

POZZOLANAS

RICE HUSK ASH (RHA) AND PULVERISED FUEL ASH (PFA)

Pozzolanas are materials containing reactive silica and/or alumina which on their own have little or no binding property but, when mixed with lime in the presence of water, will set and harden like a cement.

Pozzolanas are an important ingredient in the production of alternative cementing materials to Portland cement (OPC). (See the leaflets in this series [Alternatives to Portland cement - an introduction](#) and [Pozzolanas - an introduction](#).)

Alternative cements provide an excellent technical option to OPC at a much lower cost and have the potential to make a significant contribution towards the provision of low-cost building materials and consequently affordable shelter.

Pozzolanas can be used in combination with lime and/or OPC. When mixed with lime, pozzolanas will greatly improve the properties of lime-based mortars, concretes and renders for use in a wide range of building applications. Alternatively, they can be blended with OPC to improve the durability of concrete and its workability, and considerably reduce its cost.

A wide variety of siliceous or aluminous materials may be pozzolanic, including the ash from a number of agricultural and industrial wastes. Of the agricultural wastes, rice husk has been identified as having the greatest potential as it is widely available and, on burning, produces a relatively large proportion of ash, which contains around 90% silica.

Pulverized fuel ash (PFA), which is often referred to as fly ash, has probably the greatest potential of the industrial wastes due to its widespread availability in spite of its only moderate pozzolanic reactivity. It is probably the pozzolana in greatest use today with a worldwide estimate of over 30 million tonnes in use and an annual increase in usage of about 10%.

Rice husk ash

About one tonne of husk is produced from five tonnes of rice paddy and it has been estimated that some 120 million tonnes of husk could be available annually on a global basis for pozzolana production. As the ash content by weight is about 20%, there are potentially 24 million tonnes of RHA available as a pozzolana.

Rice is grown in large quantities in many Third World countries including China, the Indian sub-continent, South-east Asia and, in smaller quantities, in some regions of Africa and South America. Table 1 gives the rice production of some of the principal rice growing countries of the world in the early 1980s. Production is likely to have more than doubled in most of these countries by 2004.

Traditionally, rice husk has been considered a waste material and has generally been disposed of by dumping or burning, although some has been used as a low-grade fuel. Nevertheless, RHA has been successfully used as a pozzolana in commercial production in a number of countries including Columbia, Thailand and India.

Research and pilot projects have been undertaken in most of the major rice-growing countries of the world. However it has been estimated that the total world production of cement based on RHA is only 30,000 tonnes per year, mainly undertaken in small-scale village production units. It is clear therefore that considerable potential exists to expand production on both a small and large scale.

Country	1980	1981	1982
Bangladesh	20.8	20.1	20.4
Brazil	9.8	8.6	9.7
Burma	13.3	14.2	14.0
China	142.3	146.2	148.0
India	79.8	81.7	74.0
Indonesia	29.8	32.8	32.8
Philippines	7.6	7.7	8.4
Republic of Korea	4.9	7.0	7.6
Thailand	17.4	17.8	17.0
World Total	397.2	412.2	406.6

Table 1. Production of principal rice growing countries (million tonnes)

Processing and production of RHA

- **Combustion**

To produce the best pozzolanas, the burning of the husk must be carefully controlled to keep the temperature below 700°C and to ensure that the creation of carbon is kept to a minimum by supplying an adequate quantity of air. At burning temperatures below 700°C an ash rich in amorphous silica is formed which is highly reactive. Temperatures above 700°C produce a crystalline silica which is far less reactive.

The presence of large quantities of carbon in the ash will adversely affect the strength of any concrete or mortar produced using RHA cements. Where possible, the carbon content of the ash should be limited to a maximum of 10%, although some studies have suggested higher percentages can be tolerated with only a relatively small decrease in strength.

Rice husks which have been burnt in large open heaps to dispose of waste husks, or burnt as a fuel in an industrial furnace, are unlikely to produce ashes with the specification described above. In particular, they are likely to be crystalline due to high combustion temperatures. Although this does not rule out their use as a pozzolana, ashes composed of crystalline silica will require a considerable amount of grinding (see below) to produce an acceptable reactivity. Even then they are unlikely to match the quality of amorphous ash.

There are several designs of small simple incinerators, normally made of fired clay bricks, which are capable of burning ash at temperatures below 700°C and without excessive quantities of carbon. The temperature is monitored by a pyrometer (an industrial instrument for measuring high temperatures) and rapid cooling is necessary if the temperature rises above 650°C. This is normally achieved by removing the ash and spreading it on the ground. Incinerators of this type are normally used in banks of three or four to produce approximately one tonne of ash per day.

Small incinerators have a number of advantages: they are simple and inexpensive to construct, easy to operate and will produce ash of an acceptable quality. On the other hand, their output is rather small. They also require constant supervision and, perhaps most importantly, they make no use of the energy value of the husk.

Weight for weight rice husk has an energy value about half that of coal and is therefore an important potential energy source. Although rice husk is still burnt as waste, this practice is likely to become less common, as other more traditional fuel sources become less readily available and/or more expensive. Recently attempts have been made to design kilns or furnaces for husks which will utilize the potential energy value of the husk by making it available for useful work, and which control the temperature of combustion to below 700°C. The transportation of rice husk is not an economically viable option, even over quite short distances, due to its low bulk density and the fact that only 20% of its weight can be utilized as a pozzolana. The location of incinerators or kilns has to be close to a rice mill with sufficient capacity to supply the quantity of husk required for cement production.

- **Grinding**

The second step in processing is grinding the RHA to a fine powder, and ball or hammer mills are usually used for this purpose. Crystalline ash is harder and will require more grinding in order to achieve the desired fineness.

A fineness similar to or slightly greater than that of OPC is usually recommended for pozzolanas although some have been ground considerably finer. The minimum fineness recommended by the Indian Standards for pozzolana (1344) is 320 and 250m²/kg for grade 1 and 2 pozzolanas respectively, measured by the Blaine air permeability test. Although this standard is for calcined clay, the fineness requirements are also suitable for RHA.

Pulverised fuel ash

PFA is a residue from the process of combustion in the boilers of coal fired power stations. It is extracted as a fine powder from the flue gasses and hence its other common name 'fly ash'. The ash extracted from the bottom of power station boilers, furnace bottom ash, is less suitable as a pozzolana.

There are two types of PFA, depending upon the type of coal used. These are high lime and low lime, with the former having a lime content above 10% and therefore possessing some cementing properties on its own. Low lime PFA has a lime content below 10%. Both types of PFA can be used as a pozzolana.

PFA is available, in large quantities, in countries or regions using coal fired electricity generating stations. These include most of Europe, North America, the Indian sub-continent, China and southern Africa.

The chemical composition of PFA will depend upon the type of coal used and can vary considerably, as can pozzolanic reactivity. Table 2 gives typical compositions of British, US and Indian PFA's.

Acceptable limits of composition, derived from the various national standards are:

- The percentage of the main oxides, SiO₂ + Al₂O₃ + Fe₂O₃, should not fall below 70%;
- The SO₃ content should not exceed 5% (Some Standards specify 2.5%);
- The MgO content should not exceed 5%;
- The loss on ignition should not exceed 12% (Some Standards give a 5 or 6% limit).

In addition some standards specify that the alkali metal (Na₂O) content should not exceed 1.5 %, although this is only relevant if it is used with reactive aggregate.

Physically PFA is a fine (less than 75 micron) powder, with a rounded particle shape and a colouring ranging from cream to dark grey. Its loose bulk density is approximately 800kg/m³,

which is roughly two-thirds that of OPC. As with all pozzolanas, fineness is critical to the performance of PFA, with finer pozzolanas giving faster pozzolanic reactions. Electrostatically collected PFA will be finer than PFA collected mechanically and is therefore normally preferred as a pozzolana. The Blaine method of measuring fineness is felt to be unreliable for PFA and the simpler sieving technique is often better. Standards give a maximum to be retained on a 45 micron sieve of 12.5 to 50% depending upon the country of origin.

PFA is not normally ground to produce a finer material as this will break up the rounded particle shape which is important for its water reduction and increased workability properties.

Unlike most other pozzolanas, PFA requires no processing before use. It is normally transported in bulk to the cement factory or construction site where it is blended with OPC and/or lime to form a pozzolanic cement.

Origin	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Alkalis	SO ₃	LOI
USA	47.4	18.2	19.2	7.0	1.1	4.0	2.8	1.2
British	45.9	24.4	12.3	3.6	2.5	4.2	0.9	4.1
Indian	54.0	23.7	12.1	2.6	1.4	-	0.03	5.0

Table 2. Typical percentage compositions of PFA

Utilization of RHA and PFA

The pozzolana must be blended with lime and/or OPC to produce a pozzolanic cement. This can be accomplished by human or animal-powered methods but full homogeneity is unlikely to be achieved and the strength and consistency of cements blended in this manner will be variable.

Mechanical techniques, preferably intergrinding in a ball mill or, as a second option, dry blending in a pan or concrete mixer, will give better results in terms of both strength and consistency.

Pozzolanas can be used with either lime and/or OPC. With the latter, replacement of up to 25-30% is common, although research has suggested that for non-structural purposes replacement of up to 50% can be used. With lime pozzolana cements, mixtures of 1:1 to 1:4 lime: pozzolana) by weight are used. A small percentage (normally 5-10%) addition of OPC will improve strength and decrease setting times. A larger percentage of OPC may be required if only poor quality pozzolanas are available. The exact ratio of the ingredients will depend upon the quality of the respective raw materials and on the required characteristics of the concrete or mortar made from the cement.

Amorphous RHA is a high quality pozzolana which, when mixed with a good quality lime, should produce a cement giving 7 and 28 days compressive strengths of mortars well in excess of 2 and 4 mega pascals (MPa) respectively. The pozzolanic reaction of RHA is relatively fast and, unlike most other pozzolanas, most of the strength gain of RHA-based cements will take place during the initial 28 days.

The pozzolanic reactivity of PFA is variable. In some countries quality-assured PFA is available and this should produce mortars and concretes to meet Standard strength requirements, similar to those quoted above. Other PFAs should be carefully tested. PFA is rarely used on its own to make a lime-pozzolana cement, although it has been used in combination with other pozzolanas.

The low bulk density and rounded particle shape of PFA give it better water-reducing and workability-enhancing properties than other pozzolanas. It is therefore ideal for blending with OPC, particularly if there is a coal-fired power station in the vicinity and it is available at low cost and in large quantities. PFA is also ideal for use in block and brick manufacture.

Other leaflets in this series deal in more detail with the production, properties and utilization of pozzolana cements and with testing and performance standards.

References and further reading

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