bhakra Dam and appurtment works.[49,50] Twenty per cent pozzolana was used as cement replacement. A plant for the manufacture of the calcined shale, as pozzolana, was designed, fabricated and set up by the Dam authorities in about one year. The plant capacity was 3000 tons per month. In all, 54,000 tons of pozzolana were produced. A brief description of the plant is given below.

1. Raw material:

90. The hillocks within a distance of two miles of the Bhakra Dam site were found to contain shale deposits. The deposits of siliceous shale between elevations of 1400 and 1600 ft on the right side of the Bhakra Gorge, about a mile upstream of the dam site, were considered suitable from the point of view of exploitation because of easy accessibility, location of the batching and concrete mixing plant on the right bank of the river and uniformity in composition of the pozzolanic material. Laboratory investigations were carried out for selecting the optimum temperature and time of calcination for the maximum pozzolanic activity. The optimum conditions fixed were a temperature of 1400 $\pm$ 50°F and a period of two hours. The properties of concrete containing 20 per cent pozzolana as replacement were also studied adequately.

49/ Ardman Singh, "Manufacture of Pozzolanas for the Bhakra Dam Mass Concrete", Symposium on Pozzolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec. 1964.

50/ B. R. Palta and P. S. Rao, "Experience on Use of Pozzolana at Bhakra", Symposium on Pozzolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec. 1964.

to rise out of each line of feed holes, they are successively closed so that the chimneys can exert their full power.

108. Twentyfour hours after firing has commenced, the third chamber is completely loaded and the cross-dampers are withdrawn from the second opening and put down the third. The chimneys, which are initially placed at a distance of 5 or 6 rows of feed-holes from the three rows under fire, are now shifted and placed at the end of the second chamber, the first chimney opening being closed up and properly sealed.

109. When there is a good bottom heat in the fourth row and the bricks in the first row are red hot, top firing is commenced from the first row of feed holes. Three or four hours later, a second may be commenced and so on. The ladle for charging coal from the top holds about 1¼ to 1½ lbs. of coal. On starting the firing in a fresh line, 4 to 5 ladles are charged at once, and afterwards 3 or 4 feeds per hour are required.

110. The kiln is now in full working order and top and bottom firing is continued till the first furnace has been sufficiently fired. At this stage the bottom firing is slackened down and finally stopped till about six furnaces have been fired. The furnace "mouths" are then loosely closed with bricks. When about 8 to 10 chambers have been fired, the temporary cross wall may be pulled down and unloading commenced. Loading, firing and moving the chimneys forward is now carried on in the proper order. As the fire progresses forward, the chimneys are also shifted, maintaining a distance of about 40 to 50 ft. between the fire and the chimneys. Majumdar[13] has described this kiln in fuller details.

3. <u>Quality of Surkhi</u>:

111. Surkhi produced as a by-product of brick manufacture is bound to be variable in nature. Generally, underburnt and overburnt bricks which are not easy to sell are ground to make surkhi and the corresponding products of grinding are called underburnt and overburnt surkhi respectively. This terminology is based on visual examination and obviously can be misleading as far as quality of surkhi is concerned because the terms underburnt or overburnt are relative to the temperature of producing good quality bricks which is not necessarily the right temperature for calcining brick earth for producing surkhi. Because of this reason and the differences in surkhi grindability and also the final

fineness attained by grinding (either for a definite time in a particular machine or to a definite fineness, i.e. passing a particular sieve) underburnt, wellburnt or overburnt surkhi-raws, surkhis of different reactivities were produced. Consequently, contradictory conclusions regarding the suitability of employing an under, well or overburnt surkhi were drawn.15,16,17/

112. For similar reasons no agreement could be reached on the type of surkhi even when the latter was produced specially and under controlled conditions at the big irrigation projects. Though admittedly, each of the surkhis produced and used in the big construction works was superior and uniform in quality (because of better controls on raw material and methods of manufacture) it is not possible to make generalized statements as to the nature of raw materials and methods of manufacture of surkhi from the practices followed. The situation had arisen from a general lack of a sound scientific understanding of the nature of pozzolanas18/.

C. Post-War Researches on Surkhi

113. From 1915 to 1930 the growth of the Cement Industry in India was rather slow, production rose from 85,000 tons of cement to only about 600,000 tons. In 1940 the first big leap was made when the production rose sharply to about 17 lakh tons.19/ By then the cement industry was well organised and great publicity was given to the use of cement. Because of this publicity and also the deterioration in the quality of both lime and surkhi, use of lime-surkhi mortars was on the decline. However, the Second World War had already started and demand for cement was growing faster than it could be produced. Also cement was required for military purposes. All this resulted in the scientific investigation of surkhi.

15/ S. K. Chopra and N. K. Patwardhan, "Pozzuolanas - Their Use in Mortars and Concretes", Journal Irrigation & Power, vol. XII, No. 2, April, 1955, 23-24

16/ N. R. Srinivasan, "Surkhi as a Pozzolana", Reserrch Paper No. 1, Central Road Research Institute, New Delhi, 1956.

17/ M. L. Bhatia, S. G. Banerjee, Bhadur Singh and K. S. Bhalla, "Pilot Plant Manufacture of Reactive Surkhi and Lime Reactive Surkhi Mixture at CRRI", Symposium on Puzzolanas - Their Survey, Manufacture & Utilisation, Central Road Research Institute, New Delhi, Dec., 1964.

18/ F. M. Lea, Proceedings of the Symposium on the Chemistry of Cements, Stockholm, 1938.

19/ S. L. Sharma, "Organized Industries of India - Cement", Universal Publishers Ltd., Madras (India), 1954.

114. Khan and Verman[8] were the first to carry out a detailed investigation on surkhi samples produced from bricks available around Calcutta and concluded that surkhi obtained from overburnt bricks was better than that prepared from either well burnt or underburnt bricks. Replacement of portland cement with 25 to 50 per cent of surkhi was recommended. Research on surkhi was pursued actively in India during the post-war period. The first two Five Year Plans formulated by Independent India involved execution of a number of irrigation and flood control projects. Demands on cement being very great, surkhi was studied by several research workers and organizations.[20-32] But most of the research was conditioned by the past conventions and was also limited in scope, i.e. the results were either of specific or regional value only.

20/ A. K. Dutta, "Development and Application of Village Cement and High Silica Portland Cement for the Construction of Concrete Roads", Journal of the Indian Road Congress, vol. VI, 1939.

21/ A. K. Dutta, "Further Developments in Village Cement and High Silica Portland Cement for the Construction of Concrete Roads", Journal of the Indian Roads Congress, vol. VIII, 1943.

22/ A. K. Dutta, "Lime Surkhi as a Substitute for Portland Cement", Indian & Eastern Engineer, vol. 97, 1942.

23/ A. K. Dutta, "Perfect Portland Cement and Artificial Possolanic Cements", Journal of the Institution of Engineers, vol. 24, 1943, p. 62.

24/ A. K. Dutta, "Lime Surkhi in place of Portland Cement", Journal of the Institution of Engineers, vol. 24, 1940, p. 52.

25/ Annual Reports for the years 1950 and 1951, The Krishnarajasagar Research Station, Mysore (India).

26/ Annual Reports for the years 1949, 1950 and 1951, The Hyderabad Engineering Research Laboratory, Hyderabad, Andhra Pradesh, India.

27/ Annual Reports for the years 1949, 1950, 1951 and 1953. The Panjab Irrigation Research Institute, Amritsar, Panjab, India.

28/ Annual Reports for the years 1951, 1952 and 1953. The Hirakud Research Station, Hirakud Dam Project, Hirakud, Orissa, India.

29/ "Effect of Surkhi Admixtures on Strength of Cement Surkhi Mortars for Bhawani Project", Annual Report 1948, Concrete & Research Laboratory, Madras, India.

30/ N. R. Srinivasan, "Physical and Chemical Studies on Surkhi", Report R 12/51, Annual Report, 1951, Concrete Research Laboratory, Madras, India.

31/ K. L. Rao and A. R. Venkataraman, "Surkhi as an Admixture", Report No. 65, Question No. 15, Proc. of the International Commission on Large Dams, 1951, New Delhi.

32/ C. L. Handa, C. L. Dhawan and J. C. Bahri, "Surkhi as a Possolana", Indian Concrete Journal, vol. 26, 1952, pp. 97-102.

115. The work of Mielenz, Witte and Glantz[33] on the optimum temperature of calcination of clay for best pozzolanic activity and the relationship of the latter with the type of clay minerals, evoked great interest all over the world. The Central Road Research Institute in India recognised that surkhi was essentially a burnt clay pozzolana and made elaborate mineralogical study of different types of soils burnt at different temperatures and of the pozzolanic activity of the surkhi derived from these soils. As a result it was brought out[9,14,16,34] that the type of loamy soil, fit for brick making, is not suitable type for making surkhi as it is deficient in clay fraction (particles less than 0.002 mm) which only yields reactive products under optimum conditions of calcination. But it is not to be supposed that all highly clayey soils could produce very good surkhi. Essentially one has to select the raw material in the light of its mineralogical composition and the impurities present and then calcine the clay under carefully selected conditions. Every clay has its optimum temperature and period of calcination and shows maximum activity only then. Surkhi thus made is called reactive surkhi by some[16] to differentiate it from the surkhi produced without adequate controls. The implication here is not that the latter type of surkhis are non-reactive but that in majority of samples full value in terms of activity are not possibly achieved.

D. Manufacture of Burnt Clay Pozzolana or Reactive Surkhi

116. Surkhi produced from carefully selected raw materials and in the light of modern technological developments is termed as reactive surkhi to differentiate it from the bazaar surkhi. In essence, it is nothing but a burnt clay pozzolana. Surkhi should be manufactured by suitable methods if its intrinsic properties are to be exploited to the fullest extent.

33/ R. C. Mielenz, L. P. Witte and O. J. Glantz, "Effect of Calcination on Natural Pozzolana", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia, 1950.

34/ N. R. Srinivasan, "Probable Factors Governing Pozzolanic Action", Journal of Scientific & Industrial Research, vol. 15A, 1956.

1. Raw Materials

(a) Selection of Clay:

117. The Pozzolana Sectional Committee of the Indian Standards Institution, New Delhi, responsible for the preparation of an Indian Standard on Surkhi[35] had taken into consideration the prevailing practices and experience in the manufacture and use of surkhi and also the latest research in the field. It has made the following recommendations regarding the selection of raw material: For raw material, select clays

(i) which have been used in the past and are known to yield on calcination surkhi of high activity,

(ii) whose suitability has been established by the standard laboratory and research methods.

Clays which have been found satisfactory conform generally to the following chemical requirements when analysed on an oven dry basis (at 105°C) as per the methods given in IS:1727-1960 on the Indian Standard Methods of Test for Pozzolanic Materials[36].

Constituents	Content
Silica + Alumina + Iron Oxide [SiO_2 + Al_2O_3 + Fe_2O_3]	...not less than 70 per cent
Silica, SiO_2	...not less than 40 per cent
Calcium Oxide, CaO	...not more than 10 per cent
Magnesium Oxide, MgO	...not more than 3 per cent
Sulphuric anhydride, SO_3	...not more than 3 per cent
Soda and Potash, (Na_2O + K_2O)	...not more than 3 per cent
Water soluble alkali	...not more than 0.1 per cent
Water soluble material	...not more than 1 per cent
Loss on ignition	...not more than 5 per cent

(iii) which do not contain non-essential elements in any undesirable quantities; i.e., pebbles, gritty matter, humus etc. are not present in large quantities and clay deposit is of uniform hardness,

(iv) which are not deficient in particles below 0.002 mm and are kaolinite-type, montomorillonite type or illite-type clays or mixed clay with vermiculite when examined by the established methods of identification of clay minerals,

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35/ IS:1344:1959, Indian Standard Specification for Surkhi for Use in Mortar and Concrete, Indian Standards Institution, New Delhi.

36/ Indian Standard Methods of Test for Pozzolanic Materials, IS:1727-1960, Indian Standards Institution, New Delhi.

(v) which on calcination at predetermined temperature selected from laboratory tests will yield surkhi which when ground to a minimum fineness of 2250 sqcm/g by the air permeability method will show a strength at least 600 lb per sq.in. in the lime reactivity test.

118. The other considerations to be borne in mind for a final selection of a clay deposit are

(i) the deposit is easily accessible and is near an existing or a potential market,

(ii) the overburden on clay deposit for a small or medium scale production unit of surkhi is not more than 5 feet,

(iii) the clay deposit is uniform and requires only few operations to extract the raw material,

(iv) the clay deposit is extensive in relation to the surkhi production unit. The minimum quantity of available clay should be at least 15,000 tons for small scale industry (10 years working at an annual rate of 1500 tons a year) and about 60,000 tons for medium scale industry. For a large production unit making use of rotary kiln, clay deposit should be sufficient to last at least 20 years,

(v) the clay deposit should be graded in wider context, i.e. care should be taken not to utilize the material which has more important potentials, say in ceramic or any other important industry, and

(vi) clay deposits are near industries such as lime, cement or ceramics, etc. or near major civil engineering works.

(b) Mineralogical Composition:

119. Soils, brick-earths and clays have been used as raw materials for the manufacture of surkhi. The active component of the raw material is the clay fraction, i.e. particles less than 0.002 mm in diameter. The clay fraction consists of clay minerals which are divided into three main groups:

(i) The kaolin group consisting of the minerals kaolinite, halloysite, nacrite, dickite and endellite.

(ii) The montmorillonite group consisting of montmorillonite, hectorite, beidellite, nontronite and saponite.

(iii) The hydrous mica group consisting of illite and related minerals.

120. Table 2 lists the different clay minerals and their thermal characteristics[37]. Identification of the clay minerals is usually done in a laboratory with the aid of one or more of the methods such as base exchange capacity,

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37/ A. B. Searle and R. W. Grimshaw, "The Chemistry and Physics of Clays and Other Ceramic Materials", Ernest Benn Ltd., London, 1959, pp. 890-893.

Table 2

Differential Thermal Data of Important Clay Minerals

	Clay mineral	Formula	Endothermal Peaks			Exothermal Peaks		
			Peak temp. °C	Magnitude	Cause	Peak temp. °C	Magnitude	Cause
1.	Kaolinite	$Al_4Si_4O_{10}(OH)_8$	105	small	adsorbed water	985	very large	γ-Al_2O_3 and/or nucleation of mullite
			585	large	dehydroxylation			
2.	Halloysite	$Al_4Si_4O_{10}(OH)_8 \cdot 4H_2O$	115	medium	interlayer water	985	large	γ-Al_2O_3 and/or nucleation of mullite
			550	large	dehydroxylation			
3.	Illite	$(K,H_3O)Al_2(SiAl)_4O_{10}(OH)_2$	105	v. small	adsorbed water	940	medium	spinel
			550	small	dehydroxylation			
			900	medium	lattice destruction			
4.	Montmorillonite	$(Al_{3.33}Mg_{0.67})(Si_8)O_{20}(OH)_4$ ↓ $K^+_{0.67}$	140	medium	interlayer water	920	small	spinel
			700	medium	dehydroxylation			
5.	Beidellite	$(Al_4(Si_{7.33}Al_{0.67})O_{20}(OH)_4$ ↓ $K^+_{0.67}$	150	medium	interlayer water	915	small	–
			540	small	dehydroxylation			
6.	Nontronite	$Fe^{+3}_{4.00}(Al_{0.66}Si_{7.34})O_{20}(OH)_4$ ↓ $K^+_{0.66}$	140	medium	interlayer water	900	small	spinel
			490	medium	dehydroxylation			

Table 2 (continued)

Clay mineral	Formula	Endothermal Peaks: Peak temp. °C	Endothermal Peaks: Magni-tude	Endothermal Peaks: Cause	Exothermal Peaks: Peak temp. °C	Exothermal Peaks: Magni-tude	Exothermal Peaks: Cause
7. Attapulgite	$Mg_5-Si_8O_{20}(OH)_2.8H_2O$	< 110	small	zeolitic water	940	medium	Enstatite, sillimanite and cristobalite
		225–350	medium	water co-ordinated with magnesium			
		400–525	medium	water from silicate unit			
8. Chlorite	Alternate mica-like and brucite-like						
	$[(OH)_4(SiAl)_8(Mg.Fe)_6O_{20}]$	< 200	small	adsorbed water			
	$[(Mg.Al)_6(OH)_{12}]$ layers	500–600	medium	decomposition of brucite layer	930	medium	Olivine
		850	small	dehydration of mica layer			Spinel

M^+ refers to a monovalent cation.

Source: Taken in part from "Chemistry and Physics of Clays and other Ceramic Materials" by Alfred B. Searle and Rex. W. Grimshaw, Ernest Benn Ltd., London, 1959.

potentiometric titrations, viscosity measurements, chemical analysis, differential thermal analysis, X-ray powder diffraction analysis, electron micrographs or diffraction patterns etc. Of these methods, the differential thermal analysis and X-ray powder analysis are employed commonly as these are most fruitful. But these methods require costly equipment and expert personnel to handle it.

121. Identification of clay minerals is of very wide interest because of its application both in the fields of agriculture and industry. Attempts have, therefore, been made in the past to devise simple tests. However, Keeling[38/] has described a simple method to identify clay minerals, based on the determination of IL/MA ratios The term IL refers to ignition loss of the clay mineral and is determined by substracting the loss at 375°C and CO_2 due to calcite or dolomite from the total ignition loss The term MA refers to the total moisture adsorbed by the oven dried sample when exposed to 75 per cent relative humidity. Well ordered kaolinites give a value around 7, disordered kaolinites 2-3, illites around 1, and montmorillonites less than 0.7. Since determination of MA takes about a week, Ramachandran, Kacker and Handa[39/] have suggested in its place determination of the amount of dye adsorbed which is quicker and quite reliable[40/]

(c) Effect of Heat on Clays:

122. As clays are progressively heated, the clay minerals generally undergo the following thermal changes in sequence:

(i) loss of physically adsorbed and interlayer water,

(ii) loss of the structural water, i.e. loss of hydroxyl ions,

(iii) collapse of the crystal structure and formation of an intimate mixture of oxides or a solid solution,

(iv) phase transformations in individual oxides or compounds, and

(v) interaction of the oxides to form new phases; and crystal growth.

While the temperatures and the main products of thermal decomposition of the main clay minerals are given in the last column of table 2, the data with respect to

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38/ P. S. Keeling, "The Examination of Clays by IL/MA", Transactions of the British Ceramic Society, vol. 60, April, 1961, pp. 217-244.

39/ V. S. Ramachandran, K. P. Kacker and K. N. Handa, "Identification of Clay Minerals by IL/DA Technique", Central Building Research Institute, Roorkee (U.P.), India, (under publication).

40/ V. S. Ramachandran, K. P. Kacker and N. K. Patwardhan, "Basic Dye Stuffs in Clay Mineralogy", Nature, 191, No. 4789, p. 696, 1961.

some important clays (Rayerkeri, Belgaum, Nagpur, Jamuna, Darjeeling clays) which are known to yield good to very good surkhis[16] show that clays may contain impurities too which, together with the disorders in the structure of clay minerals, can influence the temperatures of thermal changes, their course and products of thermal decomposition. (Accessary minerals in the non-clay fraction may also influence these.)

123. There seems to be a good relationship between maximum pozzolanic activity and the temperature close to the temperature at which collapse of the clay's lattice structure takes place. A highly disordered clay structure or a large percentage of the oxides of silicon, aluminium and iron in very fine and poorly crystallized state resulting from collapse of clay structure appear to be responsible for high activity. Heating at higher temperature reduces activity because of increase in particle size, improvement in crystallinity, formation and growth of stable crystals[16,34]

2. Calcination in a Down Draught Kiln:

124. In view of the importance of firing a clay at an optimum temperature of calcination for producing a reactive surkhi, use of brick kilns such as clamps, a Bull's trench kiln, overground type of kilns is not favoured as it is difficult to control temperatures in these kilns. Though Hoffmann type of kiln can give better controls on temperature, a single chambered down draft kiln of the type used in ceramic industry appears to be suitable[17] both from the point of view of temperature control and uniform heating.

(a) Processing of Raw Material

(i) Crushing and Grinding:

125. Clay is widely distributed in nature and occurs in different forms. It is, therefore, difficult to recommend any specific process for crushing because the latter is very much dependent on the nature of the raw material and the impurities present in it. Since production of surkhi in a down draft kiln at an economical price presupposes availability of cheap labour, clays which can be processed with the help of manual labour should be preferred. The processing may involve removal of any stones, pebbles or grit etc., pounding of clay with hammers and passing it through a particular screen.

126. Harder clays may be watered and thus softened. They may be kneaded under feet till the clay is a homogenous mass. In some situations pug mill or wet pan

2. **Manufacture:**

91. The manufacturing of the pozzolana was done in four stages independent of each other. Presumably this was done to have flexibility in operation to compensate for lack of experience; the Bhakra Pozzolana Manufacturing Plant being the first of its kind in India.

(a) **Quarrying and Transportation of Raw Material:**

92. The deposits at the quarry were not uniform and contained a large number of sand-stone, siltstone ribs and overburden of talus. The sand-stones and talus were rejected at the quarry site in the process of excavation, but the silstone bonds were interwoven with those of shale and the removal of the former was not possible at the quarry. However, most of the siltstone was removed by hand picking when it was being transported to the primary crusher on a slow-speed belt conveyor. The conveyor had side walk ways on both sides and start-stop push buttons conveniently located; it passed in front of the field control laboratory. The raw feed was found to contain 3 to 6 per cent of siltstone against a toleration limit of 15 per cent. The operations of quarrying and transportation were fully mechanized and made use of earth-moving equipment already available on the project.

(b) **Crushing and Sizing:**

93. The excavated raw shale was available as fine dust and big lumps. The latter were reduced to 3/4 in. maximum size in primary and secondary crushers installed in the belt conveyor system. The crushing and sizing was achieved with two jaw crushers and a single deck vibrating screen in closed circuit. The crushed shale was then conveyed, elevated and stored in a 500-ton capacity silo. This operation was carried out on single shift bas s.

(c) **Calcination:**

94. Calcining of the shale was done in a 100-foot ong rotary kiln of 5 ft. 6 in. diameter (including 6-inch thick refractory lining). The kiln was constructed with a slope of 3 per cent and revolved at the rate of one rev. per min. A 30-inch table feeder was used for controlling the feed, conveyed to the kiln by a belt conveyor. Oil was used for firing the kiln, and the temperature at the firing end was 1600-1700°F. The temperature at the feed end was 200-250°F; this low stack temperature was achieved through a chain-type heat exchanger. The latter reduced the temperature of exit gases and helped in preheating the raw feed more efficiently, thus increasing the over-all efficiency of the kiln.

may have to be used. The wet clay is then covered with mats to dry gradually till it attains the right consistency for brick moulding.

(ii) Moulding of Bricks:

127. A brick mould is a rectangular box of seasoned wood or iron. Sometimes the edges of wooden moulds are protected with strips of brass or iron screwed on and iron lining is provided inside. Moulds of quarter inch thick iron plate are used at big brick fields as they turn out cleaner and more uniform sized bricks and are economical in the long run. However, bricks for surkhi manufacture need not be perfect in shape.

128. The mould frames have generally no top or bottom plates. When a base is provided, the moulds are known as box moulds. Moulding of green bricks should be preferably done by hand. The bricks can be moulded on the ground and this process is known as ground moulding. The bricks can also be moulded on tables and the process is known as table moulding. There can be a good deal of variation in the moulding practices from one country to another. The practice most common in any one particular country for brick making should normally be adopted. Hand moulding should be preferred where labour is plenty and cheap.

(iii) Size of Bricks:

129. There is no data on the effect of brick size on the quality of surkhi produced in a brick kiln. Generally, the brick sizes common in the manufacture of burnt clay bricks are recommended for use for surkhi manufacture. A smaller brick size should be preferred as it will lead to better heat transfer and therefore a better product.

(iv) Drying of Bricks:

130. Great care and attention is required in drying and protecting the green bricks against sun, wind, rain and also frost in some cases. Immediately after moulding, the bricks are placed flat or on edge on the ground for a few days (generally 2 to 3 days). The length of drying time depends solely on weather. The bricks are placed on edges so that the sides receive proper heat and air. In India hand moulded bricks are dried mostly in sun, clays with small shrinkage are not affected by drying in sun. On the other hand, more shrinkable clays which are more common for surkhi manufacture may warp and crack in the sun. Consequently drying should be done in open sheds. The additional advantage of shed drying would be that the manufacture can be carried out even during the rainy

season. Complete drying may take from one to three weeks depending on weather conditions. Artificial drying will have to be resorted to in areas where the rainy season covers most part of the year. In such cases hot gases going waste from the calcining kiln may be used for drying purposes.

(b) Down Draught Kiln

(i) Description of the Kiln:

131. A down-draught kiln consists of a round chamber with a number of fire-boxes evenly spaced round its periphery. The kiln is covered by a domed top, the height of which above the kiln floor is related to the diameter of the kiln. The kiln is internally lined with firebricks, usually about 9 in. thick. The fire-brick wall is externally backed by about 18 inch of red brick. For higher thermal efficiency, a layer of $4\frac{1}{2}$ in. of insulating bricks can be provided between the firebrick and the external red brick wall.

132. The fuel, which is usually a high volatile bituminous coal (similar to steam coal) is burnt on grates. To secure better combustion, the grates are inclined and, in modern practice, the grates are built within the kiln walls. In the construction of the grates, charging doors and ash pits, care has to be taken to ensure that inflow of cold air is reduced to the minimum. For this purpose all the openings are covered by specially designed cast-iron doors. Both the charging and the ash-pit doors are provided with slits which can be closed either fully or partially to provide controlled inlet of primary and secondary air. The primary air, admitted through the ash pit, passes through the grates and the fuel bed. The secondary air is admitted above the fuel bed. In improved designs of such kilns, flues are built within the firebox for admitting and preheating secondary air. In such a design, the preheated secondary air is introduced at a certain height above the fuel bed where it directly meets with the stream of combustible gases rising up from the fuel bed. In this way more efficient combustion of the volatile matter is secured. Again, since the combustion of the gases takes place well within the kiln chamber and not in the fire box, more efficient utilisation of the available heat is secured.

133. Inside the chamber, bag walls are provided in front of each firebox. The function of the bag wall is twofold, viz., (i) to deflect the hot gases upwards, and (ii) to prevent the goods set close to the fireboxes from getting fire flashed. The height of the bag wall is usually about 4 ft. but it can be higher

or lower. It can also be suitably perforated to permit part of the hot gases to enter the chamber close to the floor so that the temperature differences between the top and bottom of the setting is reduced.

134. The floor of the kiln is perforated. These perforations are communicated with a number of flues constructed below the floor. The products of combustion, after giving up their heat to the charge, pass through these flues and finally discharge into a common flue which communicates with the chimney. The flues can be designed in various ways, the object always being to secure as even temperature distribution within the kiln chamber as possible.

135. A damper is generally built into the flue leading to the chimney and by regulating this, the kiln draught can be varied. In such kilns, waste gases pass into the chimney at fairly high temperatures resulting in considerable heat loss. However, part of the sensible heat of these waste gases can be utilized in drying green bricks.

136. For controlling the firing operation, thermocouples can be inserted through specially built holes through the kiln wall. The thermocouples can be connected either to indicators or recorders. A draught-gauge, either of the recording or indicating type, can also be used for controlling draught.

(ii) Loading of Kiln:

137. The bricks are stacked in several annular rings, bricks being laid radially from end to end. The bricks may be set in any suitable manner, but care must be taken to leave the perforations in the kiln floor open. Another point to be kept in mind when loading the kiln is to see to it that enough space is left between bricks and dome for combustion to take place, otherwise much of the heat will go to waste. In a kiln of 10 ft. diameter 5000 bricks (approximate dimensions of 9 in. x 4½ in. x 2-3/4 in.) can be set by four labourers working two days on 8 hours shift duty per day.

(iii) Firing of the Kiln:

138. Firing should be started simultaneously in all the fire boxes and fire box mouths should be opened sufficiently to allow the requisite amount of air to enter. At the beginning of the operation the heating should not be too rapid as the moisture in the bricks should be driven off gradually. However, the heating rate should be such that evaporated water is removed as soon as it is formed. The smoke leaving the chimney is at first black and then "white",

the latter results from the condensation of steam on leaving the chimney. The temperature at this stage is not more than 200°C. The fire is stirred and intermittent coal feeding is carried out to raise the temperature gradually and steadily. The fires are kept burning very brightly until the dome temperature reaches the required calcination temperature. Feeding of coal is now stopped and the kiln is allowed to cool slightly. The kiln temperature is again raised by light firing with steam coal. This process of alternate heating and cooling is suitably repeated until the entire charge of bricks attains the optimum calcination temperature. In this manner "temperature stabilization" of the kiln is achieved. The optimum temperature of calcination which is also the maximum temperature is then maintained for one hour or so by slow feeding of fuel. The latter is known as "soaking period".

(iv) Cooling and Unloading of the Kiln:

139. The firing is stopped at the end of the "soaking period" and the kiln temperature drops. Further cooling can be done by removing the flue hole covers and the kiln grate bricks. The spy holes and fire boxes can also be opened. Artificial cooling may be done to reduce the cooling time. Unloading of the calcined bricks should be done after the kiln has cooled down completely. Four labourers can unload the total number of calcined bricks (5000) in one day.

(c) Grinding of the Calcined Material:

140. Calcined bricks from the kiln are broken manually or in a disintegrator, the former being preferred for small scale production. The bricks are reduced to a size of about 1½ in. and then fed to a ball mill where the charge is powdered to pass IS Sieve No. 15 (B.S. Sieve No. 100). Two labourers working in one shift of 8 hours can grind about one ton of material.

(d) Production Capacity:

141. For a small scale manufacture of reactive surkhi a 10 to 12 ft. diameter down draught kiln is considered suitable both from the point of view of temperature control and uniform heating. A kiln of this capacity can yield about 14 tons of surkhi per batch. Each firing cycle may take four to six days. For producing 20 to 25 tons of reactive surkhi per batch, a kiln with 20 ft. diameter and about 10 ft. height will be required. The setting density of bricks weighing 6 to 7 pounds each is assumed to be about 50 pounds per cu.ft. Use of bigger down draught kilns is not advisable because of difficulties in temperature control and uniform heating.

3. Calcination in a Tunnel Kiln:

142. The tunnel kilns (also called Car-tunnel kilns) differ radically from other types of continuous brick kilns. The firing zone in these kilns is stationary while the goods set on cars travel progressively through the kiln. The hot gases, flames, and the air used for cooling flows in a direction counter to that of the goods. Thus in a tunnel kiln each part of the kiln remains at approximately a constant temperature which greatly facilitates temperature control and imparts stability to the kiln structure.

143. The tunnel can be built 300 ft. to 400 ft. long and usually about 9 ft. high and 6 ft. wide internally. The cars are built like small railway trucks but have about 9 in. of fire brick decking to protect them from heat. The wheels, axles and sides of the cars are protected by a sand seal.

144. The hot zone of the kiln is near the centre and the kiln gases travel from it towards the end at which the car enters and then passes up the chimney or to a dryer. The goods are thus preheated by the hot waste gases.

145. Air enters at the car exit end of the kiln and as it travels towards the hot zone, it is preheated by recovering heat from the cooling goods, which facilitates combustion. Hence a tunnel kiln, if of sufficient length, is as economical in fuel as a Hoffmann or related kilns and has the further advantage that, each part being maintained at a constant temperature, the waste which occurs in repeatedly heating and cooling kiln brickwork is entirely avoided and a more uniform temperature distribution is ensured.

146. For the same reason it is relatively easy to apply temperature and other controllers to a tunnel kiln as all they have to do is to maintain constant conditions. In other types of kilns, in which the temperature in every zone rises and falls at different rates, such automatic controls are less satisfactory. Tunnel kilns can be fired with the usual fuels such as coal, oil or gas. Electrical heating has also been successful with this type of kiln.

4. Manufacture of Surkhi in a Vertical Shaft Kiln:

147. At the present time, vertical shaft type of kilns are mostly used for burning lime. These kilns are either mixed feed or oil fired or even gas fired. The height being usually three to fives times that of internal diameter. These very kilns of suitable shape and size could be employed profitably in the course

of industrial manufacturing process of reactive surkhi and it would be just a parallel process to lime burning.

(a) Preparation of Raw Material:

148. The process consists in digging out clayey loam in the shape of earth clods. These clods are then allowed to dry before being fed to the kiln. The earth clods thus dried get hard and may be easily handled further without being damaged. These are admixed with right proportion of fuel (if mixed feed method is used) and are charged in the kiln with the aid of some mechanical device.

(b) Calcination:

149. The kiln is ignited at the bottom in the beginning and it continues to burn as more feed is charged from the top. If a temperature between 900° to 1000°C is maintained in the calcination zone, the calcined product may be drawn at the bottom through draw holes twice a day. In order to insure better draught condition a suitable blower may be used at the bottom. To improve the draft further a chimney may be provided at the top. The cooled and calcined product may be ground to the required fineness to use it in the form of surkhi.

150. However, for making reactive surkhi vertical kilns, with separate fire box, in which the fuel used is coal, may also be used for making reactive surkhi. This separate firing system with the help of steam, air and coal produces a long flame and the heat is directly utilised by the charge. The contamination of the ash of fuel with charge is avoided completely. Oil and gas fired kilns could be used advantageously in the similar manner as used in lime burning. The adaptations of oil fired kilns permit efficient extraction of heat. The absence of ash in the oil and gas fired kilns reduce the wear and tear of the refractory linings apart from the danger of contamination of ash with the charge. The oil and gas fired kilns are thermally efficient as well. In countries where oil is cheaper than solid fuel and easily available, oil should be preferred for firing.

151. Very little is reported on the manufacture of surkhi in the above mentioned kilns and hence it is not possible to make any recommendations. But it would appear that calcination of soft clays in such kilns would produce too many fines, thus creating handling problems.

5. Manufacture of Reactive Surkhi in a Rotary Kiln:

152. A general description of a rotary kiln is given on pages 49-50. A kiln of 200 ft. length and 10 ft. effective diameter will have a production capacity of 180 to 200 tons of calcined burnt clay pozzolana. For an inclination of 1 degree and one revolution per minute, the residence time would be about 4 hours. The material will remain in the calcining and soaking zone for about half the time. A rotary kiln will meet the requirements of calcining without the aid of a refractory lined soak pit as used for the Pozzolana Plant at Bakhra Dam (p. 58), as a retention time of materials in the calcination and soaking zone for 2 hours will satisfy the requirements for optimum retention time for most clays, shales and allied materials. The charge in the rotary kiln will go directly to the rotary coolers which may or may not be an integral part of the kiln. In the latter case, a 70 ft. long and 9 ft. diameter rotary cooler will serve the purpose.

153. Rotary kilns which do not satisfy the requirement of optimum residence time required for the desired structural changes in clay to develop maximum pozzolanic activity on account of one or the other reason, may be fired at temperatures higher than the optimum determined in the laboratory to compensate for reduced retention times obtainable in such kilns. Fixation of higher temperature may be done on the basis of trials and determination of lime reactivity strength of the trial batches of pozzolana produced.

6. Manufacture of Surkhi in Fluidised Bed Furnace:

154. Manufacture of reactive surkhi in a fluidised bed kiln is an attractive proposition and is under trial in India. This Fluo solids system has already been applied successfully in the manufacture of lime and this should be of a special advantage in reactive surkhi manufacture as clays and soils are many a time available in loose powdery state or in a friable lump form, which can easily be crushed to small lumps, granules or powder with little energy requirements. Clay calcined in this furnace will therefore need much less grinding after calcination. (Limestone is generally crushed to pass 6-mesh sieve for feeding purposes.)

155. A kiln unit generally consists of vertical reactor divided into compartments by a set of refractory dome-shaped structures. It is cylindrical in shape. The charge is fed by gravity through a feed pipe into the top compartment where

it gets fluidized and preheated by combustion gases rising through openings in the floor of the chamber. The feeding of fresh charge causes the material to overflow through a feed pipe to the next chamber where it is further heated. After preheating in one or more compartments, the charge enters the calcining chamber where it is finally heated and calcined by the flame from the oil burners built into the sides of the kiln. The calcined charge then overflows into a cooling compartment where it is cooled by the incoming air. Temperature control is achieved by regulating the rate of feed and the amount of air entering into system. A blower or compressor may be used for the latter purpose. In tall kilns feed is mostly elevated.

156. This type of kiln can be used for drying and calcining a variety of materials. Some processes may require only a single compartment kiln in which case the diameter of the kiln may be nearly the same as the height of the compartment. The hot gases rise through a perforated refactory bed and the charge is fluidised about 6 inches above it. The feed enters from one side and leaves the kiln from the opposite side. In this type of kiln the contact time of the charge with the hot gases is very short indeed.

157. The work done on calcination of clays in this type of kiln for producing surkhi is still in exploratory stages, but the trials+ have shown technical success on a pilot plant scale. Surkhi of high lime reactivity has been produced but nothing is yet known about the economics of this method.

7. Relative Merits of Kilns for Calcining Burnt Clay Pozzolana

158. Manufacture of surkhi in Bull's trench kiln which is commonly used in India for burning clay bricks is probably simplest and cheapest of all the different methods of calcining clay in the form of bricks. Capital investment is not much and supervision can be done easily by skilled burners. But the quality of surkhi produced is variable because of lack of temperature controls, non-uniform heating and fuel coming in contact with the bricks being burnt. In view of this, this kiln is not being favoured currently, however, some workers are not in full agreement on this point. While it is likely that surkhis produced in a Bull's trench kiln may show sufficient activity (L.R. 600 p.s.i.) to be classified as pozzolana, there is no doubt that firing of clay bricks in a down draught kiln will produce surkhi of greater activity and uniformity because of better temperature control and heat distribution possible in this kiln. Another

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+ Private communication.

advantage is that the fuel does not come in contact with goods. A down draught kiln, on the other hand, is a batch type kiln but this should not be considered a disadvantage in comparison to the continuous type Bull's trench kiln because the former permits flexibility in the operation schedule on this very account and in the production of pozzolanas this is important as pozzolanic raw materials can show variations even in the same deposit.

159. A down draught kiln is good for small scale production of surkhi and is more suited for rural and areas of lower population density as labour will be cheap and plentiful and skilled labour can operate the kiln. Also there is freedom for the choice of size of kiln in relation to annual requirements. Furthermore, the burning can be suspended when required; this is not so in Bull's trench kiln. However, the thermal efficiency of a down draught kiln is lower.

160. While tunnel kilns permit good control or burning conditions and thus are suitable for producing surkhi of high reactivity and are of continuous type, their use can't be recommended because of high capital and operational costs. Also, supervisory costs will be higher.

161. For any large scale manufacture of reactive surkhi or burnt clay pozzolana, calcination in a rotary kiln has advantages of continuous process, better temperature controls, more uniform burning conditions, choice of fuel, lesser space requirements for the kiln, automation and instrumentation. Also, the raw material requires lesser handling and processing compared to calcination in brick kilns. The calcined material also involves lesser handling and processing. Though the thermal efficiency of a rotary kiln is lower than that of Bull's trench kiln, it is greater than that of a down draught kiln. Longer kilns will result in greater thermal efficiency. But the setting up of a rotary kiln can be taken up only near big production centres where workshop facilities are available. Rotary kilns can be built to give even very large daily production, but, generally, rotary kilns of the dimensions used in lime manufacture should meet the requirements of pozzolana industry. Rotary kilns may at best be considered for a production down to 50 tons a day. Because of inadequate information, no definite recommendations can be made regarding the use of lime kilns for burning surkhi. On the other hand, there is no doubt that there are good prospects for the use of fluidised bed furnace for surkhi production.

E. Properties of Burnt Clay Pozzolana or Reactive Surkhi

162. The properties of surkhi pozzolana and of the cements prepared with it are no different from those described earlier in Chapter I. Herein the object is to compare the properties of lime-surkhi mortars and portland-surkhi cements when reactive surkhi is used in place of the traditional or bazzar surkhi produced from brick bats.

1. Lime Reactivity:

163. Table 3 gives the results of lime reactivity tests on surkhis prepared at different temperatures from the representative samples of the main soil types in India. Since the activity of pozzolana is best judged from the lime reactivity test, the following conclusions have been drawn:

(1) each clay has an optimum temperature for maximum reactivity and this depends upon the mineralogical composition of the clay

(2) the optimum temperature for the kaolin clays is about 800°C while for illite clays it is 1000°C; for montmorillonitic type of clays the optimum temperature is between 600°-800°C

(3) a clayey soil rich in clay minerals is expected to yield generally more active surkhis than the loamy soils considered suitable for brick making

(4) The pozzolanic activity appears to be very much influenced by the presence of iron oxides; red lateritic soils are expected to yield better surkhis than the black cotton soils.

164. Table 4 reports the ratings given to surkhi and pozzolana by different workers[41,42] on the basis of lime reactivity strengths. The Indian[35] and the American[43] Standards generally go by the minimum lime reactivity strength and from that point of view ratings such as very inactive, inactive and poorly active are redundant. The other ratings are helpful in grouping pozzolanas of the same activity index together when a large number of pozzolanic materials are under investigation in a laboratory.

41/ D. K. Joshi and M. R. Vinayaka, "Surkhi as Pozzolan", Note No. 1, Maharastra Engineering Research Institute, Nasik (Bombay).

42/ N. R. Srinivasan, "Surkhi as a Pozzolana", Road Research Paper No. 1, Central Road Research Institute, New Delhi, 1956, p. 47.

43/ Tentative Specifications for Raw or Calcined Natural Pozzolans for Use as Admixtures in Portland Cement Concrete", ASTM Designation C 402-63T. 1964 Handbook of ASTM Standards, Part 10, American Society for Testing and Materials, Philadelphia, U.S.A.

95. The total residence time of the feed in the rotary kiln was about an hour and the material handled in this period was about 5½ tons. Since the calcination period was much lower than the optimum period of two hours, the shale coming out of the discharge end of the kiln was dumped into an insulated soaking pit of 15 tons capacity, where it remained for 1½ to 2 hours. The calcined material was drawn from the soak pit periodically by a remote-controlled air-operated side gate which dumped the hot calcined material on a water-jacketed and enclosed drag chain conveyor. Water was used to cool off the hot product as it was being conveyed. It then went through an indirect type rotary cooler which had water spray arrangement on the outside. The uniformly cooled material was conveyed by a belt conveyor, elevated and stored in a 1000-ton capacity concrete silo.

(d) Grinding:

96. Two different grinding systems were used. The first one consisted of two 5 ft. dia. x 10 ft. long ball mills, each with a capacity of about two tons per hour of the finished material. Each mill was fed in series through a 30 in. sised high speed disintegrator which reduced the 3/4 in. feed to 8 mesh sise. Each of the mills was charged with 6 tons of chilled cast iron cylpebs.

97. Because of heavy wear and tear of the above grinding machinery, two-compartment mills were chosen for the second system, which proved to be better. Each of the compartment mills was 5 ft. dia. and 20 ft. long; the first compartment being 8 ft. and the second 12 ft. in length. The grinding media were 4 tons of 2 and 3 in. sise steel balls in the first and cylpebs in the other compartment. Each of the compartment mills could grind about 2.5 tons of charge to the required fineness. The finished possolana was conveyed through a screw conveyor, elevated and stored in two 700-ton capacity silos for supply to the batching and mixing plant.

C. Manufacture of a Natural Possolana (Trass)

98. A typical example of possolanas which do not require any calcination is the manufacture of the trass from tufaceous limestone deposit in Germany.[51] The deposit is first drilled and blasted with weakly brisant blasting powder so that

51/ H. Kremser, "The Use of Possolana in Germany", Symposium on Possolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec. 1964.

Table 3

Effect of Temperature on Lime Reactivity of Surkhis Prepared from Typical Clays

Sl. No.	Mineralogical composition	Lime reactivity strength p.s.i. for surkhis prepared at 600°C	800°C	1000°C
White kaolin	Kaolinite, feldspar, quartz	1385	1452	889
Red Lateritic (RL)				
RL soil 1	Mainly kaolinite + hydrous oxides of iron	948	622	276
RL soil 2		2067	1926	872
RL soil 3		584	644	185
Belgaum clay	About 50% kaolin + 40% montmorillonite + 10% iron oxides	682	366	248
Rayerkheri clay	About 70% montmorillonite minerals, rest kaolin and iron oxides	1512	1444	822
Nagpur clay	More than 90% montmorillonite	463	644	269
Black cotton (BC)				
BC soil 1	Mainly montmorillonite	587	517	272
BC soil 2		388	460	351
BC soil 3		396	524	250
BC soil 4		397	364	157
BC soil 5		481	439	209
Bakhra clay stone	50% illite + 40% kaolinite + chlorite and haematite	213	393	461
Darjeeling clay	40% kaolinite + 40% illite minerals, rest iron oxide, gillisite and montmorillonite	200	795	1052

Table 3 (continued)

S. No.	Mineralogical composition	Lime reactivity strength p.s.i. for surkhis prepared at 600°C	800°C	1000°C
Jamuna clay	30% kaolin minerals + 50% illite minerals + 20% montmorillonite minerals	324	839	1133
Loamy soils similar to those used in brick making (five in nos.)	Abundant of quartz and other primary minerals; clay minerals not identifiable clearly	162	200	171
		197	385	249
		496	476	307
		111	301	234
		281	486	354

Source: Data extracted from "Surkhi as a Pozzolana", H. R. Srinivasan, Road Research Paper No. 1, Central Road Research Institute, New Delhi, 1956.

Table 4

Rating of Surkhi on the Basis of Lime

Reactivity Strength

Compressive strength in lbs/sq.in.	Activity Index CRRI*	MERI	IPRI
200	Very inactive	}	Inactive
200 - 400	Inactive	}	
400 - 600	Poorly active		Poor activity
600 - 800	Medium active		Medium activity
800 - 1000	Active		Active
1000	Very active		—

*CRRI - The Central Road Research Institute, New Delhi.

MERI - The Maharashtra Engineering Research Institute, Nasik (Bombay).

IPRI - The Irrigation & Power Research Institute, Amritsar (Punjab).

2. Fineness:

165. Before the Indian Standard on Surkhi was formulated in 1960, several recommendations on the fineness of surkhi existed in the Handbooks of the Central and State Public Works Departments, Military Engineering Service Specifications and Specifications of the River Valley Project Authorities etc. The fineness was usually given in terms of the sieve analysis and surkhi passing 25 mesh British Standard sieve was mostly recommended for use. Khan and Verman's work[8/] on the sieve analysis of the -30 mesh B.S. sieve surkhis had shown large variations in the particle size distribution and this is quite understandable. Such variations appear to be partly responsible for differences in the strength results of lime-surkhi or cement-surkhi mortars reported in the literature. This is illustrated by the data on the effect of fineness of a highly active surkhi on the lime reactivity strengths (table 5). The pozzolanic reactivity is found to increase with an increase in fineness of surkhi showing thereby that, as in other pozzolanas, the fineness (now-a-days measured in terms of surface area in sqcm per g) is a very important attribute of surkhi and must satisfy the requirements laid in the relevant Standards.

3. Surkhi Mortars and Their Properties:

166. The literature on surkhi mortars is very old and extensive and much of it has only historical value. Doddiah and his coworkers[10,44/] have published two excellent reviews on the subject of Surkhi Mortar - its Development and Standardisation and have highlighted the most important findings of the earlier workers. Because of differences in the quality of lime and surkhi, fineness of surkhi, mix proportions, quantity of mixing water, consistency of mortar, curing conditions, testing procedures and other variables, it is not possible to evaluate and compare the data on these mortars except in a general way.

167. The Hyderabad Engineering Research Laboratories,[45/] Hyderabad (now in Andhra Pradesh), has reported comparative data on surkhi mortars for use at four different projects (Rajoli bunda, Sarala Sagar, Bandsura and Tungabhadra). The optimum proportions of lime:surkhi:sand were found to be as 1:2:1½, 1:1½:1, 1:2:1½ and 1:1½:½ on volume basis for the four projects respectively. Regarding

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44/ D. Doddiah, "Selection, Processing and Specifications of Stones and Mortar for the Construction of Surkhi Mortary Masonry Dams in India", Report No. 32, Question No. 24, International Commission on Large Dams, Rome, 1961.

45/ Annual Reports for the years 1949 and 1951, Hyderabad Engineering Research Laboratory, Hyderabad, Andhra Pradesh, India.

Table 5

Effect of Fineness of Surkhi on Lime Reactivity Strength

Surkhi grading in terms of B.S. Sieve						Lime reactivity strength lbs/sq.in.
7-14	14-25	25-52	52-100	100-200	-200	
16.66	16.66	16.66	16.66	16.66	16.66	389
-	20.00	20.00	20.00	20.00	20.00	508
-	-	25.00	25.00	25.00	25.00	559
-	-	-	33.33	33.33	33.33	1028
-	-	-	-	50.00	50.00	1133
-	-	-	-	-	100.00	1341

Source: Annual Report (1958-59), Central Road Research Institute, New Delhi, India, p.18.

the fineness of surkhis, the first three samples were passing the ASTM sieve No. 30 while only 56 per cent of the last sample passed through ASTM sieve No. 30. For mortar consistencies of 45.0, 29.4, 48.0 and 50.0 per cent water, the initial setting times were 24, 10, 25.5 and 2 hours respectively. The corresponding final setting times were 72.0, 120.0, 28.5 and 24.0 hours respectively. Only mortar prepared with the Tungabhadra surkhi showed the initial setting times comparable to those obtained by Mielenz, Witte and Glantz for burnt clay pozzolanas,33/ all the final setting times, however, compared favourably. But it is not possible to make any generalization because very little data is available on the setting times of lime-surkhi mortars.

168. A good deal of data is reported in the literature on the tensile and compressive strengths of lime-surkhi-sand mortars. The highest tensile strengths recorded appear to be in the neighbourhood of 250 and 325 p.s.i. after 14 and 28 days of curing respectively. A maximum strength of 120 tons per square foot in compression at 6 months is recorded for a 2:3:1 lime-surkhi-sand mortar using the Rayerkheri Surkhi.41/

169. Sometimes sand was not used in lime-surkhi mortars. Lime-surkhi mixes with one part of lime and 1 to 5 parts of surkhi by volume are mentioned in the literature. The tensile and compressive strengths of such mixes are reported in table 6. 1:3 kankar lime-fine surkhi was selected for use at the Vanivilas Sagar Dam on the basis of both strengths and costs. In the Krishnarajasagar Dam surkhi in the form of 1 to 1½ in. brick bats were used with lime and the mix was ground for about 35 minutes in a mortar mill.

170. Lime-reactive surkhi mortars possess superior properties. Ghosh, Srinivasan, Bhatia and Banerjee46/ have shown that when surkhi is produced with scientific controls lime-surkhi mortars are comparable in compressive strength to 1:5-6 cement-sand mortars even at 7 days. For equivalent compressive strength at 28 days, the lime reactive surkhi mortars generally show appreciably higher flexural and tensile strengths (table 7). The strength characteristics of lime-surkhi mortars are influenced by water content, fineness and grading of aggregate etc. as for the cement mortars. The modulus of elasticity (E) of lime reactive surkhi mortars is somewhat lower than that of 1:6 cement-sand mortar. Lime

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46/ R. K. Ghosh, N. R. Srinivasan, M. L. Bhatia and S. G. Banerjee, "A Study of Reactive Surkhi Mortars", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

Table 6

Strengths of Mortars Prepared from Different Proportions of Lime and Surkhi

Composition Lime:Surkhi	Tensile strength, p.s.i.				Compressive strength, p.s.i.			
	14 days		90 days		14 days		90 days	
	V*	K+	V	K	V	K	V	K
1:1	66	109	131	256	1230	907	2390	2240
1:2	62	100	123	260	1372	784	2240	2262
1:3	90	133	149	284	1196	1154	2632	2363
1:4	76	122	190	240	1568	896	3248	1938
1:5	96	128	191	234	1288	885	3024	1882

V* stands for the Vanivilas Sagar Dam

K+ stands for the Krishnarajasagar Dam

Source: "A Note on the Up to Date Position with regard to the Use of Surkhi as a Pozzolana", Road Research Paper No. 24, Central Road Research Institute, New Delhi, 1958.

Table 7a

Strength of Lime Reactive Surkhi Mortars

Mortar Proportions by weight Lime:Surkhi:Sand*	Strength of mortars in pounds per square inch			
	Compressive		Flexural	Tensile
	7 days	28 days	28 days	28 days
1 : 1 : 1	785	1119	324	198
1 : 1 : 2	659	1085	293	150
1 : 1 : 4	509	663	212	130
1 : 1 : 6	353	428	149	93
1 : 1 : 8	148	300	108	65
1 : 1 : 10	62	167	54	32
1 : 2 : 2	667	915	148	148
1 : 2 : 4	604	837	96	110
1 : 2 : 6	573	708	82	83
1 : 2 : 8	396	481	66	63
1 : 2 : 10	203	298	54	20
1 : 2 : 12	118	132	42	8
1 : 3 : 3	637	817	174	87
1 : 3 : 6	374	513	124	58
1 : 3 : 9	296	417	86	38
1 : 3 : 12	211	308	63	28
1 : 3 : 15	170	204	52	18
1 : 3 : 18	85	102	34	5

Table 7b

Portland Cement : Sand Mortars

Mortar Proportions by weight Cement : Sand	Strength of mortars in pounds per square inch			
	Compressive		Flexural	Tensile
	7 days	28 days	28 days	28 days
1 : 3	2645	4583	554	313
1 : 4	1225	2517	357	193
1 : 5	850	1913	222	125
1 : 6	583	917	141	77
1 : 7	308	583	83	47
1 : 8	167	325	35	23

* Medium coarse sand

Note: All mortars were prepared with a medium coarse sand and were brought to the same consistency, i.e. 100 per cent flow as per Method of Test for Measuring Mortar-Making Properties of Fine Aggregate as per ASTM Designation C 87-64.

Source: "A Study of Reactive Surkhi Mortars", by R. K. Ghosh, N. R. Srinivasan, M. L. Bhatia and S. G. Banerjee, Symposium on Pozzolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec. 1964.

reactive surkhi mortars, however, show greater initial shrinkage. But, after 28 days, the shrinkage is not any different from that of cement-sand mortars.

4. Properties of Surkhi as Cement Replacement:

171. Investigations on the use of surkhi as part replacement of cement in concrete are comparatively of recent origin. In most of the investigations the raw materials chosen were brick earths or soils available in the neighbourhood of a big project. The magnitude of replacement tried was up to 30 per cent by weight. The selection of surkhi was done mostly in the conventional manner, i.e. on the basis of under-burnt, well burnt or overburnt surkhi. The fineness was controlled mostly in terms of the surkhi passing B.S. sieve No. 30, 100 or 200. The tests performed, in general, were determination of standard consistency and tensile and compressive strengths of 1:3 cement-sand mortars at various ages. Some data on the properties of concretes is also available.

172. On the whole the surkhis used were mostly coarser than the portland cement. Only the surkhis passing through B.S. sieve No. 100 or 200 had specific surface near about the minimum specified for portland cement. For example, Handa, Dhawan and Bahri[32] found the surkhi passing B.S. sieve No. 30 had surface areas ranging from 743-1967 sqcm per g. The corresponding ranges for surkhi passing 100 and 200 B.S. sieves were 1134 - 2519 and 2584 - 3449 sqcm per g respectively.

173. The water requirements for the normal (or Standard) consistency are reported to be generally higher for portland surkhi cements and, according to Handa, Dhawan and Bahri, are related to water absorption capacity of the surkhis. For example, underburnt surkhi which showed maximum water absorption also showed maximum increase in water requirements over the portland cement paste. Hoon[47] has reported up to 20 per cent increase in water requirements for normal consistency when the magnitude of replacement was 25 per cent. Consequently, the initial and final setting times of cements containing 20 to 25 per cent of surkhi replacement were also found to increase.

174. With few exceptions, replacement of 15 - 20 per cent of portland cement by surkhi was found to result in equal or higher tensile strengths than those of the control (1:3 cement-standard sand mortar) only after 28 days of curing. Very few surkhis have resulted in equal compressive strengths in 1:3 cement-standard sand mortar at a 20 - 25 per cent level of replacement of cement within

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47/ R. C. Hoon, "Development of Portland Pozzolana Cements for Mass Concrete Constructions", Indian Concrete Journal, vol. 26, 1952, pp. 225-231, 253-258.

material smaller in size than 150 mm is least possible. Blocks greater than 500 mm are crushed with pneumatic hammers and a sliding separating machine then sorts the crushed material into 0-150 mm and 150-500 mm groups automatically. Blocks of size 150-500 mm are air dried, while 0-150 mm material is dried in a drying plant. Both the groups of materials are crushed to a walnut size by means of a hammer crusher. Natural moist material is then dried artificially for a short time at about 400°C. The dried and crushed material is either pulverised in an edge-runner or ground in a ball mill with air separation as in the case of cement, the latter being the current practice.

28 days. Curing for longer periods extending even up to one year were required for equal strength development in portland cement-surkhi mortars. The Indian Standard 1489:1962 specifies more than 80 per cent of the strength of 1:3 portland-cement standard sand mortar at 28 days for a 20 per cent replacement of cement by a pozzolana. The compressive strength data of Uppal and Singh[48] show that only a surkhi passing B.S. sieve No. 200 will fulfill this requirement.

175. Puri and Srinivasan[9] obtained data on the strengths of a concrete (1:2.1:3.9 cement:sand:coarse aggregate) wherein a reactive surkhi had been used as a pozzolana and concluded that there is practically no reduction in compressive and flexural strengths up to 20 - 25 per cent replacement of cement by the reactive surkhi passing B.S. sieve No. 200. The rate of strength development in coarser surkhi was, however, lower (table 8). The data on modulus of elasticity of concretes containing 15, 20 and 25 per cent of reactive surkhi replacements have shown[49] that the modulus of elasticity was generally 1 to 8 per cent lower than that of straight portland cement concrete at 28 days and 12 to 17 per cent at 6 months.

176. Most of the reactive surkhis have been found effective in counteracting the alkali aggregate reaction in concretes to a great extent. The mortar bar expansion tests[50,51] show that for the maximum efficiency of surkhi for inhibiting alkali-aggregate reaction, montmorillonitic and kaolinitic clays require a calcination temperature of 800°C and illitic clays require 1000°C. Regarding resistance to sulphate attack, results on calcination at 400°, 600°, 800°, and 1000°C have shown that for a 20 per cent replacement of cement by surkhi, clays calcined at higher temperatures are more effective in preventing sulphate attack than those calcined at lower temperatures. It appears the optimum temperature of calcination for getting surkhi of maximum reactivity for strength development may not hold equally valid for achieving maximum protection

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48/ H. L. Uppal and Gursharan Singh, "Puzzolanic Surkhi from some Burnt Clay Bricks of Punjab", Symposium on Pussolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec., 1964.

49/ Ram Lall, "Elastic, Strength and Abrasive Properties of Hardened Pozzolana Concretes, Journal The Indian Road Congress, vol. XXVIII-3, No. 3, Oct., 1964, pp. 461-470.

50/ Annual Report for 1958-1959, Central Road Research Institute, New Delhi.

51/ Annual Report for 1959-1960, Central Road Research Institute, New Delhi.

Table 8

Strengths of Concrete Containing Reactive Surkhi as Cement Replacement

Cement replacement in per cent	Compressive strengths in lbs/sq.in.						Flexural strength lbs/sq.in. 100 per cent passing B.S. Sieve No. 200		
	56 per cent passing B.S. Sieve No. 200			100 per cent passing B.S. Sieve No. 200					
	1 M*	3 M	6 M	1 M	3 M	6 M	1 M	3 M	6 M
0	100	100	100	100	100	100	100	100	100
15	98.2	93.0	92.8	102.3	98.7	102.7	112.4	93.0	95.9
20	78.2	93.9	86.4	90.2	96.6	102.7	112.4	93.5	100.0
25	82.9	80.6	83.3	94.5	96.0	90.2	103.0	102.2	103.3

M* denotes period of curing in months

Source: "A Note on Up to Date Position with regard to the Use of Surkhi as a Pozzolana", Road Research Paper No. 24, Central Road Research Institute, New Delhi, 1958.

to concrete against sulphate attack. Calcination at 1000°C is recommended[52] for producing surkhi for greater sulphate resistance irrespective of the material of clay minerals.

177. Replacement of cement by surkhi has been found to increase the shrinkage of concrete; the finer the surkhi, greater was the increase in drying shrinkage. Nevertheless, the shrinkage of surkhi concrete was well within the permissible limits[51]. The abrasive resistance of concrete with very reactive surkhi up to 25 per cent replacement has been found to be even better than that of straight portland cement concrete at all ages; for surkhis of lower activity, the abrasive resistance is comparable to that of portland cement concrete.

178. Properties of fresh concrete such as workability, bleeding and segregation etc. appear to depend mainly on the fineness of surkhi. The results show that despite a slight decrease in workability, a very reactive and fine surkhi produces a more plastic and cohesive mix. The bleeding and tendency for segregation of fresh concrete are also reduced.[51]

F. Uses of Surkhi

179. In India surkhi pozzolana has found more widespread use combined with lime in mortars for brickwork and masonry. It has been used with great success in the construction of masonry dams and other irrigation works. Lime-surkhi mixes have also been used for rendering and pointing walls. Lime-surkhi concrete has found several applications in building and road constructions. Only special uses of surkhi as a cement replacement have been mentioned here because the other uses are covered in Chapter V on the "Uses of Pozzolanas".

1. Lime-Surkhi Mixes in Buildings

(a) In Mortars:

180. Use of lime-surkhi mortars is recommended for low and medium loads in buildings.[53] The most common mixes used in the past are 1 part of lime with 2 or 3 parts of surkhi by volume and lime-surkhi-sand mixes of composition 1:1:1, 1:1:2, 1:2:1½ and so on.

52/ M. L. Puri, N. S. Bawa and N. R. Srinivasan, "Durability of Concrete with respect to Sulphate Attack", RILEM Symposium on Concrete and Reinforced Concrete in Hot Countries, Israel, 1960.

53/ IS:1625-1962 Code of Practice for Preparation and Use of Lime Mortar in Buildings, Indian Standards Institution, New Delhi.

181. Rahman, Rehsi and Chopra[54] had investigated the strengths of brick masonry built with bricks of mean strength of about 1800 p.s.i. and surkhi having a lime reactivity of 600 p.s.i. The recommendations on the working stresses are reported in table 9. It is obvious that lime-surkhi mortars are suitable for one or two storeyed buildings and cannot replace the cement-sand mortars which permit faster rate of construction. But it may be appreciated that this is partly on account of fixation of comparatively much higher factors of safety in the former mortars because of lack of quality control.

182. Recent work of Ghosh, Srinivasan, Bhatia and Banerjee has shown that when active to very active surkhi possessing lime reactivity strengths from 800 to 1000 p.s.i. or above are used, lime-surkhi mortars would result having masonry strengths of the same order as cement mortars.[46] On the basis of 28-days compressive strength of the mortar having a flow of about 100 per cent when tested by the ASTM method, lime-reactive surkhi-sand mortars have been divided into four strength categories. The mixture compositions recommended are given in table 10. A mixture in the ratio 1:2:8 lime:reactive surkhi:sand gives a mortar with compressive strength ranging from 30 to 50 kg/cm^2 is recommended for use in place of 1:6 portland cement-sand mortar.

183. Because of lower modulus of elasticity and greater flexural strengths of lime-reactive surkhi-sand mortars in comparison to those of cement-sand mortars, the former can undergo higher deflections without cracking. In other words, these mortars have greater strain bearing capacity[55] and offer greater resistance to cracking and, therefore, are superior from this point of view. However, their early rate of hardening is lower. For early hardening properties, a small amount of portland cement (10 - 20 per cent) can replace lime-reactive surkhi component in mortar without affecting the strain-taking capacity of the mortars. Such mortars are superior in performance and may be employed in situations where attainment of early strengths is necessary on account of technical reasons or speed in construction.

54/ Rahman, S. S. Rehsi and S. K. Chopra, "Strength of Brick Masonry", N.B.O. Project Report, Jour. National Buildings Organisation, New Delhi, Oct., 1961, vol. 6, pp. 49-61.

55/ "Cement-Reactive Surkhi-Sand Mortars with and without lime", Joint Report of the Central Water and Power Commission and the Central Road Research Institute, New Delhi, Symposium on Puzzolanas - Their Survey, Manufacture & Utilisation, Central Road Research Institute, New Delhi, Dec., 1964.

Table 9

Recommended Working Stresses

S. No.	Proportions of constituents of mortar	Recommended working stress: Age	Recommended working stress: lb/sq.in.	Factor of safety against observed first crack load	Factor of safety against ultimate load
1	1:½:4 C:L:S*	7 days	120**	2.00	6.30
2	1:6 C:S	14 days	120**	1.67	6.85
3	1:2 L:SS	28 days	50	3.38	11.00
4	1:3 L:SS	28 days	80	3.80	9.05
5	1:1:2 L:S:SS	28 days	50	2.92	9.30

* C, L and S are portland cement, hydrated lime and sand respectively; SS is surkhi.

Source: **Data extracted from the British Standard Code of Practice 111, British Standards Institution, London.

Table 10

Mortar Mixes for Different Strength Requirements

28 days compressive strength kg/cm²	Medium Active Surkhi (Minimum lime reactivity value 600 psi)					Active to Very Active Surkhi (Minimum lime reactivity value 800 psi)				
	Lime	:	Surkhi	:	Sand	Lime	:	Surkhi	:	Sand
7-15	1		1		2	1		3		14
15-20	1		2		0	1		3		12
20-30	1		3		0	1		3		10
30-50	-		-		-	1		2		8

Source: "A Note on the Manufacture of Packaged Lime-Reactive Surkhi Mixture for Use in Building Mortars and Foundation Concretes", Central Road Research Institute, New Delhi, August 1965.

(b) In Plasters:

184. Rich lime-surkhi mixes with or without fine sand have also been used in the past for plastering walls in low cost or temporary buildings. Such plasters showed cracking because of slower rate of hardening, richness of mixes and high drying shrinkage. To enhance the early rate of hardening, it is desirable to use active to very active surkhis and a recent study[46] has shown that 1:2:8-12 mixes of lime:reactive surkhi:fine sand (by weight) are quite suitable for plastering work. The compressive and tensile strengths of such mortars compare well with 1:6-8 cement-sand mixes used commonly for plastering; the workability of the two types of mortars being the same. However, the high early shrinkage of surkhi plasters could result in pattern cracking in plaster works. For freedom from the pattern cracking, mixes with $\frac{\text{sand}}{\text{lime + surkhi}}$ ratio of 4 or more are recommended. The conventional mix for pointing brickwork is 1:1½ lime-surkhi by volume. Kapur[56] has recommended a 2:3:8 mix of lime-reactive surkhi and sand on the basis of his experience.

2. Lime-Surkhi Mortars in Masonry Dams:

185. Important examples of the use of lime-surkhi mortars in masonry dams and other hydraulic works were given earlier. The most recent examples of use of lime-surkhi are in the construction of the Linganamakki and the Tala Kalale dams in the Mysore State.[44] The height of these masonry dams is about 200 feet above the lowest river bed. One part of freshly burnt pulverized lime and four parts of pulverised surkhi were proportioned by weight. The fineness of lime and surkhi were 90 and 70 per cent passing through ASTM sieve No. 100. Lime was first fed into the pan of a 3 oft. capacity diesel driven mortar grinder, adding enough quantity of tap water for complete slaking of lime. It was ground for 7 minutes after which surkhi was added in small quantities. Simultaneously water was added at a gradual rate until the mortar produced was a uniform, workable and plastic mixture. The mortar was further ground for another 23 minutes. Such mortars gave a compressive strength of more than 100 tons per sq. ft. after 90 days aging.

56/ O. P. Kapur, "Use of Reactive Surkhi in Building Construction", Symposium on Pussolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

186. Recently valuable data has been reported on the strength of surkhi mortar masonry versus the cement mortar masonry and concrete.57/ Table 11 gives typical results of the relevant tests on the different materials. While strict comparisons are not possible because of lack of data at comparative stages, it may be concluded that 28 days compressive strength of 1:4 lime-surkhi mortar masonry is equal to that of 1:3 cement-sand mortar masonry and that lime-surkhi mortars are suitable for adoption in the construction of masonry dams.

3. Lime-Surkhi Concrete

(a) In Buildings:

187. Lime concrete is used in India in building construction in wall foundations for moderately tall buildings, under floor finishes, for filling haunches over masonry arch work and for roof terracing work etc. The Indian Standard Code of Practice for use of Lime-Concrete in Buildings recommends58/ the mixes given in table 12 for various situations. The quality of the ingredients of lime concrete is controlled through the respective Indian Standards on Lime, Surkhi, Sand and Aggregates such as broken brick and stone aggregate or cinder etc. The workability of lime concrete is generally satisfactory and this concrete has good water retention properties. The hardening of this concrete, though slower than that of cement concrete, is satisfactory for most of the normal uses to which it is put in building work except where early strength is required, such as, in emergency works or in works under very wet conditions. The setting time of lime concrete will depend upon the class of lime used and is variable. Though initial set may occur in 2-3 hours, when hydraulic lime is used, the final set does not usually occur in less than 10-12 hours.

188. A properly prepared, laid and cured lime concrete is quite durable. However, lime concrete is subject to attack by sulphate action which may occur when the sub-soil water level is high and soil contains considerable quantities of soluble sulphates (usually more than one per cent). The permeability of lime concrete is significant for roof terracing work and it can be reduced by increasing mortar or paste content, using well graded aggregate, by thorough compaction and by sprinkling certain solutions on the surface during compaction...

57/ M. S. Thirumale Iyengar, "The Tests on Lime Surkhi Rubble Masonry at the 4.5 Million Pounds Testing Station, Hirakud, Ministry of Irrigation & Power, New Delhi.

58/ Indian Standard Code of Practice for Use of Lime Concrete in Buildings, IS:2541-1965, Indian Standards Institution, New Delhi.

Table 11

Crushing Strength Data on Stone Masonry and Cement Concrete

Size of Specimen - 30 in. cubes

Stone masonry							Cement concrete			
Cement-sand mortar				Lime-surkhi mortar						
Mix ratio (by vol.)	W/C ratio (by wt.)	Age	Strength p.s.i.	Mix ratio (by vol.)	Age days	Strength p.s.i.	Mix ratio	W/C ratio (by wt.)	Age	Strength p.s.i.
1	2	3	4	5	6	7	8	9	10	11
1:4	0.70	2 yrs	3984	1:4	90	2737	1:10.28	0.70	2 yrs	3984
1:4	0.70	-do-	4357	1:4	90	2675	1:10.28	0.70	-do-	3970
1:4	0.70	-do-	4046	1:4	90	2302	1: 8.36	0.70	-do-	3226
1:4	0.70	-do-	3964	1:4	90	2670			Average	3727
1:4	0.70	-do-	3797	1:4	90	2551	1: 8.36	0.58	2 yrs	3982
1:4	0.70	-do-	3984	1:4	90	2364	1: 8.36	0.52	-do-	3745
		Average	4022		Average	2550	1:10.57	0.62	-do-	3733
1:4	0.75	2 yrs	4046	1:4	28	2471				
1:4	0.75	-do-	3548	1:4	28	2242				
1:4	0.75	-do-	3859	1:4	28	2490				
		Average	3818	1:4	28	2241				
				1:4	28	2677				
					Average	2424				

Table 11 (continued)

1	2	3	4	5	6	7	8	9	10	11
1:3	0.65	2 yrs	4938							
1:3	0.65	-do-	4480							
		Average	4709							
1:3	0.75	28 days	2302							
1:3	0.75	-do-	2427							
1:3	0.75	-do-	2490							
1:3	0.75	-do-	2365							
1:3	0.75	-do-	2427							
1:3	0.75	-do-	2551							
1:3	0.75	-do-	2053							
1:3	0.75	-do-	2116							
		Average	2342							

Source: "Selection, Processing and Specifications of Stones and Mortar for the Construction of Surkhi Mortar Masonry Dams in India", by D. Boddiah, International Commission on Large Dams, Rome, 1961 (Report 32, Question No. 24).

CHAPTER III. INDIAN SURKHI - ITS MANUFACTURE, PROPERTIES AND USES

A. Historical

1. Use of Surkhi with Lime:

99. In India "Surkhi" or ground bricks (also pronounced as Soorkee) mixed with lime is a traditional construction material. Many of the ancient structures which are standing even today had used lime-surkhi in mortars or in masonry. In more recent times, of which the records are available, earliest large scale use of fat lime and surkhi mortar was made in 1850 in the construction of the big and small structures relating to the Ganga Canal Project[1] in Northern India. In the State of Madras[2], lime-surkhi was used in the construction of Periyar Dam between 1895-1906. This was a 1241 feet long random rubble masonry dam whose core is of concrete in surkhi mortar. The structure of the Kodyar Dam (1895-1906) in Kerala State, India consisted of blasted rubble stone in lime-surkhi mortar on sides and top and blasted metal concrete in stone lime-surkhi mortar with plums embedded in the core of the dam[3].

100. A mixture of one part of kankar* lime with three parts by volume of powdered well burnt-surkhi was used at the Vani Vilas Sagar Dam (1898-1907) in

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1/ The Roorkee Treatise on Civil Engineering in India compiled by Lt.Col. J. G. Modley, R.E., vol. 1, Third Edition, Enlarged & Improved, Edited by Major A. M. Laug, Royal Engineer, Printed & Published at the Thomson College Press, Roorkee, 1873, pp. 126-129.

2/ J. Walter, "Puzzolanas - Their Utilization in Irrigation Projects of Madras State", Symposium on Puzzolanas - Their Survey, Manufacture & Utilisation, Central Road Research Institute, New Delhi, Dec., 1964.

3/ R. C. Hoon, "The Use of Kankar Lime and Building Materials for the Major Engineering Works", R 24 Question No. 11, International Commission on High Dams, Stockhom, 1948.

* "The word Kankar originally described any form of gravel, whether the rock fragments of which it was composed were rounded or not, but its meaning is now restricted, at any rate amongst Indian geologists and civil engineers, to those small, irregular concretions of carbonate of lime, which are so widespread throughout the surface deposits of India, parts of Pakistan and some regions in the dry zone of Burma. The commonest forms are small, uneven nodules, from half an inch to three or four inches in diameter, composed of fairly compact carbonate of calcium within, and a mixture of this compound with clay on the outside. More massive varieties frequently fill cracks and are found occasionally as ill-defined beds in the older alluvium. Such block kankar has been employed as a building stone and was used for instance, in connexion with the Ganga canal works." Extract from "India's Mineral Wealth" by J. Coggin Brown and A. K. Dey - Oxford University Press 1955 (Third Edition).

Table 12

Recommended Mixes for Use in Lime Concrete

Sl. No.	Situations	Type of mortars (all proportions by volume)	Class of lime as in IS:712-1964*	Type of coarse aggregate	Maximum size of coarse aggregate	Proportion of mortar to coarse aggregate (by volume)	Remarks
1	2	3	4	5	6	7	8
(i)	In foundations	1 Lime, 2 Sand	A	Stone or broken brick	50 mm	40 to 50 parts of mortar to 100 parts of aggregate depending upon the grading of aggregate.	Normally suitable for buildings not more than three storeys high and in places with dry sub-grade, that is, sub-soil water level not within 2.5 metres of foundation level.
		1 Lime, 1 SURKHI or Cinder, 1 Sand	B or C or A	-do-	50 mm		
		1 Lime, 2 SURKHI or Cinder	B or C or A	-do-	50 mm		
		1 Cement, 3 Lime 12 Sand	B or C				
(ii)	Base concrete under floor finishes on ground	1 Lime, 2 Sand	A	-do-	50 mm	40 to 50 parts of mortar to 100 parts of aggregate depending upon the grading of aggregate	Suitable for dry and tolerably wet sub-grades.
		1 Lime, 1 SURKHI or Cinder, 1 Sand	B or C or A	-do-	50 mm		
		1 Lime, 2 SURKHI or Cinder	B or C or A	-do-	50 mm		
		1 Cement, 3 Lime, 12 Sand	B or C	-do-	50 mm		

Table 12 (continued)

1	2	3	4	5	6	7	8
(iii)	Levelling course or cushioning layer under floor finishes laid on structural slabs	1 Lime, 2 Sand	A	Broken brick or cinder	20 to 25 mm	40 to 50 parts of mortar to 100 parts of aggregate	-
		1 Lime, 1 SURKHI or Cinder, 1 Sand	B or C or A	-do-	-do-		
		1 Lime, 2 SURKHI or Cinder	B or C or A	-do-	-do-		
		1 Cement, 3 Lime, 12 Sand	B or C	-do-	-do-		
(iv)	Filling over haunches of masonry arch work	1 Lime, 2 SURKHI	B or C or A	Broken brick	25 mm	45 parts of mortar to 100 parts of aggregate	-
		1 Lime, 1 SURKHI, 1 Sand	B or C or A	-do-	25 mm		
(v)	Roof terracing	1 Lime, 2 SURKHI	C	-do-	25 mm	-do-	-
(vi)	Light filling over structural slabs	1 Lime, 2 Sand	A	Broken brick or cinder	Any suitable size but usually not more than 25 mm	40 to 50 parts of mortar to 100 parts of aggregate	-
		1 Lime, 1 SURKHI or Cinder, 1 Sand	B or C or A	-do-			
		1 Lime, 2 SURKHI or Cinder	B or C or A	-do-			
		1 Cement, 3 Lime, 12 Sand	B or C	-do-			

NOTE: The mixes given in the table are for general guidance and may be modified to suit the strength requirements for various uses to which the concrete is put. The minimum compressive strength of lime concrete shall be 10 and 12 kg/cm^2 at 28 and 90 days respectively. The minimum transverse strength shall be 2 kg/cm^2 at 90 days.

* Specification for building limes (revised).

Source: Indian Standard Code of Practice for Use of Lime Concrete in Buildings, IS:2541-1965, Indian Standards Institution, New Delhi, July, 1965.

The rate of hardening of lime concrete can be increased by finer grinding of surkhi or by addition of 40 to 50 kg of cement per cubic meter of concrete.

(b) In Road Construction:

189. Lime fly ash mixture for use with local aggregate in making concrete to form a pavement base has been in use[59] in U.S.A. since 1957. It appears that compared to crushed stone base, a lime-pozzolana concrete base spreads the load stresses over a far greater area of the subgrade through its bridging action due to flexural rigidity and thereby reducing the stresses in the sub-grade.[60] In view of comparable activity of some of the reactive surkhis to that of fly ash being used in U.S.A., the Central Road Research Institute, New Delhi, has carried out investigations on the use of lime-reactive surkhi concrete as road base.[61] On the basis of tests, a 1:2:6:11 lime-reactive surkhi:sand:aggregate (3/4 in. size) was chosen[62] and a comparison of its properties with those of a 1:2:4 lean cement concrete suggested the use of lime-surkhi concrete as a part of the rigid pavement. (The lower abrasive resistance of lime-reactive surkhi concrete precludes its use in the surface course of pavements.) Experiments further showed that sufficiently high bond strength can be easily obtained between courses of lime-reactive surkhi concrete and cement concrete when one is laid immediately after the other. Ghosh and his coauthors[61] expect a fairly high degree of monolithicity in this type of system. Comparative results on test slabs show distinctly the scope of use of a composite slab consisting of lime-reactive surkhi concrete bonded underlay and bonded cement concrete over-lay. Another suggested use by the above authors is sandwiched construction in which 6 in. thick layer of lime-reactive surkhi concrete is sandwiched between two 3 in. thick cement concrete layers. This type of construction is considered to be cheaper.

59/ George C. Lindsay, "Corson Prescribes Research for Success", Rock Products, vol. 64, April, 1961, pp. 104-106.

60/ H. L. Ahlberg and E. J. Barenberg, "Pozzolanic Base Course Research", Progress Report, Engineering Research Station, University of Illinois, Illinois (U.S.A.).

61/ R. K. Ghosh, M. P. Dhir, N. R. Srinivasan and M. L. Bhatia, "Lime-Reactive Surkhi Concrete in Road Construction", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

62/ Annual Report 1963-1964, Central Road Research Institute, New Delhi, pp.18-19.

4. Red Cement Mortar in Masonry Dams:

190. The construction of the Mettur Dam in the Madras State and the Tunga Bhadra Dam in the Mysore State involved random rubble masonry which consists of spreading good and hard variety stones of certain sizes in layers and filling the intervening spaces with mortar and packing with smaller pieces of stone. Both the front and the rear faces were built with sized stones.44/ The portland cement-sand mortar was used with 20 per cent of fine surkhi. The mortar was termed as "Red Cement Mortar". The other dams which made use of surkhi as cement replacement are listed in table 1.

5. Cement-Reactive Surkhi Concrete in Road Construction:

191. Relatively high initial cost of cement concrete and satisfactory performance of a 170 feet experimental puzzolana concrete pavement track over a period of three years in the Institute's premises prompted the Central Road Research Institute,63/ New Delhi, to construct an experimental pozzolana concrete road stretch in the National Highway No. 2. Pozzolana concrete slabs with 28 days flexural strength of 520-660 p.s.i. were laid to find the effects of surkhis of different activities. Plain concrete slabs prepared from two cements differing in tricalcium silicate contents have also been laid for the sake of comparison. The performance of the sections in pozzolana concrete since May, 1964 has been reported to be satisfactory.

63/ R. K. Ghosh, N. R. Srinivasan and Ram Lall, "Construction of an Experimental Pozzolana Concrete Road Stretch in the National Highway No. 2", Symposium on Puzzolanas - Their Survey, Manufacture and Utilisation, Central Road Research Institute, New Delhi, Dec., 1964

CHAPTER IV. PRODUCTION COSTS OF POZZOLANAS AND POZZOLANIC CEMENTS

A. General

192. For establishing a plant, a techno-economical survey is a must. It can be done in two stages; the first stage enquiring about the market potentials, availability of raw materials, fuel, power, water and labour, extent of raw materials deposit or resources, and requirements of capital. Developing countries should include foreign exchange requirements, if any, at this very stage. If the report of the preliminary survey is favourable, a detailed investigation should be carried out by a specialist or a consultant who will formulate a project proposal. This is the second stage of survey and involves the preparation of estimates of material and energy requirements, capital investment on land, buildings and machinery, labour and supervisory charges etc. for a plant of two or three differenct capacities for selecting an economic unit. In short, the technical soundness of the project should be ascertained. The commercial viability of the project should then be determined from the cost standpoint and market survey consisting of current price and quality of the product or alternate product already on the market, supply position, growth rate and any new use of the product to be manufactured.

B. Production Costs

193. Possolana manufacture has yet to become an industry in the way portland cement, glass, plywood, fibre board and particle board industries are and, therefore, firm figures on production cost are not available. Also there is no set pattern of possolana manufacture as it varies from country to country depending upon the type of pozzolanic material available and level of technology. Differences in the extent of machinery employed in a particular process further complicate the situation. In view of this uniform basis of cost of production are not possible. At best an estimated cost of production can be worked out for a particular situation.

194. Investment costs in a plant are dependent upon the plant capacity and local conditions. The latter are equally important as their ignorance may make all the difference between success and failure in some cases. For example, great distance between the equipment suppliers and factory site may affect the investment costs disproportionately. If the communication facilities are

inadequate, investment costs may rise steeply. Setting up of a factory in an area more industrialized than assumed in an estimate, may put up total investment on land, buildings and roads. On the other hand, investment on workshop and erection costs could be lower in an industrialized area. Rise in investment costs may also take place, particularly, in developing countries due to lack of technical skill in the initial operations stage. Comparatively higher engineering or consultation fees and longer time for plant erection and installations in developing countries may offset any reduction in costs due to lower labour costs. Lower investment costs in developing countries thus appear to be more feasible through lesser mechanisation or indigenous design and manufacture of machinery, and planning.

195. Royalities on plant or on finished product should be given a serious consideration as these are to be paid mostly in foreign currency. Rate of interest on capital investment is an important item. When rate of interest is high, of the different alternative plants, the one which involves lesser capital and shorter period for erection may be preferred. This recommendation assumes that cost of production per ton is not unduly high for the lower capacity plant.

C. Estimated Production Costs

1. General:

196. Estimation of total production cost (Rupees/ton) can be done in different ways; there is no standard practice. But the elements which make it are direct and indirect production costs and fixed charges. The former consists of cost of raw materials and operating expenses such as fuel, power, and repair and maintainance. Indirect production costs comprise costs of labour, supervision and depreciation and interest on working capital. Fixed charges mean interest on capital, insurance and property tax and overheads.

197. Raw materials for pozzolana industry are either naturally occurring materials or industrial wastes and hence cost of raw material per ton of pozzolana is low. Costs of fuel and power may tend to be higher in lesser developed countries. Maintainance cost may also be higher because of both shortage and lesser efficiency of skilled labour. The latter, however, cannot be taken for granted. Labour costs will be comparatively lower in developing countries.

198. The following estimates assume location of the plant in a town with a population of about 500,000; cost of land has been taken at Rs. 10/- per sq.yd. The cost of raw material does not include transportation charges as they are highly variable. Market prices have been taken for fuel and power. Depreciation on plant machinery has been taken at 6 or 10 per ce t and about 3 per cent on buildings. Similar rates have been taken for maintainance. Insurance, property tax and overheads have been neglected. The former could be taken at 1 per cent each and overheads as 5 per cent of production cost. Interest on fixed capital is also not accounted for because it varies from country to country.

199. Estimates for the cost of production in Indian rupees (Rs. 4.80 equals one U.S. dollar before rupee devaluation) per ton are reported for typical possolanas and possolanic cements. The estimates were prepared on uniform basis and therefore, comparisons amongst themselves are valid. Also the estimates are fairly detailed and basic data has been provided so that new estimates can be prepared if the rates are different from those chosen in this report. The cost of machinery+ has been taken collectively but particulars of machinery (excepting minor equipment and instruments) have been given to enable a fresh estimation of machinery costs if this be needed.

2. <u>Choice of Projects for Estimation:</u>

200. Fly ash is the most attractive possolana as it is an industrial waste and requires little processing. Estimates have, therefore, been prepared for the cost of handling and bagging of fly ash. Manufacture of burnt clay possolana involves probably maximum processing of a naturally occuring material and this was included for estimation on this account. One proposal gives estimates for manufacture in a down draught kiln; the second one deals with large scale manufacture in a rotary kiln. Manufacture of lime-possolana mortars can be done on traditional methods and an estimate has been provided on the basis of past experience. This may be of interest to some of the developing countries only. Cost of production has also been worked out for a factory finished lime-possolana cement.

\+ Based on quotations or market prices.

18. 5. 73

Mysore State and a mortar consisting of one part of kankar lime and four parts of surkhi was selected for use at the Krishnarajasagar Dam 4/ (1911-1932). Rubble masonry in surkhi mortar was used in the construction of the Chamarayasagar Dam (1930-1933) in the State of Mysore. Coarse rubble masonry in lime-surkhi mortar was employed in the construction of the Radhanagari (1910-1913) and the Mulshi Dams 3/ (1921-1929), both in the State of Bombay. Surkhi was also used in the face work of the Nizamsagar Dam 5/ (1923-1931) in Andhra State.

2. Use of Surkhi with Portland Cement:

101. The use of surkhi had declined after the advent of portland cement. This was partly due to competition with a stronger cementing material and partly due to the deterioration in the quality of both lime and surkhi. But surkhi was once more in the forefront in the post independence period because of portland cement shortage for executing the major and minor river valley project schemes and a better appreciation of its technical advantages 6,7,8/ of use of possolana in mass concrete constructions. Savings in money by replacement of cement by surkhi also provided great incentive. All this resulted in the use of surkhi, this time in combination with portland cement, in almost all the Irrigation Projects that were completed during the First (1951-56) and Second (1956-61) Five Year Plans 2/. Table 1 lists the various dams together with the savings in money achieved through the use of surkhi possolana. Portland cement-surkhi combination is popularly known as red cement.

4/ M. C. Sampathiengar, "A Note on Surkhi Mortar", Central Board of Irrigation, Annual Report (Technical), 1947, pp. 611-618.

5/ S. P. Raja, "History of the Nizamsagar Project", Hyderabad Government Central Press, Hyderabad, Andhra Pradesh (India), 1939.

6/ J. L. Savage, "Special Cements for Mass Concrete", U.S. Bureau of Reclamation, Denver, 1936.

7/ R. E. Davis, "A Review of Possolanic Materials and their Use in Concretes", Symposium on Use of Possolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia, 1950, pp. 3-15.

8/ C. A. R. Khan and Lal C. Verman, "Burnt Clay or Surkhi as Possolana", Bulletin of Indian Industrial Research No. 24, Director Scientific & Industrial Research, Department of Commerce, India, Delhi, 1941.

Table 1

Use of Surkhi as Cement Replacement in the Construction of Masonry Dams

Sl. No.	Name of project	Salient Features: Length of masonry portion	Salient Features: Height of masonry portion	Salient Features: Quantity of masonry used (100 cft.)	Approximate quantity of surkhi used (cement saved)	Approximate savings effected by the use of surkhi in Rs	Remarks
1.	Lower Bhavani	1523 ft.	161.5 ft.	136000	217600 Cft.	6,96,000	
2.	Manimuthar	1230 "	150 "	101600	162432 "	5,20,000	
3.	Amaravathi	1067 "	164 "	89910	143956	4,61,000	
4.	Sathanur	1400 "	147 "	81000	129600 "	4,15,000	
5.	Krishnagiri	911 "	96 "	26460	42236 "	1,35,000	
6.	Vaigai	1035 "	111 "	49950	79920 "	2,56,000	
7.	Vidur	430 "	50 "	11340	18144 "	58,000	
8.	Parambikulam	1010 "	205 "	6918000*	122600* "	6,25,000*	*Under construction
9.	Sholiyar	2150 "	319 "	230000*	328000* "	10,49,600*	*Figures are probable ones.

Source: "Puzzolanas - Their Utilisation in Irrigation Projects of Madras State" by J. Walter, Symposium on "Puzzolanas - Their Survey, Manufacture and Utilisation", Central Road Research Institute, New Delhi, December, 1964.

B. Traditional Methods of Manufacturing Surkhi

1. General:

102. Surkhi appears to have been produced originally by powdering bricks or brick bats. It is difficult to say whether the origin of its use had resulted from the discovery of the pozzolanic activity of the calcined clays (and manufacture of surkhi by burning and powdering bricks was only a means to an end) or from an accidental use of the rejected bricks. The latter is probably more true as even up to this day surkhi is being produced both in rural and urban areas by crushing and powdering bricks rejected at a kiln and is considered a by-product of the brick industry. In olden days bricks or brick bats were crushed and then powdered manually or in animal driven stone mills[1/].

103. With time the knowledge of the manufacture and use of surkhi advanced and surkhi was produced specially for or by the project authorities for use in the major civil engineering works. In more recent times, surkhi was produced by moulding bricks from a brick earth and firing bricks in brick kilns in common use in the region in those days. The choice of raw material was limited to those brick earths which were known to produce good surkhi. In general, loamy soils were preferred. Puri and Srinivasan[9/] have described the manufacturing practices adopted at Nizamsagar, Mettur and other dams. Doddiah and Gurushankaraiah[10/] and Barber[11/] have also dealt with this topic.

2. Types of Kilns:

104. The traditional methods of manufacturing surkhi were in essence those employed in the brick or lime manufacture. The brick kilns which were used in the past or are in current use can be divided into three categories, e.g. (i) clamps, (ii) overground kilns like the Allahabad or Sind kiln and (iii) continuous kilns like the Hoffman and the Bull's trench kiln etc. These kilns together

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9/ M. L. Puri and N. R. Srinivasan, "A Note on the Up-to-date Position with regard to the Use of Surkhi as a Pozzolana", Road Research Paper No. 24, Central Road Research Institute, New Delhi, 1958.

10/ D. Doddiah and M. S. Gurushankaraiah, "Surkhi Mortar - Its Development and Standardisation", Journal of Central Board of Irrigation & Power, vol. 12, 1955, pp. 420-449.

11/ C. G. Barber, "History of Cauvery-Mettur Project", Government of Madras, 1940.

with the modifications they have undergone are described in literature[9,12,13,14]. A Bull's trench kiln which is most commonly used is described below.

(a) Firing in Bull's Trench Kiln:

105. The trench is usually 20 to 25 ft. wide with an over-all length of 200 ft. Fig. Ia (top half) of the accompanying sketch is of a common Bull's trench kiln. It is a part plan showing the method of commencing the setting and the temporary cross-wall for starting the fire. Fig. Ib is a part plan showing the top of the setting. The bottom halves of the above figures show a plan of a part of the kiln covered and ready for firing. Fig. Ic shows a cross-section through feed holes and furnaces. Figs. Id and Ie show longitudinal section of Figs Ia and Ib.

106. In the average kiln a pair of chimneys made of 1/16" sheet steel and each about 30 to 35 ft. high, are sufficient to give a good draught. Two convenient methods of setting are shown in Fig. 11. For setting the bricks a table template (wooden) may be used for correctly spacing the courses, and a space of 1/2" or more should be left in between the bricks.

107. As each chamber is filled, the top of the setting, as shown in Fig. Ic, is covered by a compact layer of dry earth and ash (about 6" thick). The feed holes are then covered with cast iron caps and properly sealed. When two chamber lengths and a part of the third have been set, the temporary cross-wall with the furnaces at the foot of it may be constructed at a distance of about 9 inches from the first row of bricks (see Fig. Ia). At the bottom of furnaces bricks are arranged to form grates over which coal is burnt. Initial firing may also be started with wood, coal being charged only when the bricks are sufficiently hot. The cross-damper is put at the end of the second chamber. The space between the damper and the walls should be plastered over with mud so that no leakage of the kiln gases can take place. Initially the feed-holes in the firing zone are kept open and a very slow fire is kept up. As steam ceases

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12/ S. K. Chopra and N. K. Patwardhan, "A Survey on Brick Production in India", Bulletin No. 1, vol. 2, Central Building Research Institute, Roorkee, India, April, 1954.

13/ N. C. Majumdar, "Firing of Bull's Trench Kiln", Indian Builder, Sept., 1957.

14/ N. R. Srinivasan, "Some Aspects of Surkhi as a Pozzolana", Symposium on Plain and Reinforced Concrete", Central Building Research Institute, Roorkee (India), 1953.

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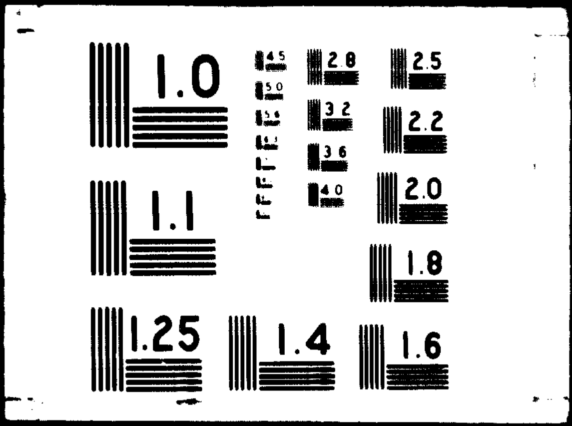

201. Portland-pozzolana cements are factory finished products and are produced either by blending portland cement with pozzolana or by intergrinding portland cement clinker with pozzolana. Examples have been included for both the processes.

3. Handling and Bagging of Fly Ash Plant with 60 tons/day Capacity:

202. Fly ash is collected in thermal power plants either in electrostatic precipitators or mechanical cyclones. The particle size of fly ash collected depends on the type of collection unit installed in a particular power station; particles collected in primary stage are mostly coarser than particles collected in subsequent stages. Only fly ash comparable to portland cement in fineness and passing the minimum standard requirements should be selected for bagging. If, however, a mixture of fractions of fly ash collected in different stages and disposed from a station is not fine enough for a pozzolana, arrangements may have to be made for a separate discharge of finer fractions.

203. Fly ash from thermal power station is conveyed by a pneumatic pump if the handling and bagging plant is close to the power station; otherwise, trucks, tipping wagons or other means can be employed for transporting fly ash over longer distances. Normally the plant should be located preferably near the source. Fly ash is stored in factories in silos which can be emptied pneumatically by means of an air duct system. Compressed air is blown into these air ducts and passes through aeration plates into the silo thus transporting fly ash into flux state. Fly ash is drained off through a discharge cock and is continuously discharged into an elevator. The material is fed with the help of an elevator into the hopper at the top of the bagging plant from where it is fed into the automatic bag packing and weighing machine. Fly ash is thus packed and delivered for sale just like bagged lime or portland cement. The costs of production of 'naked' fly ash works out to be Rs. 5.40 and Rs. 25.40 per ton for bagged fly ash; the cost of gunny bags required to pack 1 ton of fly ash being Rs. 20. The estimated details are as follows:
US $ taken at 7.5 Rs.

e. <u>Depreciation and Maintenance</u>

		Rupees in thousands	(US$) x1000
Depreciation on buildings, sheds, silos etc. at 3% on Rs. 448,000	...	13.4	1.787
Depreciation on machinery and electrical installations at 10% on Rs. 3,400,000	...	340.0	45.333
Maintenance cost of machinery and electrical installations at 10% on Rs. 3,400,000	...	340.0	45.333
Maintenance of buildings at 2¼% on Rs. 448,000	...	10.1	1.347
Interest on working capital based on 60 days working on Rs. 356,000 at 6%	...	21.4	2.853
Total	...	724.9	96.653

f. <u>Total Cost of Production</u>

Salaries and wages	...	260.4	34.720
Raw Material and power	...	817.5	109.000
Depreciation and maintenance etc.	...	724.9	96.653
Total	...	1802.8	240.373

g. <u>Cost of Production per Ton</u>

Cost of reactive surkhi or burnt clay pozzolana	Say Rs.	30/-/ton	US$ 4.000/ton

6. <u>Cost of Production of Lime-Pozzolana Cements:</u>

207. The traditional method of producing this type of cement is by wet grinding of pozzolana with lime in a mortar mill. The capital investment for this process is low because even for producing a calcined pozzolana, say surkhi, brick kilns could be employed conveniently and grinding could be done in an animal driven stone mill.

The cost of production of surkhi mortar used for Tunga Anicut Works[1] in Mysore State (India) in 1949 is as follows:

a. Bricks

Brick moulding	... Rs. 3.0 per cu.yd.
Brick burning	... Rs. 3.40 per cu.yd.
Conveyance	... Rs. 0.50 per cu.yd.
Breaking and stacking	... Rs. 1.00 per cu.yd.
Total	... Rs. 7.90 US $1.0533

b. Surkhi Mortar

		(US$)
Cost of 1/4 cu.yd. of lime	... Rs. 7.32	0.9760
Cost of 1 cu.yd. of surkhi	... Rs. 7.90	1.0533
Loading, grinding and unloading charges	... Rs. 2.63	0.3506
Total	... Rs.17.85	2.3799

.'. Cost of surkhi mortar at the mortar mill is Rs. 17.85 or (2.38 US$) per cu.yd.

Assuming a bulk density of 83 lbs/cft, cost of surkhi works out to be Rs. 10.50 per ton. According to 1966 price level, the cost will be about Rs. 21 (2.8 US$) per ton.

208. According to a recent estimate,[2] the cost of surkhi in Panjab (India) where bricks are cheap, works out to Rs. 20 (2.66 US$) per ton on the following basis:

		(US$)
i) Cost of brick bats to produce one ton of surkhi including transportation from kiln site to production site at five miles distance	... Rs. 6.00	0.800

1/ D. Doddiah and M.S. Gurushankaraiah, "Surkhi-Mortar-Its Development and Standardisation", Journal of Central Board of Irrigation & Power, vol. 12, 1955, pp. 420-449.

2/ H.L. Uppal and Gursharan Singh, "Possolanic Surkhi from Some Burnt Clay Bricks of Punjab", Symposium on Pussolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

			(US$)
ii)	Grinding charges including depreciation of machinery, electricity and labour	... Rs. 12.00	1.600
iii)	Supervision charges	... Rs. 2.00	0.266
	Total	... Rs. 20.00	2.666

209. Taking the cost of lime as Rs. 100 (13.333 US$) per ton, a lime-surkhi mix in 1:2 ratio by volume (or 1:4 by weight) would cost Rs. 39 (5.20 US$) per ton including Rs. 3/- per ton towards grinding in an animal driven mortar mill.

210. Factory finished lime-possolana cement could be produced by inter-grinding possolana with lime. The cost of burnt clay possolana produced by the rotary method was estimated at Rs. 30/- (4.00 US$) per ton. Assuming the cost of hydrated lime as Rs. 100/- (13.333 US$) per ton and cost of grinding lime no more than that of possolana, the cost of 1:2 lime-possolana cement works out to Rs. 44/- (5.8666 US$) per ton. If the proportion of lime to possolana is 1:3 by volume (i.e., 1:6 by weight), the cost of cement will be Rs. 40/- (5.333 US$) per ton.

7. <u>Production of Portland Possolana Cement by Blending Portland Cement with Fly Ash:</u>

(Blending Plant - 50 tons/hour)

211. A flow diagram of the blending plant (Fig. IV) shows that it is a simple process and can produce 400 tons of portland fly ash cement in 8 hours day shift. Blending is done in a large homogenising steel silo and a continuous charge and discharge system is adopted for this plant. Two such plants were set up in Japan and it is understood that CaO in the blended cement (80 parts of portland with 20 parts of fly ash) varied ± 0.5 per cent from the average value of 50.1 per cent.+ The variation could be reduced further if batch system is adopted for blending.

\+ Information supplied by the Indian Sugar and General Engineering Corporation, Yamunanagar (HARYANA), INDIA.

212. Depreciation on machinery has been taken at 6 per cent of the investment cost instead of the usual rate of 10 per cent as the wear and tear is considerably less in the blending plant. An estimated cost of production of a 80:20 portland fly ash blended cement works out to Rs. 126 (16.80 US$) per ton against Rs. 150 (20.0 US$) per ton of ordinary portland cement. The saving per ton is about Rs. 24 (3.20 US$) when the blending plant is set up near a thermal power station and portland cement is purchased from the market. Transportation and handling costs of fly ash will be extra if blending is to be done in a cement factory situated at a distance from the thermal power station.

ESTIMATED COSTS

		Rupees in thousands	(US$) x1000
a.	Land and Buildings		
	Developed land 10,000 sq.yds. at Rs. 10/- per sq.yd. ...	100.0	13.333
	Factory shed, 6000 sq.ft. at Rs. 8/- per sq.ft. ...	48.0	6.400
	Office, control laboratory (1,500 sq.ft. at Rs. 16/- per sq.ft.)		
	Civil construction including foundations.	100.0	13.333
	4 Steel silos for storing and homogenising	450.0	60.000
	Total ...	698.0	93.066

b. Plant and Machinery*

Bucket elevators, 3 nos. with capacity 50 tons/hour each and 2 nos. with capacity 30 tons/hour each

Overflow tanks, 3 nos., with conical bottom portion and with extraction unit, welded steel plate construction

Overflow screw conveyors, 2 nos., with capacity 10 tons/hour each and 1 overflow return screw conveyor of capacity 10 tons/hour

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* Based on quotations

	Rupees in thousands	(US$) x1000
Constant weight feeders, 2 nos., with capacity 10 tons/hour each		
Screw conveyors, 2 nos., with capacity 30 tons/hour each and 3 nos. with capacity 50 tons/hour each		
Steel surge tank, 20 ft.dia.x100 ft. high		
Rotary screen, capacity 50 tons/hour		
Packer feed bin, steel made, one		
One four spout auto packer with capacity 50 tons/hour, complete with fittings and drive etc.		
Motors and switch gear for above machines		
Transformer, electrical installations		
Tube well, overhead tank, workshop and laboratory equipment etc.		
Including erection costs		
Total ...	950.0	126.667

c. **Salaries and Wages**

	Rupees in thousands	(US$) x1000
Manager at Rs. 1000/- p.m. ...	12.0	
Works Engineer at Rs. 1000/- p.m. ...	12.0	
Chemical Engineer/Chemist at Rs. 800/- p.m. ...	9.6	
Laboratory Assistant at Rs. 300/- p.m....	3.6	
Foreman at Rs. 400/- p.m. ...	4.8	
Mechanics 5 nos. at Rs. 300/- p.m. ...	18.0	
Electrician at Rs. 300/- p.m. ...	3.6	
Packers and Silo Attendants, 6 nos. at Rs. 150/- p.m. ...	10.8	
Unskilled labourers 12 nos. at Rs. 3/- per day for 300 working days ...	11.9	
Total ...	86.3	11.507

		Rupees in thousands	(US$) x1000
d.	<u>Raw Material and Power</u>		
	Portland cement* 108,000 tons at Rs. 150/- per ton (with 2 per cent loss in transport) ...	16200.0	2160.0
	Fly ash 27,800 tons at Rs. 1/- per ton (with 5% loss in transport) ...	27.8	3.707
	Power, 228,000 KWH at 10 paise per KWH ..	22.8	3.04
	Total ...	16250.6	2166.747
e.	<u>Depreciation and Maintenance etc.</u>		
	Depreciation on buildings, sheds, silos at 3% on Rs. 5,98,000 ...	17.9	
	Depreciation on machinery at 6% on Rs. 8,00,000 ...	48.0	
	Depreciation on electrical installations, water supply etc. on Rs. 1,50,000 at 6%..	9.0	
	Maintenance cost of buildings, sheds and silos etc. at 2¼% on Rs. 5,98,000 ...	13.5	
	Maintenance cost of machinery at 6% on Rs. 8,00,000 ...	48.4	
	Interest on working capital based on 60 days working on Rs. 30,00,000 at 6% ...	180.0	
	Total ...	316.8	42.240
f.	<u>Total Cost of Production</u>		
	Salaries and wages ...	86.3	11.507
	Raw material and power ...	16250.6	2166.747
	Depreciation and maintenance etc. ...	316.8	42.240
	Total ...	16653.7	2220.494

* Bulk supply of portland cement

		Rupees in thousands	(US$) x1000
g.	**Cost of Production per Ton**		
	Cost of production of 'naked' pozzolana cement ...	126.0	16.80
	Cost of 'bagged' pozzolana cement (including Rs. 20/- for bagging charges)	146.0	19.467

8. **Production of Portland Pozzolana Cement by Intergrinding Clinker with Burnt Clay Pozzolana:**

(Plant Capacity 1000 tons/day)

213. The pozzolana is calcined in a rotary kiln of capacity 200 tons per day. For producing a portland pozzolana cement with a pozzolana content of 20 per cent, about 800 tons of portland cement clinker is required. Pozzolana and clinker are interground and the rest of processing is similar to that in a cement factory.

214. Cost of portland cement clinker in the present estimates is assumed to be Rs. 85/- per ton. The cost of production of portland pozzolana cement works out to be Rs. 80/- per ton. The saving will be roughly about Rs. 15/- per ton if cost of grinding portland cement clinker is assumed to be Rs. 10/- per ton. The detailed estimate is as follows:

ESTIMATED COSTS

		Rupees in thousands	(US$) x1000
a.	**Land and Buildings**		
	Developed land, 10 acres at Rs. 10/- per sq.yd. ...	484.0	64.53
	Railway siding within the factory - 400 meters at Rs. 350/- per meter ...	140.0	18.67
	Factory shed, 50,000 sq.ft. at Rs. 12/- per sq.ft. ...	600.0	80.00
	Office, control laboratory buildings, 5000 sq.ft. at Rs. 16/- per sq.ft. ...	80.0	10.67
	Silos, 3 nos., for portland cement, 1 no. for reactive surkhi and 1 no. for gypsum ...	600.0	80.00
	Total ...	1904.0	253.87

		Rupees in thousands	(US$) x1000
b.	**Plant, Machinery & Installed Equipment**		
(i)	For production of 200 tons of 1/2 - 3/4 inch size burnt clay pozzolana vertical elevators, crushing equipment, rotary kiln, rotary cooler, rotary table feeders, hoppers, for the production of 200 tons of calcined clay of size 1/2 - 3/4 inch, including 12 per cent erection charges ...	1819.4	242.45
(ii)	For handling, conveying, feeding, intergrinding of pozzolana, portland cement clinker and gypsum; pneumatic conveying of cement for storage including 12 per cent erection charges ...	4500.0	600.00
(iii)	Installed Equipment Transformer, electric motors, electrical installations, chute connections, tubewell, workshop equipment, laboratory equipment, control equipment etc. ...	950.0	126.67
	Total ...	7270.0	969.3

		Rupees in thousands
c.	**Salaries and Wages**	
	Manager at Rs. 2000/- p.m. ...	24.0
	Office Superintendent at Rs. 1000/- p.m..	12.0
	Accountant at Rs. 800/- p.m. ...	9.6
	Clerks 15 nos. at Rs. 300/- each p.m. ...	54.0
	Storekeepers 4 nos. at Rs. 200/- p.m. ...	9.6
	Stenographers 2 nos. at Rs. 700/- p.m....	16.8
	Chief Engineer at Rs. 1500/- p.m. ...	18.0
	Chief Chemist at Rs. 1500/- p.m. ...	18.0
	Shift Chemists, 3 nos. at Rs. 1000/- p.m.	36.0

	Rupees in thousands	(US$) x1000
Electrical Foreman at Rs. 800/- p.m. ...	9.6	
Mechanical Foreman at Rs. 800/- p.m. ...	9.6	
Electricians, 5 nos. at Rs. 300/- p.m....	18.0	
Operators, 15 nos. at Rs. 300/- p.m. ...	54.0	
Silo Attendants, 6 nos. at Rs. 150/- p.m.	10.8	
Crane Drivers, 6 nos. at Rs. 200/- p.m. .	14.4	
Switch board attendants, 6 nos. at Rs. 150/- p.m. ...	10.8	
Oil men, 6 nos. at Rs. 150/- p.m. ...	10.8	
Laboratory Assistants, 3 nos. at Rs. 150/- p.m. ...	5.4	
Workshop staff ...	25.0	
Total ...	366.4	48.85

d. **Raw Materials, Fuel and Power**

	Rupees in thousands	(US$) x1000
Clay 75,000 tons at 50 paise per ton ...	37.5	5.00
Portland cement clinker, 2,32,700 tons with 1 per cent loss at Rs. 85/- per ton.	19779.5	2637.27
Gypsum 12,360 tons with 3 per cent loss at Rs. 45/- per ton ...	556.2	74.16
Cost of fuel (furnace oil) ...	480.0	64.00
Power ...	881.8	117.57
Total ...	21735.0	2898.00

e. **Depreciation and Maintenance etc.**

	Rupees in thousands	(US$) x1000
Depreciation on buildings, sheds, silos etc. at 3% on Rs. 14,20,000 ...	42.6	5.68
Depreciation on machinery at 10% on Rs. 63,20,000 ...	632.0	84.27
Depreciation on electrical installations at 10% on Rs. 9,50,000 ...	95.0	12.67

		Rupees in thousands	(US$) x1000
Maintenance cost of machinery and electrical installations at 10% on Rs. 72,70,000	...	727.0	96.93
Maintenance cost of buildings at 2½% on Rs. 12,80,000	...	28.8	3.84
Interest on working capital based on 60 days working on Rs. 47,25,350 at 6%	...	283.5	37.80
Total	...	1808.9	241.19

f. Total Cost of Production

Salaries and wages	...	366.4	48.85
Raw material, fuel and power	...	21735.0	2898.00
Depreciation and maintenance etc.	...	1808.9	241.19
Total	...	23910.3	3188.04

g. Cost of Production per Ton

Portland reactive surkhi cement ... Rs. 80.0 US$ 10.667/ton

9. Comparative Costs of Production:

215. The cost of handling and bagging fly ash possolana is the lowest; about Rs. 5 (0.667 US$) and Rs. 25 (3.333 US$) per ton for 'naked' and 'bagged' fly ash respectively. The costs of surkhi or burnt clay possolana which needs maximum operations range between Rs. 20 (2.667 US$) to 38 (5.067 US$) per ton for 'naked' possolana and Rs. 40 (5.333 US$) to 58 (7.733 US$) for bagged possolana. The costs of other possolanas are likely to fall in between these costs unless the winning of raw material becomes very expensive in a particular situation.

216. The cost of production of surkhi from brick bats is estimated at Rs. 20 (2.667 US$) per ton. If surkhi or burnt clay possolana is produced as an industrial product, the cost of production works out Rs. 38 (5.067 US$) by the down draught method and Rs. 30 (4.00 US$) by the rotary kiln method.

ESTIMATED COSTS - 60 ton/day plant

		Rupees in thousands	(US$) x1000
a. Land and Buildings			
Developed Land 2000 sq.yds. at Rs. 10/- per sq.yd.	...	20.0	
Factory Shed 1000 sq.ft. at Rs. 8/- per sq.ft.	...	8.0	
Office and Control Laboratory building, 500 sq.ft. at Rs. 16/- per sq.ft.	...	8.0	
Silo for storing 100 tons of fly ash	...	15.0	
Total	...	51.0	6.8
b. Plant and Machinery			
Flux-O-Pump for pneumatic transport of fly ash	...		
Silo equipment (aeration plates, valves, cocks etc.)	...		
Compressor, Bucket Elevator	...		
Feeding hopper for feeding fly ash to automatic valved bag packing and weighing machine hopper, complete with supporting structure	...		
Bagging plant complete, capacity about 10 tons per hour	...		
Electrical installations	...		
Erection charges at 12 per cent of cost of machinery	...		
Total	...	222.5	29.7

A higher production cost by the former method is mostly due to higher labour and supervision charges per ton of surkhi. It shows that if high quality surkhi or burnt clay pozzolana is to be produced, manufacturing in a rotary kiln is quite economical.

217. In India selling price of portland cement is controlled and is uniform throughout the country. A bag of cement costs the same all over the country. The cost of portland cement given in estimate under 6 is for the bulk supply and includes excise duty. The cost of portland pozzolana cement by blending is lower by about Rs. 24 (3.20 US$) per ton. As against this, the saving is about Rs. 15 (2.00 US$) per ton if burnt clay pozzolana is used. But these estimates should not be taken to infer that production of portland pozzolana cement by blending is more economical than by intergrinding as the pozzolanas used in the two examples require different processing operations.

CHAPTER V. USES OF POZZOLANA AND POZZOLANA CEMENTS

218. Historically pozzolanas were first used in lime pozzolana mortars. Subsequently, pozzolana based cements were developed; the most important being portland pozzolana cement. A contemporary development was the use of pozzolanas in concrete for special purposes. So far use of natural or artificial pozzolanas was mostly confined to the above fields. But with the availability of fly ash, the uses of pozzolanas were extended to diverse fields because of the pressing problem of its disposal. Consequently, since 1932 more uses of fly ashes have been discovered than of any other pozzolana.[1/] Some are still in experimental stage. In view of this and in context of the scope of the present report, only well established uses of pozzolana in cement and concrete technology have been described here.

A. Lime-Pozzolana Cements

1. In Mortars and Plasters:

219. Mixes of lime with natural pozzolanas, used as building mortars in many parts of Europe about 2000 years ago are still in use in Italy, Germany and a few other countries. In Italy, the specifications for natural pozzolanas require that the maximum grains size shall not exceed 5 mm and that a normal mortar, prepared in the ratio of one part by weight of hydrated lime and three parts of reactive pozzolana will have tensile and compressive strengths not less than 5 and 25 kg/cm^2 at 28 days when tested according to the Standard procedure.[2/] The corresponding values for a weak reactive pozzolana should be 3 and 12 kg/cm^2. The traditional mortar in Italy is 1 volume of slaked lime putty to 2 volumes unground pozzolana, but ratios of 1:3 or 1:3.5 are recommended now for these coarse pozzolanas.[3/] The coarser particles act more or less as inert aggregate

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1/ Edward A. Abdun Nur, "Fly Ash in Concrete - An Evaluation", Highway Research Board Bulletin 284, National Academy of Sciences, Washington, D.C., 1961, p. 6

2/ G. Malquori, "Natural Italian Pozzolanas", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec. 1964.

3/ F.M. Lea, "The Chemistry of Cement and Concrete", Edward Arnold (Publishers) Ltd., London, 1956, p. 368.

and only the finer grades act as pozzolana. According to Malquori[2] the substitution of lime putty by hydrated lime powder generally needs dosages of about 15 kgs. of hydrated lime per 100 kgs of granular pozzolana with normal moisture content.

220. Recent trends in Italy are to substitute a moderate portion of granular pozzolana by the same pozzolana having fineness equal to that of portland cement. Another trend is the addition of portland cement to pozzolanic mortars where relatively coarse pozzolana is used.[2] These modifications in the mortar composition bring about an over-all improvement in the properties of the mortars prepared from this type of cements. Setting times and early strengths are particularly improved.[3,4] When pozzolana used with lime is coarse then sand is generally not required for preparing mortars. However, both natural and artificial pozzolanas may be available only as fine powders. Under such circumstances, use of sand aggregate becomes necessary for preparing mortars.

221. The latest trend in this field is the production of lime-pozzolana cements as a factory finished product. The examples are lime-trass cement in Germany[5] and lime-reactive surkhi and lime-fly ash in India.[6,7] This development is of particular interest to the countries where portland cement is in short supply, production cost is high and lime is cheaper than portland cement. Because of quality control, factory produced lime-pozzolana cement will be additionally suitable for plastering and in road construction.[6,8]

4/ "Cement-Reactive Surkhi-Sand Mortars with and without Lime", Joint Report of Central Water & Power Commission and Central Road Research Institute, New Delhi, Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

5/ H. Kremser, "The Use of Pozzolana in Germany", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

6/ R.K. Gosh, N.R. Srinivasan, M. L. Bhatia and S G Banerjee, "A Study of Reactive Surkhi Mortars", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

7/ Linient, Mortar to Build a Growing India, Alipore Road, Delhi (INDIA).

8/ R.K. Gosh, K.P. Dhir, N.R. Srinivasan and M.L. Bhatia, "Lime-Reactive Surkhi Concrete in Road Construction", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

2. <u>In Concrete</u>:

222. Lime-pozzolana concretes used in Italy in the past have shown excellent performance. The mix commonly used consisted of 1 volume of lime putty, 2 volumes of unground pozzolana and 3 volumes of aggregate i.e., about 2:7:16-24 by weight. Nowadays, however, the practice is to use lower ratios of lime to pozzolana, the ratio of the lime-pozzolana mortar to aggregate being maintained at about 1:2 by volume.9/ While lime-pozzolana concretes, characterized by an accelerated rate of hardening, can be exposed to the wash of waves within a day of placing, others may give such performance only either on replacement of part of coarse pozzolana with fine pozzolana or on addition of portland cement. For example, mixed lime-trass-portland cement concretes have been used to some extent in Germany, as in the locks on the Rhine-Herne canal in which a 4:5:8:27:54 volume mix of portland cement-lime-trass-sand-ballast was employed.5,9/ The latter type of cement is more useful for placing concrete in situations where the prevailing temperatures are low and the normal lime-pozzolana concrete will set and harden slowly.

223. Lime-pozzolana cement can also be used in making foundation concrete. The conditions under which use of lime-pozzolana concrete is recommended have already been discussed (paras 187 and 188). Similarly, the prospects of use of lime-pozzolana concrete in base course were discussed earlier (para.189).

3. <u>In Soil Stabilization</u>:

224. Lime pozzolana mix could replace cement-pozzolana mix for soil stabilisation in countries where reactive pozzolanas are available and lime is comparatively cheaper. However, the speed of execution of the job is an important factor for consideration for longer curing periods are required for lime-pozzolana mixes as against cement-pozzolana mixes. Also, if prevailing temperatures are low, the balance may shift in favour of cement-pozzolana mixtures. The determination of optimum ratio between the two constituents by tests carried out in laboratory or in field is essential for ensuring success of use of lime-pozzolana and the recommended curing conditions should also be adhered to in the field strictly. Control of optimum moisture content and compaction are as vital as in any stabilisation work.

9/ F.M. Lea, "The Chemistry of Cement and Concrete", Edward Arnolds (Publishers) Ltd., London, 1956, p.368.

225. Though any pozzolana can be used, fly ash appears to be the most attractive pozzolana for stabilization presumably because of its disposal problem. Also some fly ashes are self-hardening.[10/] The various uses of stabilized soil mentioned in the literature are in road base courses, hard shoulders, bridge abutments, footpaths, etc.[11/] Millions of tons of fly ash have been used as embankment filling for highways in England[12/] and America.[13/]

B. Portland-Pozzolana Cement

1. For Mass Concrete Construction

226. Portland-pozzolana cement was originally used for improvod durability and hydraulic and underground structures.[9/] Its most wide-spread use has been in mass concrete because of evolution of lower heat of hydration, lower thermal shrinkage and reduced cracking which permits use of larger blocks for speeding up construction. Table 1 lists the important examples of its use in mass concrete for the construction of dams, aquaducts, bridges, etc.[14-19/] Apart from

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10/ S. Raymond, "Shear Strength and Other Properties of Compacted Fly Ash", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

11/ S. Raymond and P.H. Smith, "The Use of Stabilized Fly Ash in Road Construction", Civ. Eng. & P W. Review, London, January-February-March, 1964.

12/ S. Raymond, "Pulverized Fuel Ash as Embankment Material", Proc. I C.E., Vol. 19, London, August, 1961.

13/ Walter H. Cobbs (Jr.) "Using Powdered-Coal Fly Ash", Power, Vol. 959, pp. 87-89, May, 1951.

14/ H.S. Meissner, "Pozzolans Used in Mass Concrete", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication, No. 99 American Society for Testing Materials, Philadelphia, 1950, pp. 16-29.

15/ F.M. Lea, "The Chemistry of Cement and Concrete", Edward Arnolds (Publishers) Ltd., London, 1956, p. 369.

16/ R.S. Gill and Harish Chander, "Manufacture and Control of Concrete for the Bhakra Dam", Indian Concrete Journal, vol.34, Nov., 1960, pp. 444-446.

17/ S.K. Jain, K.M. Maheshwari and G.D. Agarwala, "Investigation of Coal and Fly Ashes for Use As Puzzolana For Rihand", Indian Concrete Journal, vol. 34, Nov., 1960, pp. 429-431.

18/ M. Kokubu, "The Development in Japan of Fly Ash as An Admixture for Concrete", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

19/ K. Yoshikoshi, "Investigation on Fly Ash as Pozzolanic Admixture", Transactions, Japan Society of Civil Engineers, No. 31, Nov., 1955 (In Japanese).

TABLE 1

Use of Pozzolanas as Cement Replacement in Dams and other Hydraulic Structures

Particulars of hydraulic structure (1)	Pozzolana used (2)	Considerations for use (3)
San Francisco Bay Bridges, U.S.A.	Calcined Monterey shale	Favourable heat generation, resistance to alkali soils and sulfate waters.
Bonneville Dam, Spillway portion Columbia River, U.S.A.	Calcined pozzolana	Lower cost, less tendency in concrete to segregate, lower water gain, greater tensile strength, greater impermeability and favourable heat generation.
Friant Dam, San Joaquin River, U.S.A.	Natural fine Fresno pumicite	Considerations of low heat of hydration to build the monolithic blocks of the da
Altus Dam, U.S.A.	Natural pumicite	Consideration of low heat of hydration
Davis Dam Lower Colorado River, U.S.A.	Calcined reactive siliceous material (shale)	To avoid danger from potential alkali-aggregate reaction.
Hungry Horse Dam, Flathead River, U.S.A.	Fly ash	Improvement in concrete properties and economy in portland cement consumption.
Liberty Dam, Baltimore, U.S.A.	Fly ash	--As above--
Scottish Dams in U.K.	Fly ash	--not known--
Sudagai Dam and twelve other dams in Japan	Fly ash	Improvement in concrete properties.
Bhakra Dam, River Sutlej, India	Calcined shale	Improvement in concrete properties, Economies in cement consumption.
Rihand Dam, India	Bokaro fly ash	————do————
Rana Partap Sagar Dam, Rajasthan India	Reactive surkhi	————do————

technical advantages accruing from the modifications in the properties of fresh and hardened portland cement concrete by replacement of a part of portland cement by pozzolana, substantial savings in money also result by using portland-pozzolana cement because of the lower cost of pozzolana cement and lower costs of cooling concrete.

2. <u>For Resisting Aggressive Water Effects</u>:

227. Use of portland-pozzolana cements is also preferred for two other applications i.e., for concrete work for use in sulphate bearing waters and sea-water and for counteracting expansions in concrete arising from alkali-aggregate reaction. When chemical resistance against sulphates is to be improved, portland cement clinker to be blended with pozzolana should be low in tricalcium aluminate (i.e., brownmilleritic clinker). In Italy, pozzolana is blended with a Ferrari-type portland cement of low Al_2O_3 to Fe_2O_3 ratio[15]. The type of pozzolana also seems to influence the sulphate resisting property of the portland pozzolana cement. For example, Davis, Hanna and Brown[20] found that while the use of pozzolanas, such as Monterey shale and pumicite in blended cements improved resistance to sulphate attack, in general, blends containing calcined or uncalcined clays, and crystalline silica such as quartz and granite were little, if any, more resistant to sulfate action than the corresponding straight portland cement[20]. Kondo's work has also shown[21] that portland silica cement is no better than straight portland cement thus confirming the earlier

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20/ R.E. Davis, W.C. Hanna and E.H. Brown, "Strength, Volume Changes and Sulfate Resistance of Mortars Containing Portland-Pozzolan Cements", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No.99, American Society for Testing Materials, Philadelphia, 1950, pp.131-152.

21/ R. Kondo, "Chemical Resistivities of Various Types of Cements", Chemistry of Cement, Proceedings of the Fourth International Symposium, Washington, National Bureau of Standards, Monograph 43, U.S. Department of Commerce, 1960, vol. II, pp. 881-888 results. Puri, Bawa and Srinivasan[22/] have also opined that blends containing calcined clay or pozzolana do not enhance sulphate resistance unless clays are calcined at temperatures higher than that required for producing oxides of silicon and aluminium in their most reactive state. Turriziani[23/] has found sulphate expansion to decrease with increase in the ratio (R) of reactive silica to reactive alumina. In view of this the general recommendations made for using a portland-pozzolana cement for sulphate resistance jobs are that

(i) a pozzolana containing low alumina and that too in less active form should be preferred;

(ii) a pozzolana with high silica content should be selected, the ratio of reactive silica to alumina should be greater than 6;

(iii) a portland cement with low tricalcium aluminate ($3CaO.Al_2O_3$) content should be preferred;

(iv) a suitable mixture for portland cement clinker and pozzolana should be selected on the basis of laboratory tests; and

(v) a portland-pozzolana cement should have an optimum amount of gypsum as set-retarder. This may be determined by laboratory tests.

3. For Inhibiting Alkali-Aggregate Reaction:

228. In circumstances where the use of alkali-reactive aggregates cannot be avoided, the general recommendations are to use a cement with an alkali content below 0.60 per cent Na_2O equivalent to the total alkali ($Na_2O + K_2O$) or to make use of portland-pozzolana cements or both. American researches have shown that porcelaneous shales and opaline cherts of the Miocene era in the Monterey formation of California, consisting predominantly of highly siliceous marine sedimentary rocks, possess superior qualities as correctives for alkali-aggregate

22/ I.L. Puri, N.S. Bawa and N.R. Srinivasan, "Durability of Concrete with respect to Sulphate Attack", RILEM Symposium on Concrete and Reinforced Concrete in Hot Countries, Israel, 1960.

23/ R. Turriziani, "Aspects of the Chemistry of Pozzolanas", The Chemistry of Cements, Edited by H.F.W. Taylor, Academic Press, London and New York, 1964, pp. 83-85.

reaction compared to the lower silica content non-marine sedimentary rocks.[24] In other words, not all pozzolanas are equally effective; in fact some may make the situation worse while others like high opal content cherts reduce expansions only under some conditions. According to Stanton the activity of the pozzolana as a corrective appears to be related to the percentage of silica readily soluble in sodium hydroxide, more than the reduction in alkalinity as determined by the rapid chemical test.[25] Since the mechanism of the action of pozzolanas in reducing expansion is not clear,[26] it is best to test and evaluate pozzolanas in the laboratory with the help of standard test.[27] As a general recommendation, pozzolanas such as diatomaceous earths, certain burnt clays and some fly ashes, and natural pozzolanas of the type mentioned above may be used. There is nothing against the use of pozzolana high in alkali content but, otherwise, established safe from the point of view of practice over long periods. Italian pozzolanas are an example.[28]

4. <u>For General Construction Work</u>:

229. Use of portland pozzolana cement in the past has been confined mostly to constructions of mass concrete dams and marine works. Because of their lower early strengths, relatively greater moisture movements and greater sensitiveness

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24/ T.E. Stanton, "Studies of Use of Pozzolans for Counteracting Excessive Concrete Expansions resulting from Reaction between Aggregates and the Alkalies in Cement", Symposium on Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No.99, American Society for Testing Materials, 1950, pp. 178-201.

25/ R.C. Mielenz, K.T. Green and E.J. Benton, "Chemical Test for Reactivity of Aggregates with Cement Alkalies; Chemical Processes on Cement-Aggregate Reaction", Proc. Am. Concrete Inst., 44, pp. 193-221 (1947).

26/ P. Bredsdorff, G.M. Idorn, A. Kjaer, N.M. Plum and E. Poulsen, "Chemical Reactions Involving Aggregate", Chemistry of Cement, Proceedings of the Fourth International Symposium, National Bureau of Standards, Monograph 43, U.S. Department of Commerce, 1960, vol. II, pp. 749-780.

27/ Standard Method of Test for Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar Bar Method), ASTM Designation C 227-64, 1964 Handbook of ASTM, Standards Part 10.

28/ G. Malquori, "National Italian Pozzolanas", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

to curing conditions and frost action, portland-pozzolana cement was not widely used as a general purpose cement. But the uses of a portland-pozzolana cement (30-40 per cent pozzolana) in Italy in the same proportions as portland cement for concrete in general building constructions and for reinforced concrete in sea water[28] indicate that inhibitions on the wider uses of this cement are not justified. According to Malquori,[29] with the exception of thin and light prestressed structure, the job requirements for almost all applications of portland cement in concrete can be fulfilled equally well by portland-pozzolana cement manufactured in the light of modern technological processes. In fact, use of high early strength portland cement for many such jobs is uncalled for on technical grounds, such as evolution of higher heat of hydration, increased drying shrinkage and diminished corrosion and frost resistance and hence may be considered even as wasteful. Malquori's assessment in his own words is as follows:

> "In other words, portland-pozzolana cement stands on the same footing as portland in satisfying the demands of a considerable part of the cement uses contemplated by current building techniques."

5. For Reinforced Concrete:

230. Not much has been published either in favour or against the specific use of portland pozzolana cement in reinforced concrete. Some of the possible reasons could be easy availability of portland cement and apprehensions about the deleterious effects of pozzolanas and the quality of pozzolana cement concretes, coupled with lack of understanding of factors and conditions under which corrosion is promoted.

231. Most of the natural pozzolanas contain alkali originally or released as a result of pozzolanic action. Since in high pH enviroment (pH 12-13), little or no corrosion is expected, natural pozzolanas, in general, are satisfactory from this point of view. However, this cannot be said of artificial pozzolanas and it is desirable to assess the corrosion resisting characteristics of each pozzolana individually on scientific basis. Such an

29/ G.Malquori, "Portland-Pozzolan Cement", Proceedings of the Fourth International Symposium, National Bureau of Standards, Monograph 43, U.S. Department of Commerce, Washington, 1960, vol. II, pp. 996-998.

		Rupees in thousands	(US$) x1000
c.	Depreciation and Maintenance		
	Depreciation on buildings, sheds, silos etc. at 3% on Rs. 31,000 ...	0.9	
	Depreciation on machinery at 6% on Rs. 1,72,500 ...	10.4	
	Depreciation on electrical installations at 10% on Rs. 50,000 ...	5.0	
	Maintenance cost of machinery electrical installations at 10% on Rs. 2,22,500 ...	22.3	
	Maintenance cost on buildings at 2½% on Rs. 31,000 ...	0.7	
	Interest on working capital based on 60 days working on Rs. 19,160 at 6% ...	1.5	
	Total ...	40.8	5.44
d.	Salaries and Wages		
	Manager-cum-Salesman at Rs. 600/- per month ...	7.2	
	Mechanical Foreman at Rs. 400/- per month ...	4.8	
	Mechanic at Rs. 250/- per month ...	3.0	
	Packers and Silo attendants; 6 attendants at Rs. 150/- per month ...	10.8	
	Unskilled labour at Rs. 3/- per day; 5 labourers for 330 working days ...	5.0	
	Total ...	30.8	4.107

evaluation has been done by Abdun Nur[30] in respect of fly ash, a well known pozzolana.

232. Regarding the ill effects of sulphur content in fly ash, it is made out that the sulphur content of fly ash is limited by specifications and is no more in portland-pozzolana cement than in the portland cement. Regarding the fears of greater corrosion due to the presence of unburnt carbon which is supposed to increase electrical conductivity, it is opined that low specified limits on carbon and its presence in a highly dispersed state in concrete are sufficient safeguards. Japanese work[31] further shows that addition of calcium lignosulphonate to the concrete mix will be an additional precaution as it inhibits corrosion. The French[32] claim that fly ash cement improves the resistance of concrete to electrolytic corrosion is of great significance. Fly ash has been used in Japan for reinforced concrete work in substations and structures for underground transmission of electricity[33].

233. Since the successful use of fly ash in fabrication of reinforced concrete transmission line poles by the Madras Electricity Board[34] use of fly ash in reinforced concrete has aroused great interest in India. Rangaswamy, Balasubramanian

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30/ E.A. Abdun Nur, "Fly Ash in Concrete - An Evaluation", Bulletin 284, Highway Research Board, National Academy of Sciences, Washington, D.C., 1961, p. 31

31/ Y. Kondo, A. Takeda and S. Hideshima, "Effect of Admixtures on Electrolytic Corrosion of Steel Bars in Reinforced Concrete", Proceedings, American Concrete Institute, vol 56, pp. 299-312, October, 1959.

32/ P. Fouilloux, "Pozzolanic Slag Cements of High Chemical Resistance and Normal Strength Gain", Revue des Materiaux de Construction, No. 502, July, 1957, pp. 191-196.

33/ T. Misukoshi and H. Hasegawa, "Utilisation of Fly Ash at Tokyo Electric Power", Symposium on Pozzolanas - Their Survey, Manufacture & Utilisation, Central Road Research Institute, New Delhi, Dec., 1964.

34/ J. Walter, "Pozzolanas - Their Utilisation in Irrigation Projects of Madras State", Symposium on Pozzolanas - Their Survey, Manufacture & Utilisation, Central Road Research Institute, New Delhi, Dec., 1964 and Rajagopalan[35] who measured electrical resistance and potentials of portland and fly ash cement concretes have concluded that there is no evidence of acceleration of corrosion in the fly ash concrete. However, these workers caution against the presence of a high percentage of chlorides in which case protection reinforcement by application of glue-cement slurry coating is recommended.[35]

234. Regarding the effect of quality of portland-pozzolana cement concrete on corrosion, it is generally believed that moist or water cured pozzolanic concretes are less permeable and thus minimize the ingress of moisture and oxygen necessary for corrosion. However, this would not be true for pozzolanas which increase the water requirements of concrete considerably as the early strengths and impermeability of concrete may be affected adversely. In such like conditions steps such as reproportioning of pozzolana concrete,[36,43] longer curing of the concrete and protection of reinforcement may be helpful. The protective treatments have to be simple and inexpensive, otherwise, the use of straight portland cement would be favoured.

6. <u>For Precast Concrete Products</u>:

235. Use of portland pozzolana cements in the production of blocks, pipes[37] and precast concrete units is not being practised on any appreciable scale even though the usual prejudices against its use in reinforced and other type of concretes are much less valid in this particular field of application. For example, dry to very dry concrete mixes which can be filled in moulds by tamping and vibration are used in the precast industry and thus there are fewer chances of lower early strengths. In many instances, incorporation of pozzolana may cut down the water requirements for the same workability which implies little or no sacrifice of strength. Moreover, curing at elevated temperatures is the accepted practice in countries where precast concrete industry has established itself firmly. Under these curing conditions the pozzolanic action takes place faster and results in higher early strengths.

35/ N.S. Rangaswamy, T.B. Balasubramanian and K.S. Rajagopalan, "Effect of Admixture of Fly Ash with Portland Cement on Reinforcement", Corrosion, Journal National Buildings Organisation, India, 11 (1), 1966, pp. 45-50.

36/ C.E. Lovewell and G.W. Washa, "Proportioning Concrete Mixtures Using Fly Ash", Proc. American Concrete Institute, vol. 29, No. 12, June 1958.

37/ R.E. Davis, "Pozzolanic Material with Special Reference to their Use in Concrete Pipe", American Concrete Pipe Association, Technical Memorandum, Sept., 1954.

236. The precast concrete industry has used fly ash pozzolana mostly and Abdun Nur[38] has listed the following advantages of use of fly ash on the basis of several investigations:

(i) the concrete mix bleeds less, holds more water for curing; less sand streaking occurs, particularly in pipe and precast units

(ii) it permits earlier stripping and handling of units because of better green strengths

(iii) it reduces wear on moulds an machinery; gives better appearance

(iv) it permits a reduction in cement; in pipes additional advantages are improved resistance to sulfate, reduced permeability and leaching.

237. In countries where curing of concrete products at elevated temperature is still not in vogue and normal curing methods are being practised owing to one or the other reason, the above advantages will have to be weighed carefully because any undue delay in the release of moulds may upset the relative economics of the use of pozzolana in the precast concrete industry.

C. Pozzolana As a Cement Replacement

238. The most extensive and popular use of pozzolana, in the near past, has been as a replacement for part of portland cement in mass concrete because of technical advantages discussed earlier. Savings in the consumption of portland cement and economy in the construction costs were achieved in the construction of dams and other hydraulic structures. For small jobs use of pozzolana as part replacement of portland cement in the concrete mixer will give full value in terms of technical advantages and economy, only if pozzolana produced under controlled conditions is being marketed like portland cement i.e., in bags or air-tight drums because, otherwise, handling of pozzolana is difficult and its quality and, in turn that of concrete, may suffer. For a large scale use of pozzolana as a cement replacement, setting up of a handling and batching plant for pozzolana is desirable and large projects or concrete product plants can afford this additional expenditure because of the over-all economy.

38/ E.A. Abdun Nur, "Fly Ash in Concrete - An Evaluation", Highway Research Board Bulletin 284, National Academy of Sciences, Washington, D.C., 1961, pp. 22-23.

D. Pozzolana As an Admixture

1. Definition of Admixture:

239. According to ASTM Standard Definitions,[39/] an admixture is a material other than water, aggregates, and portland cement (including air-entraining portland cement and portland blast-furnace slag cement) that is used as an ingredient of concrete and is added to the batch immediately before or during its mixing. Pozzolanas fall under the category of finely divided mineral admixture which is one of the fiteen types of admixtures classified by the American Concrete Institute Committee.[40/] The distinction between the fine material in the cement and that in the aggregate in a concrete mix is more or less arbitrary. Similarly, in a concrete mix no distinction is possible between pozzolana used as cement replacement or addition.

2. Pozzolana as an Addition:

240. While the two concretes of straight portland cement and portland pozzolana cement may be having equal quantities of cementing material, of which pozzolana is a consituent in the latter concrete, the actual portland cement component is lower in the portland-pozzolana concrete. Another manner of using pozzolana in concrete is as an "addition" when both, a pozzolana containing concrete and a straight portland cement concrete will have equal portland cement contents. Of course, the tacitical assumption here is that but for the pozzolana the relative proportions of other ingredients are the same in the two concretes.

3. Use of Pozzolanic Addition:

(a) For Modifying Concrete Properties:

241. Since the pozzolanic action is common both in the use of pozzolana either as "replacement" or "addition", the properties of the two hardened concretes (i.e., the one containing pozzolana as replacement and the other as addition)

39/ "Standard Definitions of Terms Relating to Concrete and Concrete Aggregates", ASTM Designation C 125-58, 1964 Handbook of ASTM Standards, Part 10, American Society for Testing & Materials, Philadelphia, U.S.A.*/

40/ "Admixtures for Concrete", Reported by American Concrete Institute Committee 212, Proceedings American Concrete Institute, vol. 60, No. 11, Nov., 1963, p 1486.

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*/ Editorial note: ASTM Designation C 125-58 of 1964 has now (1968) been replaced by C 125-66.

would be, in general, similar. For example, concretes containing pozzolana as 'addition' would also set slower, have lower heat of hydration, reduced drying shrinkage, reduced thermal volume change and increased extensibility etc. These concretes, like those having pozzolana as replacement, may show improved moulding qualities and mould wear, higher tensile strengths, higher ultimate modulus of elasticity, lower permeability and leaching, reduced alkali-aggregate reaction and higher resistance to sulfates and fresh waters etc.

(b) For Improving Properties of Fresh Concrete:

242. Generally, use of pozzolana as an addition is made for improving the properties of freshly mixed concrete. Addition of pozzolana to concrete mixes could improve workability, reduce the rate and amount of bleeding and segregation. Mixes which have high portland cement contents and are not deficient in fines may no show an improvement in workability for a given water content.

243. Pozzolanas which do not increase the water content for achieving a desired level of workability should be chosen and as such the pozzolana particles should not have unfavourable shapes. Also the specific surface of the pozzolana should neither be too low or too high in comparison with portland cement. Generally, additions of 5 to 15 per cent of the amount of cement are made for pozzolanas of greatest fineness; for others the range is 15 to 30 per cent.

(c) For Correcting Deficiency in Aggregate Gradation:

244. Pozzolanas may also be added to act as correctives for deficiencies in an aggregate gradation in concrete mixes, say deficiency in 'fines' (particularly material passing ASTM sieve No. 200). The aggregate characteristics such as size, shape and surface texture may also be responsible for poor workability in some concrete mixes. Such concrete mixes may require a larger amount of portland cement than would be required to develop adequate strength, otherwise, the ratio of surface area of solids to volume of water in the mix, which governs the bleeding characteristics and degree of plasticity of fresh concrete would be lower. Alternately, a cheaper method could be addition of a suitable pozzolana which will also achieve the same objective i.e., increase the above ratio and increase the paste content of the mix and thereby its capacity for plastic deformation.

(d) For Improving Strenght of Lean Mixes:

245. Pozzolanic additions, in general, improve the strength of lean mixes and

affect the strength of rich mixes adversely. Both the properties of pozzolana and characteristics of concrete mixes are important. The most important pozzolanas employed for use as additions are fly ash, diatomaceous earth and volcanic tuffs.

(e) For Improving Durability of Concrete:

246. The other fields of application of pozzolana as an addition are in counteracting alkali-aggregate reaction and increasing sulfate resistance. For the former use, pozzolana must be evaluated in the laboratory as it is not safe to give recommendations regarding the nature and proportions of pozzolana to be used on the basis of published information. Pozzolanas are employed also for increasing sulfate resistance; 1 part of pozzolana to 2 to 5 parts of portland cement, either by weight or by absolute volume, is used for this purpose.

(f) For Reducing Permeability:

247. Generally speaking, use of pozzolana as 'addition' reduces permeability of concrete provided there is no undue increase in water requirements of the mix for a specified level of consistency or workability and concrete is moist cured for long time. Under conditions of continuous supply of moisture, such as in many mass concrete constructions and hydraulic structures, use of pozzolana will lead to greater water tightness; the effect being influenced by the nature and magnitude of pozzolana addition, mix proportions of concrete, age of maturity of concrete etc. Addition of pozzolana is more beneficial in lean mixes.

4. Pozzolana Concrete Technology:

(a) General:

248. When portland-pozzolana cement is a factory finished product and is supplied in standard weight bags or drums or barrels like ordinary portland cement, concrete technologists should consider it as another type of cement. Since such a cement is mostly the result of intergrinding of portland cement clinker with pozzolana, there is every likelihood of its early strengths comparing well with some of the portland cements and being substantially higher than the minimum specified in the Standards for the Portland pozzolana Cement. In such situations, methods followed for designing, preparing and placing portland cement concrete may be adopted for pozzolana concrete. Methods of quality control of portland cement concrete are equally applicable.

249. Use of pozzolana as an additional ingredient at the concrete mixer poses problems of quality control of both pozzolana and pozzolana concrete. Since pozzolana acts here as a diluent of cement and contribution of pozzolanic action in the beginning is not substantial, early strengths of pozzolanic concrete, if not properly proportioned, may be comparatively lower. This may lead to the false impression that pozzolana concrete is somewhat inferior. In view of this, the more important aspects of pozzolana concrete technology have been discussed below for the benefit of practice and field engineers. Nevertheless, it must be appreciated that pozzolana concrete in general requires greater quality control and one must guard against variability in moisture contents of pozzolana and aggregates. For big construction jobs setting up of project or field laboratories may prove economical in the long run. For example, with 258 lb of cement to each cubic yard of concrete the strength obtained at the Bhakra Dam Project was 2,600 p.s.i. at 28 days.[16] This strength is usually specified for a 1:3:6 cement:sand:aggregate mix where the quantity of cement used is 384 lb per cubic yard of concrete.

(b) New Type of Concrete:

250. Addition of certain pozzolanas improves the properties of fresh concrete. Strength and other properties of hardened concrete containing portland cement equal to that used in making straight portland cement concrete may also get improved due to this or pozzolanic action or both. If concrete is reproportioned economically, consumption of portland cement in the pozzolana concrete can be reduced i.e., actual portland cement content in concrete containing pozzolana could be somewhat reduced. In other words, pozzolana acts as a cement replacement. Under such circumstances distinction between use of pozzolana as 'replacement' or 'addition' loses much of its significance and it may be better to refer to use of pozzolana as an admixture for concrete. Abdun Nur[41] feels that the use of the term 'replacement' which has come into use should be discouraged. According to him, structural materials should be compared on the basis of their engineering properties, irrespective of their constituents, as long as such constituents are not detrimental and no reference

41/ E.A. Abdun Nur, "Fly Ash in Concrete - An Evaluation", Bulletin 284, Highway Research Board, Washington, D.C., 1961, p. 37.

should be made to the use of pozzolana as 'replacement' or 'addition'. Arthur[42] opines that use of pozzolana as a replacement of part of cement or sand or as an admixture in concrete, though considered by different investigators as separate, are, in effect, three different ways of looking at the same thing. It is, therefore, suggested that a concrete containing, say fly ash pozzolana, should be regarded as a new type of concrete and designed accordingly.

(o) Proportioning of Pozzolanic Concrete Mixes:

251. Scientific studies on the design of concretes containing pozzolanas are comparatively few because the use of pozzolanas has been widespread only in mass concrete where strength considerations are not as important as for structural concrete and use of pozzolanas as cement replacement in concrete mixes necessarily does not involve much change in mix design.

252. Regarding use of pozzolana in structural concrete, the basic approach has been to attain strengths equal to the strength of corresponding portland cement concrete at 28 days. Lovewell and Washa's work[37] has shown that in proportioning concrete mixtures using fly ash the water requirements could be reduced and strength increased by making certain adjustments in the amounts of fly ash, sand and gravel. Rehsi and Garg[43] have followed a similar approach in proportioning concrete mixes containing fly ash and their data show that with careful proportioning it is possible to attain equal 28 days strengths even with the Indian fly ashes which are comparatively coarser and have a higher content of unburnt fuel.[44] The proportioning of concrete mixes by Rehsi and Garg was done essentially on absolute volume basis following the recommendation of the American Concrete Institute.[45] Arthur[42] has reported a scientific basis for the design of fly ash concrete.

42/ P.D. Arthur, "The Design of Mixes for Fly Ash Concrete", Symposium on Puzzolanas - Their Survey, Manufacture & Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

43/ S.S. Rehsi and S.K. Garg, "Proportioning Concrete Mix containing Fly Ash", J. Institution of Engineers (India), Vol. XLV, No.1, Pt. Cl 1, Sept., 1964

44/ S.K. Chopra and S.N. Narain, "Measurement of the Specific Surface of Fly Ash", Jour. Materials Research & Standards, (U.S.A.), 4 (9), Sept., 1964, pp. 487-490.

45/ "ACI-613-54: ACI Standard Recommended Practice for Selecting Proportions for Concrete", ACI-613-54, American Concrete Institute, 1954.

(d) Use of Surface Active Agents:

253. Some fly ashes may reduce the workability at a given water content and necessitate the placement of concrete by vibration. Chopra, Rhesi and Garg[46/] observed this effect in concretes prepared with Indian fly ashes and found that the use of water-reducing and set-reducing agents are beneficial, not only in improving the workability and thereby making concrete fit for placement by tamping but also found that they increase early strengths. The fly ash concrete strengths were equal to those of straight portland cement concrete from 7 to 28 days showing thereby that use of fly ash does not delay the removal of formwork. In other words, there are no disadvantages of use of fly ash in concrete. Wallace and Ore[47/] have also reported enhancement in the strengths of fly ash concrete with water- and set-reducing agents.

254. Use of air entraining agents with portland pozzolana cements is permitted by the American Standards[48/] Davis and Klein[49/] found an improvement in the properties of fresh and hardened pozzolana concrete by using suitable air entraining agent. Entrained air is particularly known for increasing the resistance of concrete to freezing and thawing and thereby improving its durability.[50/] Since presence of pozzolana may reduce the amount of air entrained by a quantity of air-entraining agent, the selection of an agent for a particular pozzolana should be based on laboratory trials as was done at the two large dams[16,17/] recently constructed in India with pozzolana concrete.

46/ S.K. Chopra, S.S. Rehsi and S.K. Garg, "Use of Water- and Set-Reducing Admixtures in Fly Ash Concrete", Central Building Research Institute, Roorkee (U.P.), INDIA (Unpublished).

47/ G. Wallace and E.L. Ore, "Structural and Lean Mass Concrete as Affected by Water-Reducing Set-Reducing Agents", ASTM Special Technical Publication No. 266, American Society for Testing Materials, 1960.

48/ Tentative Specification for Portland-Pozzolan Cement, ASTM Designation: C 340-64T, 1964 Handbook of ASTM Standards, Part 10, American Society for Testing and Materials, Philadelphia U.S.A.

49/ R.E. Davis and Alexander Klein, "The Effect of Use of Diatomite treated with Air-Entraining Agents upon the Properties of Concrete", Symposium On Use of Pozzolanic Materials in Mortars and Concretes, Special Technical Publication No. 99, American Society for Testing Materials, Philadelphia, U.S.A., 1960, pp. 93-108.

50/ D.F. Orchard, "Concrete Technology", Asia Publishing House, New Delhi, Indian Edition, 1963, vol. 1 pp.101,128.

CHAPTER VI. ECONOMICS OF THE USE OF POZZOLANA CEMENTS

A. Economics

1. Pozzolana Cements versus Alternate Binders:

255. Lime pozzolana and portland pozzolana cements are the two most widely used pozzolana bearing cements. Considering the different uses of lime-pozzolana cement (Chapter V), it is clear that alternative to lime pozzolana mortars is the use of hydraulic lime mortars, portland cement mortars, composite (i.e. portland cement-lime-sand) mortars and Masonry cement mortars. Except lime mortars, all other mortars contain portland cement as one of the constituents and hence will be costlier than lime pozzolana mortars. Since the cost of production of pozzolana is generally lower than that of lime, hydraulic lime mortars could be cheaper in situations where cost of hydraulic lime is considerably lower than that of high calcium lime. But lime pozzolana mortars will, in all probability, be cheaper if pozzolana of high reactivity is available because the sand carrying capacity of lime pozzolana mix will then be at least equal to or greater than that of hydraulic lime and the lime content will be lower than that in lime mortars. These considerations hold good equally well for the use of lime pozzolana cement in concretes.

256. Portland pozzolana cement is generally compared to ordinary portland cement in its cementing value. Since the cost of production of even a calcined pozzolana, which needs maximum processing, works out to be lower than that of portland cement (paras. 215-217), the use of portland pozzolana cement is definitely beneficial from the point of view of savings in costs. Since early strengths of some portland pozzolana cement may be comparatively lower, the quantity of cement may have to be increased for attaining equal 28 days strengths. Even then there is a likelihood of savings in portland cement consumption. According to Chopra, Rehsi and Garg[1/] for a concrete strength of 2250 p.s.i., which is generally specified for reinforced concrete work, 12.0 bags of fly ash pozzolana cement are required against 11.75 bags of ordinary portland cement for the same strength. However, the actual quantity of

1/ S.K. Chopra, S.S. Rehsi and S.K. Garg, "Use of Fly Ash as a Pozzolana", Symposium on Pozzolanas - Their Survey, Manufacture and Utilization, Central Road Research Institute, New Delhi, Dec., 1964.

		Rupees in thousands	(US$) x1000
e. **Raw Materials and Power**			
Fly ash 21,000 tons (taking losses into account) at Rs. 1/- per ton excluding cost of transportation	...	21.0	
Power, 1,44,000 KWH at 10 paise per KWH	...	14.4	
Total	...	35.4	4.72
f. **Total Cost of Production**			
Salaries and wages	...	30.8	
Raw material and power	...	35.4	
Depreciation and maintenance etc.	...	40.8	
Total	...	107.0	14.267
g. **Cost of Production per Ton**			
'Naked' fly ash	...	Rs. 5.4	US $0.72
'Bagged' fly ash including Rs. 20/- towards cost of jute bags	...	Rs. 25.4	US $3.3866

4. **Cost of Production of Reactive Surkhi in Down Draught Kiln:**
(Production 6000 tons per annum)

204. Raw clay is received in a clay shed where it is crushed and screened. Brick moulding is done in the open. Bricks are then dried in the open. The down draught kilns (all of which should be in the same area) are then loaded. After calcination, bricks are taken to the milling shed where they are crushed in a disintegrator and then ground in a ball mill. Grinding is done in batches and ground material is elevated and stored in silo.

205. Extra space for brick moulding and drying shed will have to be included in the estimates for locations where weather conditions do not permit moulding and drying in the open. The ground surkhi may be stored in closed bins or in bags manually thus obviating the construction of a silo and use of an elevator in rural areas. The estimated cost of production works out to be Rs. 38/- per ton as follows:

portland cement in fly ash concrete is only 9.5 bags. Thus a saving of 2.25 bags of ordinary portland cement for 100 cft. of concrete, i.e., about 19 per cent, was achieved. For a concrete strength of 3500 p.s.i., the saving was 13.6 per cent showing thereby that savings in richer mixes are lower. If, however, pozzolana concrete is designed properly, the savings can be substantial. Table 1 gives costs of materials for 100 cft. of concrete prepared with ordinary portland cement and portland fly ash cement to have equal strength at 28 days. It is apparent that the savings in costs towards materials are of the order of Rs. 27 to Rs. 34/- per 100 cft. The net savings will be somewhat lower because of additional costs of handling and transportation of fly ash.

2. Cost considerations:

257. Cost of lime seems to govern the cost of lime pozzolana cement. This is evident from the cost of a cement containing lime and surkhi in 1:2 ratio by volume. The cost of production worked out to Rs. 44/- and Rs. 39/- per ton when reactive surkhi costing Rs. 30/- per ton and 'bazzar' surkhi costing Rs. 20/- per ton only were used respectively (paras. 209 and 210). Though the 'bazzar' surkhi was cheaper by Rs. 10/- per ton, the reduction in the cement price was only Rs. 5/-. Apparently cost of lime is an important factor.

258. Next in importance is the reactivity of a pozzolana. A more reactive pozzolana will permit leaner mortar and concrete mixes. For example, against a 1:2:4 lime:pozzolana:sand mortar employing a pozzolana of L.R. (Lime Reactivity) value of 600 p.s.i., a 1:3:14 mortar could be used if the L.R. value is more than 1200 p.s.i., the job requirements for the two mortars being the same. The actual lime content in the latter mix is lower and so will be its cost.

259. Manufacture of controlled and uniform quality of both lime and pozzolana and their intimate mixing are better possible in a factory and consequently production of factory finished lime pozzolana cement should be economical by virtue of their better bonding efficiency. But the necessity of packing this type of cement will add to the cost. Since lime pozzolana cements deteriorate in quality on exposure, jute bags cannot be used for prolonged storage. Polyethylene or paper lined bags or multi-walled paper bags are required and this may put up the cost of this cement a good deal for it to be economical in developing countries against traditional lime pozzolana mortars.

TABLE 3

Cost of materials for 100 cft of plain and fly ash concrete mixes proportioned by C.B.R.I. method

	Rs.
A) Plain cement concrete	
Cost of 22.5 cft or 18 bags of cement @ Rs. 10.25 per bag	184.50
Cost of 52.0 cft of sand @ Rs. 25.00 per 100 cft.	13.00
Cost of 66 cft of gravel @ Rs. 66.00 per 100 cft.	43.00
Total cost of materials	240.50
B) Fly ash concrete without admixture	
Cost of 18 cft or 14.4 bags of cement @ Rs. 10.25 per bag	148.00
Cost of 557 lbs or 11.7 cft of fly ash @ Rs. 5.00 per ton	1.24
Cost of 44.6 cft of sand @ Rs. 25.00 per 100 cft.	11.15
Cost of 69.34 cft of gravel @ Rs. 66.00 per 100 cft.	45.75
Total cost of materials	206.14
C) Fly ash concrete with admixture	
Cost of 100 cft of fly ash concrete	206.14
Cost of 3.24 lbs of admixture @ Rs. 2.04 lb.	6.60
Cost of fly ash concrete with 0.2 per cent admixture	212.74
D) Savings in material costs per 100 cft of concrete	
(a) Fly ash concrete without admixture = Rs. 240.50 - Rs. 206.14	34.36
(b) Fly ash concrete with admixture = Rs. 240.50 - Rs. 212.74	27.76

NOTE: The dry bulk density of cement, sand and gravel was assumed to be 90, 91 and 110 lbs/cft respectively. The cost of portland cement bag is for the private consumer; the price is lower for government departments.

260. The above discussion outlines the most probable trends. For choosing between lime pozzolana cements of different qualities, the actual cost of mortars or concrete per unit volume (100 cu.ft. or 1 cu.yd.) should be worked out because comparisons are possible only on that basis The properties of cement also come into play, for example, the water requirements for attaining a particular level of masons workability, and volume yield of mortar or concrete. Of the two cements with equal price and strength properties, the one capable of giving greater volume yield will be more economical to use.

261. Economics of use of portland pozzolana cement against portland cement are apparent because the cost of production of pozzolana is much lower and it influences the cost of production of pozzolana cement directly. The lower the cost of pozzolana, the greater is the relative economy of use of pozzolana cement. Similarly, a pozzolana with greater activity should theoretically lead to reduced costs of pozzolana cements because of higher magnitude of cement replacement (or higher pozzolana content) possible with it.

3. <u>Technical Considerations</u>:

262. The technical advantage of use of pozzolana cements was described in detail in Chapter V. The uses for which pozzolana cements are superior to ordinary portland cement are for mass concrete constructions, for hydraulic works and for marine constructions wherein comparative economy is of secondary importance. For uses in other situations, relative economy may be of prime consideration and should be worked out. However, pozzolanic cements are likely to result in substantial economy in precast and reinforced concrete structures also, if the pozzolana cement concrete is designed scientifically.

B. Development of Pozzolana Industry

263. In these days of planned development, estimates of requirements of cements for different types of constructions are generally available. In the light of the different uses of pozzolana in concrete technology already mentioned, the prospects of uses of pozzolanas can be assessed. If huge quantities of cement are required for mass concrete constructions, there is a good case for processing and manufacture of pozzolana for which purposes the sources of pozzolanic materials are to be identified and located. A survey of natural pozzolanas will have to be taken up and a search made for artificial pozzolanas.

264. Introduction of a pozzolana in a country and development of a pozzolana industry are best possible through its use in mass concrete as such jobs are big and infuse confidence in minds of engineers and technologists. Also, the returns in the form of savings in cement and money are substantial and this produces an immediate impact. Technological advanced countries which produce portland cement together with a variety of other cements in sufficient quantities may not find production of portland pozzolana cement, as a general purpose cement, as attractive as developing countries which produce or import only one kind of cement i.e., portland cement. The latter is, generally, in short supply. Since cement technology is well advanced, manufacture of portland pozzolana cement is not likely to present any technical problems except that some adjustment may have to be made in the capacity of bags because of somewhat lower specific gravity of pozzolana cements. Introduction of portland pozzolana cement in a developing country, however, requires some preparation, because it has to stand competition from portland cement which is already in the market. Technical and trade literature on the properties and uses of pozzolana cement may be publicized amongst engineers and builders. The economic aspect should be brought out clearly and even demonstrated because it is this factor that attracts the attention and imagination of consumers quickly.

265. Though traditional lime pozzolana mortars may not be as good in over-all performance as mortars prepared with factory finished lime pozzolana cement, the former are good enough for several jobs. Attempts should be made to improve upon their quality rather than replace them as these traditional mortars still have a place as building materials in a developing country's economy. They are cheaper to produce and do not require extra skill to produce or use. In India, in spite of advancement of knowledge and technology in pozzolana field, lime pozzolana mortars prepared in an animal driven mortar mill are being used extensively. Development of an efficient and mechanized mortar mill at a low cost will be a step in the right direction.

266. An alternative suggestion is to market packed pozzolana so that consumer is free to use it either cement replacement in concrete or with lime in making mortars and plasters. Since pozzolana does not deteriorate in its quality on storage as much as lime pozzolana cement, even jute bags can be used for packing. Manufacture and introduction of lime pozzolana cement is easier for countries where ready mixed mortars and plasters and packed lime are being

marketed. Establishment of lime pozzolana cement industry in developing countries may have to face difficulties such as non-availability of standard quality lime and a suitable packing material, lack of quick transportation facilities and competition from traditional lime pozzolana mortars and fear of adulteration. Establishments manufacturing and packing pozzolanas may also face some of these problems. Nevertheless, because of pressing housing problems, there is a great need for development of pozzolan and pozzolana cement industries in developing countries. This will not only provide a country with more binder material and save in portland cement, but also offer new employment opportunities. But, in those countries where building materials science and technology are still new and organized building material industry does not exist to popularize products through technical and trade literature, introduction of new materials should be done with full preparation as, once a material goes into disrepute on account of technical flaw in its production, marketing or use, it will be difficult to rehabilitate it.

Figure 1

Diagram of Bull's trench kiln

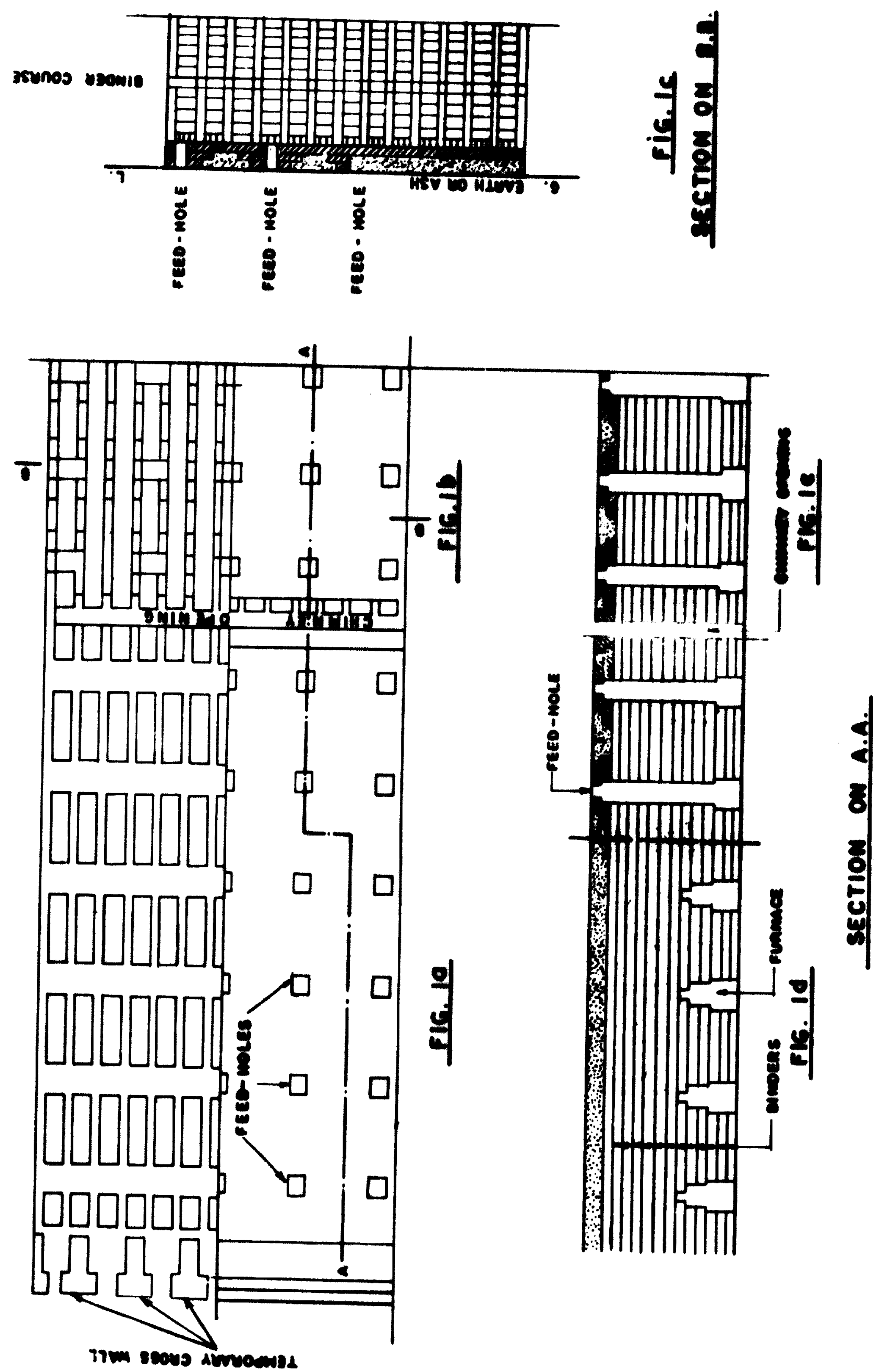


Figure 2

Details of setting

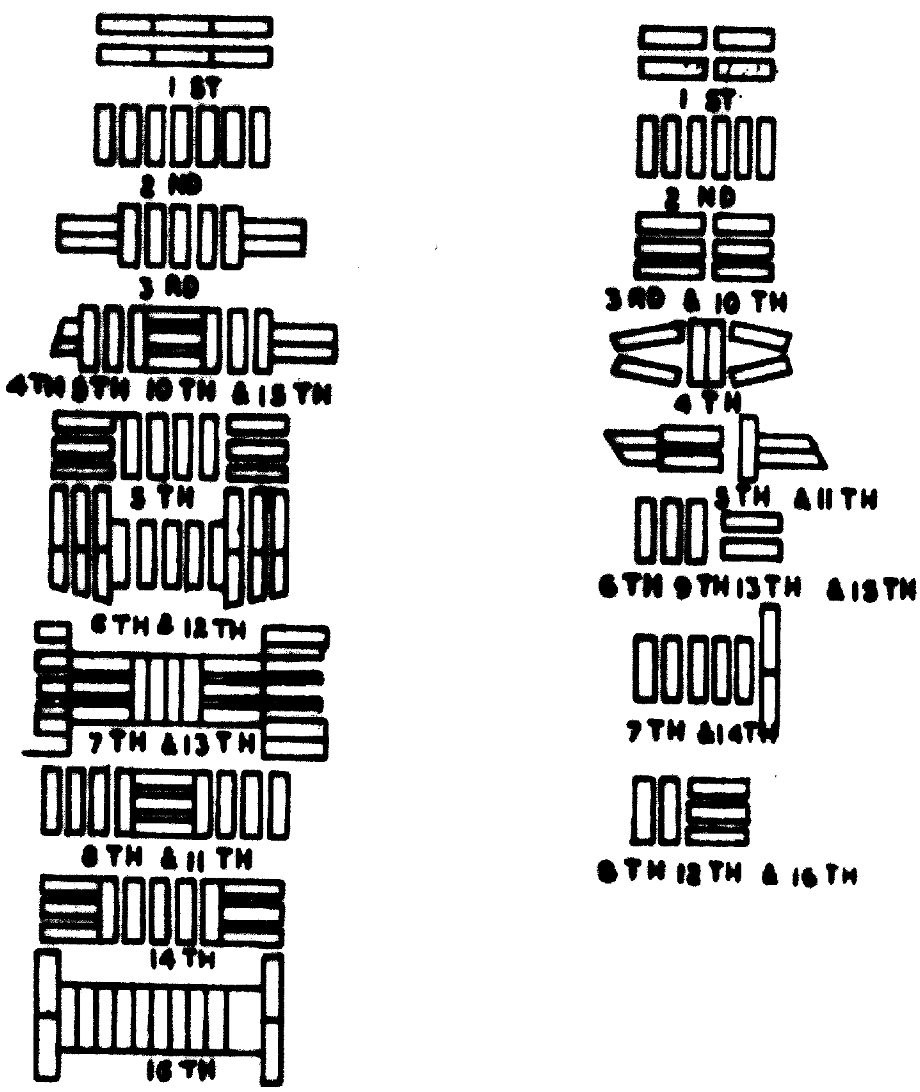
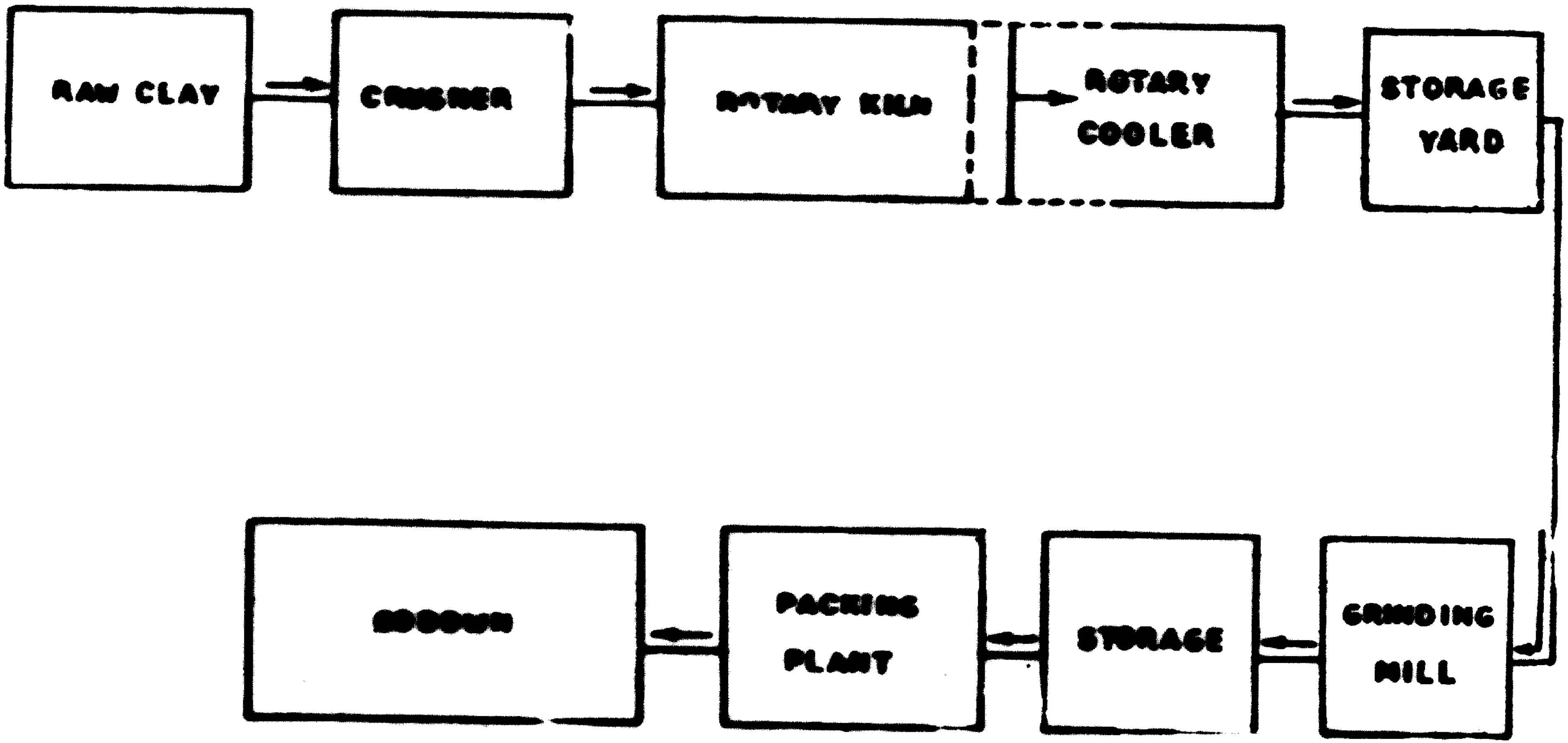


Figure 1

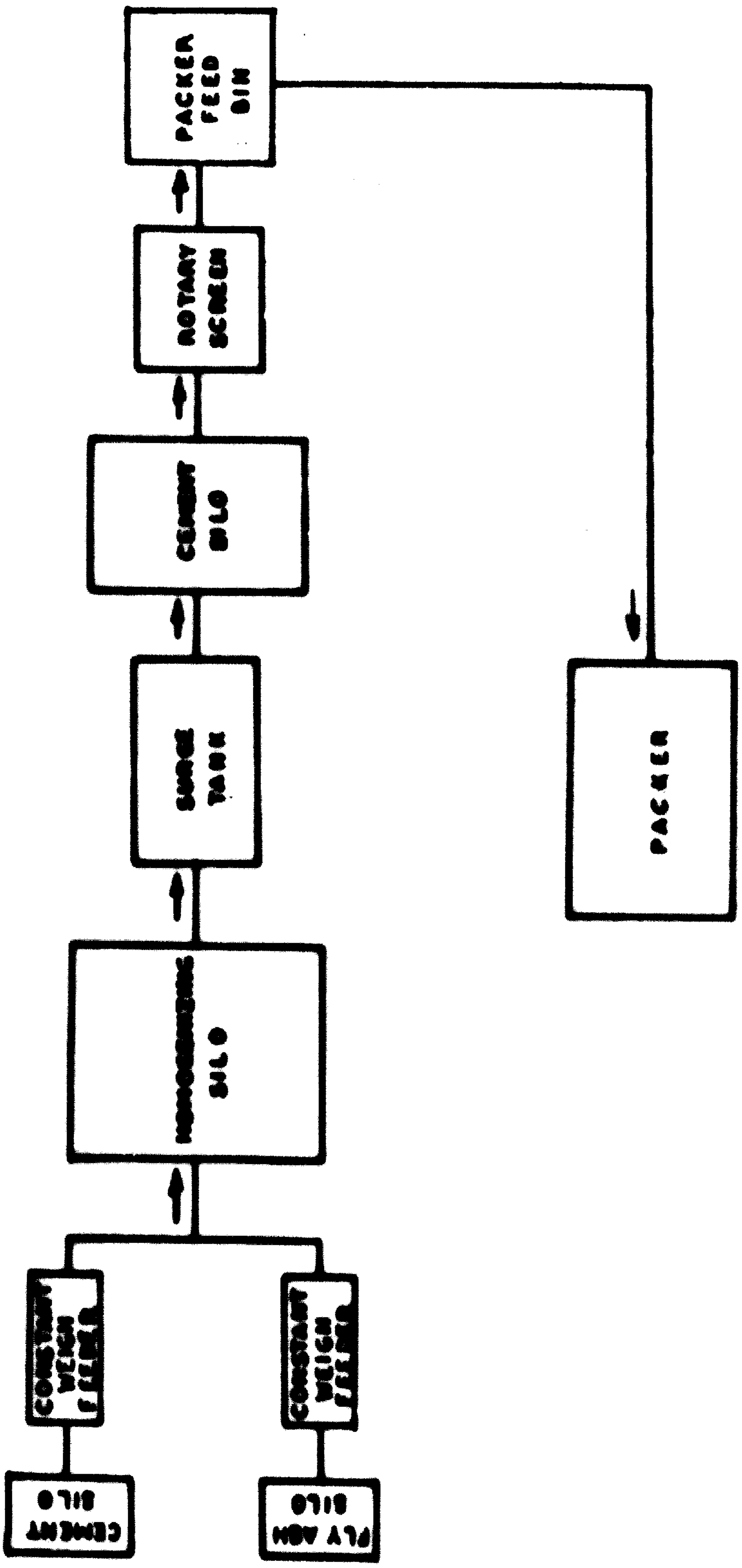
Flow sheet of burnt clay pozzolana manufacture



Note: The dotted lines indicate that rotary cooler could be an integral part of the rotary kiln.

Figure 4

Flow sheet of portland cement fly ash blending plant



ESTIMATED COSTS

		Rupees in thousands	(US$) x1000
a. **Land and Buildings**			
Developed land 1 acre at Rs. 10/- per sq.yd.	...	48.4	
Factory shed, 1500 sq.ft at Rs. 8/- per sq.ft.	...	12.0	
Office and control laboratory building 500 sq.ft. at Rs. 16/- per sq.ft.	...	8.0	
Silo for storing 100 tons of reactive surkhi	...	15.0	
Total	...	83.4	11.12
b. **Cost of Kilns and Machinery**			
Cost of down draught kilns complete with chimneys	...	120.0	
Crushing and screening equipment	...	30.0	
Grinding mills, disintegrator and motors	...	90.0	
Elevator (one)	...	10.0	
Transformer, switch gear etc.	...	40.0	
		290.0	
Add 10% erection charges	...	29.0	
Total	...	319.0	42.533

APPENDIX

Standard Specifications for Pozzolanic Cements*/ in 10 countries

1. CZECHOSLOVAKIA

DESCRIPTION

Denomination	Symbol	Designation of Standard	Year
Pucolanovy cement	(POZ 1)	CSN 72 2121	1956
Two qualities: "250" "350"			
Cement trasovy	(POZ 2)	CSN 72 2122	1957
Two qualities: "250" "350"			

CHARACTERISTICS OF MANUFACTURE

POZ 1 Content of pozzolana and gypsum 30-50% — Special additions: max. 1%

Content of trass and gypsum

POZ 2 "250" max. 45% — Special additions: max. 1%

POZ 2 "350" max. 35% — Special additions: max. 1%

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

	MgO	Insoluble residue
Portland cement clinker	≤ 6%	≤ 2%
Possolan, trass, gypsum	Instructions are being prepared	

CHEMICAL REQUIREMENTS

Maximum percentage

SO_3

3

PHYSICAL REQUIREMENTS

Fineness	Aperture of sieve μ	Residue max. %
	200	1
	90	10

In certain cases other agreements can be made concerning fineness.

Setting time	Method: Vicat	Initial minutes	Final hours
		≥ 60	≤ 12

In certain cases other agreements can be made concerning starting of setting.

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*/ Source: 'Review of Standards for Cements other than Portland', CTT BUREAU, The Cement Statistical & Technical Association, Malmo, Sweden, 1958.

Soundness (1) Cold water storage test, 28 days
(2) Boiling test, heating 1 hour, boiling 3 hours.

If cement fails, the boiling test may be repeated on cement which has been aerated for 3 days.

STRENGTH REQUIREMENTS

Sand for strength tests

Standard sand, passing sieve with openings 1.350 mm, retained on sieve with openings 0.775 mm.

Tensile strength	kg/cm^2 7 days		lb/in^2 28 days	
POZ 1 "250"	13	185	21	299
"350"	20	284	28	398
POZ 2 "250"	13	185	25	356
"350"	20	284	30	427

Preparation of specimens for tensile strength test

Eight shaped specimens. Mix 1:3, water/cement ratio 0.32 is adjusted if water does not exude after 90-110 blows. Mortar compacted with 150 strokes by Boehme-Martens hammer apparatus.

Compressive strength	kg/cm^2 7 days		lb/in^2 28 days	
POZ 1, POZ 2 "250"	130	1 849	250	3 555
"350"	230	3 271	350	4 977

Preparation of specimens for compressive strength test

Cubes, side 7.07 cm. Mix, water/cement ratio etc., see Tensile strength test.

REMARKS

Sampling instructions available.

2. FRANCE

DESCRIPTION

Denominaton	Symbol	Designation of standard	Year
Ciment Portland artificiel aux cendres volantes 160-250	CPA + C 160-250	Pr P 15-302*	1958
Ciment Portland artificiel aux cendres volantes 250-315	CPA + C 250-315		
Ciment Portland a haute resistance initial, aux cendres volantes 315-400	HRI + C 315-400		
Ciment Portland artificiel a la pouzzolane 160-250	CPA + P 160-250		

* In use but not yet formally adopted

Ciment Portland artificiel a la pouzzolana 250-315	CPA + P 250-315
Ciment Portland a haute resistance initiale, a la pouzzolane 315-400	HRI + P 315-400

CHARACTERISTICS OF MANUFACTURE

	Content of fly ash	Content of pozzolana	Admitted additions
CPA + C	10-20	-	Max. 1 % of soluble salt
CPA + P	-	10-20	
HRI + C	0-10	-	
HRI + P	-	0.10	

CHEMICAL REQUIREMENTS

Maximum percentage

	MgO	SO_3	Insoluble residue	Loss on ignition
CPA + C, CPA + P	5	3	20	6.5
HRI + C, HRI + P	5	3	10	5

PHYSICAL REQUIREMENTS

Fineness

CPA + C, CPA + P 250-315 — The fineness of the grinding, measured with Blaine Fineness Meter, shall be comprised between 2 500 and 3 500 cm^2/g, and may not exceed the latter figure. For siliceous cements defined according to the ratio

$$\frac{SiO_2}{R_2O_3} \geq 3$$

the upper limit will be raised by 250 cm^2/g for each increase of 1 unit above 3 in the ratio.

Setting time Method: Vicat — Initial minutes

≥ 30

Soundness Method: Le Chatelier Max. expansion 10 mm after 3 hours boiling

CPA + C, CPA + P — If the cement contains over 3% MgO, the boiling is prolonged until constant expansion is obtained during 2 hours. Max. expansion = 10 mm. Cold water storage is also applied (7 days), but no max. limit is given

STRENGTH REQUIREMENTS

Sand for strength tests

Sand from Leucate (Aude) equal parts (tol. 10%), 0.5-1 mm, 1-1.6 mm, 1.6-2 mm.

Tensile strength	kg/cm² 2 days	lb/in²	kg/cm² 7 days	lb/in²	kg/cm² 28 days	lb/in²
CPA + C, CPA + P 160-250						
CAP + C, CPA + P 250-315			20	285	25	355
HRI + C, HRI + P 315-400	18	255	25	355	30	430

Preparation of specimens for tensile strength test

Eightshaped specimens, section 5 cm². Mix 1:3, water according to normal consistency of neat cement paste, mortar pressed in by means of iron pestle (8 mm diam. by 20 cm) with round end.

Compressive strength	kg/cm² 2 days	lb/in²	kg/cm² 7 days	lb/in²	kg/cm² 28 days	lb/in²
CPA + C, CPA + P 160-250			160	2 275	250	3 555
CPA + C, CPA + P 250-315			250	3 555	315	4 480
HRI + C, HRI + P 315-400	160	2 275	315	4 480	400	5 690

Preparation of specimens for compressive strength test

Cubes, side 5 cm. Mix etc. see Tensile strength test.

REMARKS

Sampling instructions available.

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3. GERMANY, West

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
Trasszement 30:70	(POZ 1)	DIN 1167 with amendment of 1958	1940
Three qualities: Zement 275, Zement 375, Zement 475			
Trasszement 40:60	(POZ 2)		
Three qualities: Zement 275, Zement 375, Zement 475			

CHARACTERISTICS OF MANUFACTURE

	Content of pozzolana (trass)*	Admitted addition
POZ 1	30%	Max. 3% calculated on clinker portion.
POZ 2	40%	

* Rules for calculating "Trass" percentage from chemical analysis results are given.

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

The Portland cement clinker shall conform to DIN 1164.

The pozzolana (trass) shall conform to DIN 5 1043.

PHYSICAL REQUIREMENTS

Fineness	Sieve meshes/cm²	Aperture µ	Residue max. %
	900	200	0.5
	4 900	90	8

Setting time Method:	Needle test	Initial minutes	Final hours
		≥60	≤12

Alternatively, there is a test according to which a cement pat should not crack at the edges on being pressed 1 1/2 cms from the edge with a bar (⌀ 3 mm) within one hour after preparation.

In case of dispute the needle test governs.

Soundness (1) Boiling test (2 hours) on cement pats. In case of failure, repeated test with cement which has been aerated for 3 days.

(2) Cold water storage test (27 days) on cement pats.

STRENGTH REQUIREMENTS

Sand for strength tests

Standard sand, two parts coarse (from Freienwald an der Oder), 1.39-0.74 mm., and one part fine (from Hohenbrocka).

Bending strength	kg/cm² 1 day	lb/in²	3 days		7 days		28 days	
Zement 275	-	-	-	-	30	427	50	711
Zement 375	-	-	30	427	40	569	60	853
Zement 475	30	427	50	711	60	853	70	995

Compressive strength	kg/cm² 1 day	lb/in²	3 days		7 days		28 days	
Zement 275	-	-	-	-	110	1 564	275	3 913
Zement 375	-	-	150	2 133	225	3 200	375	5 336
Zement 475	100	1 422	300	4 266	360	5 119	475	6 759

Preparation of specimens for bending and compressive strength tests

Prisms 4 x 4 x 16 cm. Mix 1:3, water/cement ratio 0.60. Mortar compacted by 2 20 strokes with tamper (weight 700 g).

Compressive strength on broken prisms from bending test.

4. GREECE

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
Greek type Portland cement		Government Decree No.160	1954
Two qualities:	(POZ 1) (POZ 2)		

CHARACTERISTICS OF MANUFACTURE

The cement contains Santorin Earth (possolanic material)

Admitted additions
Max. 1% (in special cases 3%).

CHEMICAL REQUIREMENTS

Maximum percentage MgO	SO_3	Insoluble residue	Loss on ignition
5	3	10	5

PHYSICAL REQUIREMENTS

Fineness	Sieve meshes/cm²	Residue max. %
	4 900	20

Setting time Method: Vicat	Initial minutes	Final hours
	≥60	≤12

Soundness Cold water storage test on cement pats (28 days)

STRENGTH REQUIREMENTS

Sand for strength tests

Standard sand from United Kingdom, to pass BS sieve No. 18 (853), and to be retained on BS Sieve No. 25 (599).

Tensile strength kg/cm² lb/in²

	3 days		7 days		28 days		28 days cs	
POZ 1	-	-	18	256	25	356	30	427
POZ 2	25	356	-	-	30	427	40	569

Preparation of specimens for tensile strength test

Eightshaped specimens. Mix 1:3, mortar compacted in Tetmajer apparatus with 120 strokes by tamper (weight 2.25 kg) falling 25 cm.

Compressive strength kg/cm² lb/in²

	3 days		7 days		28 days		28 days cs	
POZ 1	-	-	180	2 560	275	3 911	350	4 977
POZ 2	250	3 555	-	-	400	5 688	500	7 110

Preparation of specimens for bending and compressive strength tests

Cubes, side 7.07 cm. Mix 1:3, mortar compacted in Tetmajer apparatus with 160 strokes by tamper (weight 3.00 kg) falling 50 cm.

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5. ITALY

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
Cemento pozzolanico	(POZ 1)	Norme per l'accettazione dei leganti idraulici	1939
Cemento pozzolanico ad alta resistenzia	(POZ 2)	Regi decreti 16 nov. 1939-XVIII	

CHARACTERISTICS OF MANUFACTURE

No limits for content of pozzolana. The clinker can be produced by burning lime and pozzolan. No inert materials may be added.

CHEMICAL REQUIREMENTS

Molecular ratio		Maximum percentage $CaCO_3$	MgO	SO_3	Insoluble residue
$\frac{SiO_2 + R_2O_3}{CaO}$	≥ 1	5	3	2.5	16

PHYSICAL REQUIREMENTS

Fineness	Sieve meshes/cm^2		Aperture μ	Residue max. %
	900		200	2
Setting time	Method:	Vicat	Initial minutes	Final hours
			≥ 60	≤ 4
Soundness	Method:	Le Chatelier	Max. expansion mm	
			10 after boiling 3 hours	

STRENGTH REQUIREMENTS

Sand for strength tests

Sand from Massacciucooli Lake, passing sieve with aperture 1.5 mm and retained on sieve with aperture 1.0 mm.

Tensile strength	kg/cm^2 3 days	lb/in^2	7 days		28 days	
POZ 1	-	-	26	370	32	455
POZ 2	21	299	31	441	37	526

No tolerance

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		Rupees in thousands	(US$) x1000
c. **Salaries and Wages**			
One Manager-cum-Salesman at Rs. 1000/- per month	...	12.0	
Foreman 1 no. at Rs. 400/- per month	...	4.8	
Burners 10 nos. at 150/- each per month	...	18.0	
Mechanic 3 nos. at Rs. 200/- each per month	...	7.2	
Labourers 50 nos. at Rs. 3/- per day for 330 working days	...	49.5	
Total	...	91.5	12.20
d. **Raw Material, Fuel and Power**			
Raw clay 8000 tons per annum (including loss) at 50 paises per ton (excluding transportation)	...	4.0	
Coal at Rs. 45/- per ton (including transportation)	...	54.0	
Power, 430,000 KWH at 10 paise per KWH	...	43.0	
Total	...	101.0	13.467
e. **Depreciation and Maintenance**			
Depreciation on buildings, sheds, silos at 3% on Rs. 35,000	...	1.1	
Depreciation on machinery etc. at 6% on Rs. 2,90,000	...	17.4	
Maintenance cost of buildings, sheds silos etc. at 2½% on Rs. 35,000	...	0.8	
Maintenance cost of machinery and equipment at 6% on Rs. 2,90,000	...	17.4	
Interest on working capital on Rs. 1,00,000 at 6%	...	1.1	
Total	...	37.8	5.04

		Rupees in thousands	(US $) x1000
f. **Total cost of Production**			
Salaries and wages	...	91.5	
Raw Material, fuel and power	...	101.0	
Depreciation and maintenance etc.	...	37.8	
Total	...	230.3	30.667

g. **Cost of Production per Ton**

∴ Cost of production of reactive surkhi per ton ... Rs. 38.40 US $5.12

5. **Manufacture of Burnt Clay Pozzolana in Rotary Kiln:**

(Plant capacity = 200 tons/day)

206. A flow sheet is given in Fig. III. The raw clay is fed into the hopper with the help of a bucket elevator (or a belt conveyor). It is then fed to the crusher through an apron feeder. Crushed clay is elevated to feed a hopper and the feed to the rotary kiln could be controlled with a table feeder. Calcined clay will pass next through a rotary cooler if a rotary kiln with integral coolers is not used. Calcined material is conveyed to a storage yard with the help of a drag chain conveyor. Calcined clay is then elevated and fed into storage hoppers. The feed to the grinding mill may be controlled with table feeders. Ground material is elevated and stored in silos and then it goes into the packing plant. The latter is not required if calcined clay is to be supplied as 'naked' pozzolana. The cost of production per ton works out to be Rs. 30/- (4 US$). The details are given below:

ESTIMATED COSTS

		Rupees in thousands	(US$) x1000
a. **Land and Buildings**			
Developed land, 7 acres at Rs. 10/- per sq.yd.	...	338.8	45.173
Factory shed 30,000 sq.ft. at Rs. 12/- per sq.ft.	...	360.0	48.000
Office and control laboratory building, 3000 sq.ft. at Rs. 16/- per sq.ft.	...	48.0	6.400

		Rupees in thousands	(US $) x1000
Silos for storing of reactive surkhi	...	40.0	5.333
Total	...	786.8	104.907

b. <u>Plant and Machinery</u>

Crushing equipment Vertical elevators (3 nos.) or belt conveyors Rotary kiln, 200 ft. effective length and 10 ft. effective diameter, refractory lining, oiling, pumping and firing equipment; high pressure blower; designed to rotate, reduction gear, variable speed motor, fan, chimney, motors etc. complete in all respects. Rotary cooler Rotary table feeders Grinding mills, grit separator, cyclone separator, bag filters, induced fan, screw conveyor pneumatic conveyor, air compressor, grinding media etc. for grinding department Air compressor, rotary screen, screw feeder, packer feed bin, packing machine, screw conveyor, chutes etc. Motors for the plant Laboratory equipment, tubewell, water pump etc.	...	3400.0	453.33
Add 12% for erection charges	...	408.0	54.40
Total	...	3808.0	507.73

		Rupees in thousands	(US$) x1000
c. Salaries and Wages			
Manager at Rs. 2000/- p.m.	...	24.0	
Chief Chemist at Rs. 1500/- p.m.	...	18.0	
Shift Chemists, 4 nos. at Rs. 1000/- p.m.	...	48.0	
Office Superintendent at Rs. 1000/- p.m.	...	12.0	
Office Clerks, 2 nos. at Rs. 300/- p.m.	...	7.2	
Store clerks, 4 nos. at Rs. 300/- p.m.	...	14.4	
Mechanic-cum-Electrician, 3 nos. at Rs. 300/- p.m.	...	10.8	
Foreman, 3 nos. at Rs. 500/- p.m.	...	18.0	
Burners, 3 nos. at Rs. 250/- p.m.	...	9.0	
Shift mechanics, 3 nos. at Rs. 250/- p.m.	...	9.0	
Skilled labourers 30 nos. at Rs. 5/- per day, 300 working days	...	45.0	
Unskilled labourers, 50 nos. at Rs. 3/- per day, 300 working days	...	45.0	
Total	...	260.4	34.720
d. Raw Materials and Power			
Clay 75,000 tons at 50 paise per ton (excluding transport charges)	...	37.5	5.000
Cost of fuel	...	480.0	64.000
Power, 30,00,000 KWH at 10 paise per KWH	...	300.0	40.000
Total	...	817.5	109.000

4 OF 4

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Preparation of specimens for tensile strength test

Eightshaped specimens, section 22.5 x 22.5 mm. Mix 1:3, quantity of water should be indicated by producer; when not indicated, water/cement ratio 0.32. Mortar compacted with 120 strokes of hammer weighing 2 kg. falling 25 cm.

Compressive strength	kg/cm^2	lb/in^2				
	3 days		7 days		28 days	
POZ 1	-	-	380	5 404	500	7 110
POZ 2	290	4 124	500	7 110	680	9 670

Preparation of specimens for compressive strength test

Cubes side 7.07 cm. Mix 1:3, quantity of water see Tensile strength test.

Mortar compacted with 160 strokes of 3 kg hammer falling 50 cm.

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6. JAPAN

DESCRIPTION

Denomination	Designation of standard	Year
Pozzolanic Cement	JIS R 5212	1956

CHARACTERISTICS OF MANUFACTURE

Content of pozzolana
max. 30%

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

The percentage of SiO_2 in the pozzolanic material shall be less than 60%.

CHEMICAL REQUIREMENTS

Maximum percentage	
MgO	SO_3
5.0	2.5

PHYSICAL REQUIREMENTS

Fineness	1. Aperture of sieve μ	Residue max. %
	88	8
	2. Air permeability test (Blaine)	Specific surface cm^2/g min. 3 000

Setting time	Method: Vicat	Initial minutes	Final hours
		≥ 60	≤ 10

Soundness Cold water storage test on cement pats or Boiling pat test

Specific weight ≥ 2.5 g/cm^2 only when specially requested by the purchaser.

STRENGTH REQUIREMENTS

Sand for strength tests

Natural sand from Toyoura district to pass 300μ and retained on 110 μ

Bending strength kg/cm^2 lb/in^2

3 days		7 days		28 days	
12	171	25	356	36	512

Compressive strength kg/cm^2 lb/in^2

3 days		7 days		28 days	
45	640	90	1 280	200	2 844

Preparation of specimens for bending and compressive strength test

Specimens 4 x 4 x 16 cm. Mix 1:2, water/cement ratio 0.65. Compressive strength tests on broken prisms from bending strength test.

Note The strength at any age shall be higher than the strength at the preceding age.

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7. NETHERLANDS

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
Transportlandcement 30:70	POZ 1	N 618	1950
Transportlandcement 40:60	POZ 2		

CHARACTERISTICS OF MANUFACTURE

	Content of possolana
POZ 1	30%
POZ 2	40%

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

The ordinary Portland cement shall conform to the specifications in N 481. The trass shall conform to the specifications in N 488.

CHEMICAL REQUIREMENTS

	Content of CaO
POZ 1	45-49%
POZ 2	39-43%

Note Percentages calculated on cement dried at 100-105°C.

PHYSICAL REQUIREMENTS

Fineness	Sieve no.	Aperture µ	Residue max. %
	N 480-d-0.09	90	8

Setting time — Method: Vicat — Initial minutes

≥60

Soundness — Cold water storage test, 28 days, on cement pats. Provisional tests: Boiling test on cement pats or Le Chatelier test, max. expansion = 10 mm, 3 hours boiling.

STRENGTH REQUIREMENTS

Sand for strength tests

Quartz sand, max. 2% retained on N 480-d-1.2, 1.2, (1.2 mm), max. 2% to pass N 480-d-0.420 (420).

Tensile strength	kg/cm²	lb/in²	kg/cm²	lb/in²
	7 days		28 days	
	21	299	27	384

Preparation of specimens for tensile strength test

Eightshaped specimens. Mix 1:3, water according to normal consistency of neat cement paste. Mortar compacted with 150 strokes by Boehme hammer apparatus.

Compressive strength	kg/cm²	lb/in²	kg/cm²	lb/in²
	7 days		28 days	
	250	3 555	325	4 622

Preparation of specimens for compressive strength test

Cubes, side 7.07 cm, mix etc. see Tensile strength test.

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8. U.S.A. (Federal)

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
Portland-pozzolan cement	TYPE I	Federal SS-C-208b	1954
Air-entraining Portland-Pozzolan cement	TYPE IA		

CHARACTERISTICS OF MANUFACTURE

Content of pozzolan	Note
15-35%	The manufacture shall state the source, amount and composition of the pozzolan used.

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

Portland cement and Portland cement clinker shall comply with the chemical composition for type I SS-C-192.

Pozzolana

Type P = clay, shales, diatomaceous earths, tuffs, volcanic ash, pumicite.

Type F = fly ash.

Fineness	1.	Sieve no.	Aperture μ	Residue* max. %
	2.	Air permeability test (Blaine)		Specific surface cm^2/g min 3 000

Contribution to compressive strength	Percent of control, 28 days
Type P	75
Type F	85

CHEMICAL REQUIREMENTS

	Maximum percentage		
	SO_3	Loss on ignition	Moisture content
I	2.5	3.0	3.0
IA	2.5	3.5	3.0

PHYSICAL REQUIREMENTS

Fineness	(1)	Sieve no.	Aperture μ	Residue max. %
		325	44	12
	(2)	Air permeability test (Blaine)	Specific surface cm^2/g	
		Average value, min.	2 900	
		Minimum value, any one sample	2 700	

		Initial minutes	Final hours
Setting time	Method: Gillmore	≥ 60	≤ 10

False set Min. penetration mm. 10 (only when specially requested)

Soundness Autoclave expansion. Max. 0.5%

Air content of mortar

I	0-12% by volume.
IA	15-21% by volume

Water requirement MI required to specified flow

I	320
IA	280

* Either of the two methods can be used.

Drying shrinkage

	Max. %
I	0.12
IA	0.11

Mortar expansion

At age of 14 days, max. 0.020%
At age of 8 weeks, max. 0.060%

STRENGTH REQUIREMENTS

Sand for strength tests

Pyrex glass, sieve No. 4 - sieve No. 100 (4760-149 μ).

Compressive strength	lb/in^2		kg/cm^2	
I	1 500	105	3 000	211
IA	1 250	200	2 500	176

Note — The strength at 28 days shall be greater than at 7 days.

Preparation of specimens for compressive strength test

Prisms 1 x 1 x 11 1/4 in. Mix 1:2.25, water according to flow. Mixing with mechanical mixing machine.

REMARKS

Sampling instructions available (SS-C158c).

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9. U.S.S.R.

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
Puccolanovy portlandcement		GOST 970-41 1955 edition	1941
Five qualities:	"200" "250" "300" "400" "500"		

CHARACTERISTICS OF MANUFACTURE

Content of pozzolana 20-50%

Note: Max. 1% grinding aids.

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

The pozzolana shall conform to GOST 6269-54

CHEMICAL REQUIREMENTS

Maximum percentage

SO_2	MgO	Loss on ignition
3	4.5	5

PHYSICAL REQUIREMENTS

Setting time Method:	Needle test	Initial minutes	Final hours
		≥45	≤12

or according to arrangements between supplier and consumer.

Soundness — Boiling pat test.

STRENGTH REQUIREMENTS

Sand for strength test

Sand within sieves 64-144 meshes per sq.cm.

Tensile strength	kg/cm^2 7 days		lb/in^2 28 days	
"200"	11	150	16	228
"250"	11	150	16	228
"300"	14	200	20	284
"400"	18	256	23	327
"500"	22	313	27	384

Preparation of specimens for tensile strength test

Eightshaped specimens. Mix 1:3 dry consistency, water according to consistency of neat cement paste.

Compressive strength	kg/cm^2 7 days		lb/in^2 28 days	
"200"	100	1 422	200	2 844
"250"	130	1 849	250	3 555
"300"	160	2 275	300	4 266
"400"	220	3 128	400	5 688
"500"	300	7 110	500	7 110

Preparation of specimens for compressive strength test

Cubes, side 7.07 cm. Mix 1:3 dry consistency, water according to consistency of neat cement paste.

REMARKS

Sampling instructions available.

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10. YUGOSLAVIA

DESCRIPTION

Denomination	Symbol	Designation of standard	Year
		JUS B.C. 1.019	1954

Portland cement sa dodatkom puoolana

Three qualities: PC-p 250*
PC-p 350
PC-p 450

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* the figures omitted refer to the pozzolana content.

CHARACTERISTICS OF MANUFACTURE

	Content of pozzolana
PC-p	Max. 40%
C-p	Min. 40%

REQUIREMENTS FOR PRINCIPAL CONSTITUENTS

Pozzolana is a natural product which can bind lime during the hydration of the cement.

CHEMICAL REQUIREMENTS

Maximum percentage

MgO	SO_3	Loss on ignition	Free CaO
5	3.5	5	2

PHYSICAL REQUIREMENTS

Fineness (1) Aperture of sieve μ 90 — Residue max. % 15

(2) Air permeability test (Blaine)

	Specific surface cm^2/g
p PC-p[250], C-p[250]	≥ 2 400
PC-p[350], C-p[350]	≥ 3 500
PC-p[450], C-p[450]	

Setting time	Method: Vicat	Initial minutes	Final hours
		≥ 90	≤ 10

Soundness (1) Tests on cement pats (3 test specimens):
(1) 1-day old specimen to be boiled for 3 hours
(2) Cold storage 28 days
(3) Combined storage 28 days

(2) Le Chatelier test — Max. expansion 10 mm

STRENGTH REQUIREMENTS

Sand for strength tests

Quartz sand from Kusic near Tusla, max. 5% retained on sieve with openings 1.2 mm, max. 5% to pass sieve with openings 0.70 mm. Content of SiO_2 not less than 98%.

Bending strength	kg/cm^2 3 days	lb/in^2 3 days	kg/cm^2 7 days	lb/in^2 7 days	kg/cm^2 28 days	lb/in^2 28 days
PC-p[250], C-p[250]	-	-	30	427	45	640
PC-p[350], C-p[350]	-	-	40	569	55	782
PC-p[450], C-p[450]	35	498	45	640	60	853

Compressive strength	kg/cm^2		lb/in^2			
	3 days		7 days		28 days	
PC-p^{250}, C-p^{250}	-	-	160	2 275	250	3 555
PC-p^{350}, C-p^{350}	-	-	250	3 555	350	4 977
PC-p^{450}, C-p^{450}	200	2 844	350	4 977	450	6 399

Preparation of specimens for bending and compressive strength tests

Prisms 4 x 4 x 16 cm. Mix 1:3, water calculated on dry sand and cement 11% (water/cement ratio 0.44), plastic mortar. Mortar compacted with metal tamper, weight 1 kg. Compressive strength test on broken prisms from bending strength test.

Note The 7-day test are sufficient to determine the quality of Portland cement PC-p450, C-p450

REMARKS

Sampling instructions available.

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