POZZOLANAS

AN INTRODUCTION

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. They are an important ingredient in the production of alternative cementing material to Portland cement (OPC). (See the leaflet in this series *Alternatives to Portland cement -an introduction.)*

Figure 1: Volcanic ash in Indonesia being gathered for use as a pozzolana. Photo: Practical Action (not a Practical Action project)

Cement or some form of binding agent is a vital element in almost all types of construction and in recent years the cement market has been dominated by one product, OPC. In many countries, particularly those of the South, OPC is an expensive and sometimes scarce commodity and this has severely limited the construction of affordable housing in much of the Third World. Alternative cements provide an excellent technical option compared 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.

A wide variety of siliceous or aluminous materials may be pozzolanic. In this leaflet only those of widespread availability will be discussed. Pozzolanas can be divided into two groups: natural pozzolanas such as volcanic ash and diatomite, and artificial pozzolanas such as calcined clays, pulverized fuel ash and ash from burnt agricultural wastes. 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 and, in this form, can be used in a wide range of building applications. Alternatively, they can be blended with OPC to reduce costs considerably and to improve certain characteristics of OPC-based concretes, such as long-term strength, resistance to sulphate attack and workability.

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technical brief

The history of pozzolanas

The Greeks, pre-400BC, followed by the Romans, were the first civilisations to use pozzolanas in lime mortars. The Romans used not only crushed pottery, bricks and tiles that formed the first artificial pozzolanas, but also found that some volcanic soils were excellent for producing a hydraulic mortar when mixed with lime. (A hydraulic mortar or concrete is one which will set and harden under water. They are generally much more durable than ordinary lime mortars.) One such soil was found close to the town of Pozzuoli, near Naples - hence the name pozzolana or pozzolan.

The development of hydraulic cements based on lime-pozzolana mixtures led to radical changes in building during the Roman era. The increased strength of lime-pozzolana mixtures, their hydraulic properties and good resistance to seawater, permitted the construction of not only arches and vaults but also marine structures. Lime-pozzolana mortars were also used as waterproofing renders in the lining of baths, tanks and aqueducts. The durability of the material is attested to by the many remains of Roman structures still in evidence today.

More recently, over 100,000 tonnes of pozzolana was used in the construction of the Los Angeles aqueduct from 1910 to 1912. Since then, pozzolanas have been used in the construction of many mass concrete and marine structures such as dams and harbours, particularly in Europe, North America and Japan.

With a few notable exceptions such as Indonesia, Oman, India and China, the commercial exploitation of pozzolanas in the Third World has generally been slower. Considering the need for low-cost construction materials, this is perhaps surprising but in recent years there have been projects to develop pozzolanas in several countries, including Kenya, Tanzania, Cuba, Trinidad and Dominica.

Why use pozzolanas

The addition of a pozzolana in either a lime or OPC-based product has two major advantages. Firstly, the properties of the cement will be improved, and secondly, as the costs of a pozzolana are usually low and certainly well below that of lime or OPC, overall cost will be significantly reduced assuming the pozzolana does not have to be transported too far.

Lime-pozzolana

The addition of a pozzolana will decrease setting times and increase the strength of lime-based concretes, mortars and renders. It can produce a hydraulic cement which has the ability to set under water. While lime-pozzolana cements are unlikely to achieve the strengths of OPC they are more than adequate for all forms of low-cost shelter construction. Lime-pozzolana cements can often be produced for less than half the cost of OPC.

The use of low-cost lime-pozzolana cements in small-scale building works is common in many parts of Asia.

OPC-pozzolana

In OPC-based concretes pozzolanas are used to replace up to 30 per cent of OPC for use in structural applications and up to 50 per cent for non-structural purposes. As OPC is an expensive and sometimes scarce commodity, this can represent a significant cost saving. In addition a Portland-pozzolana blended cement has a number of significant technical advantages over plain OPC. These are:

- Improved workability
- Improved water retention/reduced bleeding
- Improved sulphate resistance
- Improved resistance to alkali aggregate reaction
- Lower heat of hydration
- Enhanced long-term strength

The only disadvantage of these blended cements is that their early strength gain is slightly slower. This might mean that the dismantling of formwork on structural concrete may need to be delayed by a day or so, but this disadvantage is far outweighed by the advantages. These technical and economic advantages are well recognized by many 'enlightened' engineers and Portland-pozzolana blends are now commonly specified, particularly on major civil engineering works, in both the developed and developing world.

Composition and chemistry of pozzolanas

The chemical composition of pozzolanas varies considerably but the following can be taken as a rough guide.

Silica + Alumina + Iron Oxide - Not less than 70 percent
Other Oxides and alkalis - Not more than 15 percent
Loss on ignition - Not more than 15 percent

Of the active oxides, silica is normally considered to be the most important and should not normally fall below 40 per cent of the total, indeed some of the best pozzolanas have silica contents above 90 per cent.

Carbon is a common constituent in pozzolana and its content should be as low as possible, below 12 per cent is normally recommended. Plant ashes will often have higher carbon contents, unless the airflow on combustion is carefully controlled. Higher carbon contents can be tolerated but will result in lower strength cements.

Types of pozzolana

Calcined clays

Calcined or burnt clays were the earliest pozzolanas used, in the form of crushed reject clay bricks, tiles, or pottery which were mixed with lime to produce a cement for mortars. This process is still used in many countries today and is known as *surkhi* in India, *homra* in Egypt and *semen merah* in Indonesia. In general, the best clays for pozzolanas will be plastic clays of the type normally used for pottery and clay tile manufacture. The optimum calcining temperature is normally taken to be between 700 and 800°C, although for some clay types it may be higher or lower than this.

Volcanic ash

Deposits of volcanic ash or tuffs are likely to be found wherever there are active or recently active volcanoes, for example in the Mediterranean, the Pacific region and central and eastern Africa. The natural state of these deposits varies considerably as does their pozzolanic reactivity. Volcanic ashes normally require no heating to enhance pozzolanic reactivity and, if they are already in a powdered state, may need little or no grinding. Volcanic ash pozzolanas are commercially exploited in many countries, for example in Germany, Italy, Kenya, Rwanda, Vanuatu and Indonesia. Other volcanic materials such as pumice may also be pozzolanic.

Pulverized fuel ash (PFA)

Pulverized fuel ash, often referred to as fly ash or PFA, is probably the pozzolana in greatest use globally today. In 1976, it was estimated that some 30 million tonnes were used annually and that the annual increase in usage was about ten per cent. PFA is the residue from the combustion of pulverized coal in power stations and is essentially a waste material. PFA is already in a fine powdered form and requires no further processing for use as a pozzolana and this, combined with its availability in bulk and low cost, makes it ideal for blending at cement factories or at large civil engineering projects. Its reactivity is not as high as other commonly used pozzolanas and it is, therefore, less frequently used in combination with lime.

technical brief

Ash from agricultural wastes

Many plant ashes have a high silica content and are therefore suitable as a pozzolana. In recent years considerable research has gone into identifying plant wastes whose ashes produce good pozzolanas and which are available in exploitable quantities. Rice husk, a waste product of rice milling has been shown to have the greatest potential:

- it is available in large quantities in many parts of the world.
- when burnt, it produces a large quantity of ash - about one tonne for every five tonnes of husk.
- the ash typically contains approximately 90 per cent silica and is therefore an excellent pozzolana.

The disadvantage of rice husk is that for its ash to be highly pozzolanic it has to be burnt under controlled conditions at temperatures below 700°C, otherwise the silica becomes crystalline and loses a degree of reactivity. Rice husk ash has been utilized as a pozzolana in cement production in Asia, particularly India, and is under research in rice growing areas of Africa. Other agricultural wastes which have been identified as having potential as a pozzolana include rice straw and bagasse.

Other pozzolanas

Other sources of pozzolanas worth mentioning include shale, diatomite, bauxite and blast furnace slag. Shale requires similar treatment to clay, as does bauxite, although the latter's temperature of calcination is lower at between 250 and 300°C. Diatomites are usually highly reactive but are rarely used as pozzolanas because they require a large quantity of water to produce a plastic mix, due to their porous nature. Blast furnace slag is a by-product of the iron and steel industry which has a limited pozzolanic reactivity but has been very successful when blended with OPC.

Processing and production

Some pozzolanas require calcining to activate their reactivity and the best results are obtained from calcining in conditions where the temperature is controlled to the optimum for that particular pozzolana. In most cases, calcining can be undertaken in a simple and inexpensive purpose-built kiln.

Materials which have been calcined or burnt for other purposes at non-optimum temperatures can also be utilized, although a drop in reactivity may have to be accepted. The use of reject bricks and pottery, and rice husk ash from a boiler are examples of this.

Unless the pozzolana is already in a fine powdered form (as is the case with PFA and some volcanic ashes), it should be ground in a ball or rod mill. The greater the amount of milling, the finer the pozzolana will become and the rate of reaction will increase. The benefits of increased fineness must however be balanced against the additional cost of grinding. The pozzolana and cement and/ or lime must be mixed as thoroughly as possible. This is best achieved by intergrinding in a ball mill for a short period. If this is not possible, dry mixing in a concrete mixer should produce reasonable results. Less efficient methods of mixing may be acceptable but the strength and consistency of the resultant cement is likely to be adversely affected. ,

Pozzolanas can be used beneficially with either lime and/ or OPC. With the latter, replacement of up to 50 per cent is possible. With lime pozzolana cements, mixtures of 1:1 to 1:4 (lime: pozzolana) are used depending upon the quality of the lime and pozzolana, and the end-use of the cement. The addition of between five and ten per cent of OPC in a lime-pozzolana mixture will increase its strength and decrease its setting time. A higher percentage addition of OPC may be necessary if the pozzolana is of poor quality .The addition of up to four per cent of powdered gypsum accelerates the strength development of some lime-pozzolana mixes.

The chemical composition of a pozzolana will only provide a rough guide to its reactivity. Chemical tests tend to indicate the presence of a pozzolanic reaction but not its magnitude. The best way to determine the reactivity of a pozzolana is to measure the compressive strength of a mortar cube made with a mixture of lime, sand and the pozzolana to be tested. A simple test of this type is described in another leaflet in this series on testing and performance standards of pozzolanas.

Reference and further reading

- *Alternatives to Portland Cement: An introduction* Practical Action Technical Brief
- *Hydraulic Lime: An Introduction* Practical Action Technical Brief
- *Pozzolanas: Lime-pozzolana Cements* Practical Action Technical Brief
- *Testing Methods for Pozzolanas* Practical Action Technical Brief
- *Pozzolanas: Portland-pozzolana Blended Cements* Practical Action Technical Brief
- *Pozzolanas: Calcined Clays and Shales, and Volcanic Ash* Practical Action Technical Brief
- *Pozzolanas: Rice Husk Ash (RHA) and Pulverised Fuel Ash (PFA)* Practical Action Technical Brief
- *The Development of CP40 Pozzolanic Cement in Cuba*, Practical Action / CIDEM Case Study
- *[*]Appropriate Building Materials*, Roland Stulz and Kiran Mukerji, co-published by ITDG Publishing – UK, SKAT Publications – Switzerland, and GATE – Germany. 1993
  Also available to order online from Development Bookshop
- [*]*Small-scale Lime Burning: A Practical Introduction*, M. Wingate and others, ITDG Publishing, 1985
- *[*]Building with Lime: A Practical Introduction, 2nd Ed*., Stafford Holmes & Michael Wingate, ITDG Publishing, 2002/3
  Also available to order online from Development Bookshop
- *Lime and Other Alternative Cements*, edited by Neville R Hill, ITDG Publishing, 1992
- [*]*Lime and Alternative Binders in East Africa*, by Elijah Agevi and others, ITDG Publishing, 1995
  Also available to order from Development Bookshop
- *Production of Red Mud Building Materials in Jamaica: Case Study 2, Production of Silicate Bonded Bricks and Pozzolanic Cement from Jamaican Red Mud*, D W McLeod, 1998, Wall Building Case Study (building advisory service and information network – basin) http://www.basin.info/gate/cs14/RedMud1.pdf & http://www.basin.info/gate/cs14/RedMud2.pdf
- *Lime and Lime Mortars*, A.D. Cowper, Building Research Special Report No.9, His Majesty's Stationary Office, London, 1927 (republished 1998 by Donhead Publishing, Shaftesbury, Dorset, England).
- Supplementary Cementing Materials for Use in Blended Cements, R.J. Detwiler, J.I. Bhatty, S. Bhattacharja, Research and Development Bulletin RD112T, Portland Cement Association, Skokie, Illinois, USA, 1996
  (8.8 Mb file size)
- *Pozzolans for Lime Mortars*, by Pat Gibbons, article from the *Building Conservation Directory*, 1997, published by Cathedral Communications Limited, Tisbury, Wiltshire, England
  The Chemistry of Cement and Concrete, F.M. Lea, Edward Arnold, London, 3rd Edn, 1970 (extensively revised and republished as – Hewlett P C (ed.), *Lea's Chemistry of Cement and Concrete* (4th Ed), A Butterworth-Heinemann, 2003)
- *Building Materials in Developing Countries,* R.J.S. Spence and D.J. Cook, John Wiley & Sons, New York, 1983.
- *Cement Replacement Materials.* R.N. Swamy, Edited by Surrey University Press/Blackie & Sons, 1986.
- *Small-scale Production of Cementitious Materials,* R.J.S. Spence, IT Publications, London, 1980.

technical brief

- *A Brief Introduction to Pozzolanas*, Bruce King,
  (extracted from *Alternative Construction - Contemporary Natural Building Methods*, edited by Elizabeth Lynne & Cassandra Adams, John Wiley & Sons, 2000
- *Adding to the Mix*, Narayan P. Singhania,
- *Supplementary Cementitious Materials Part 1: Pozzolanic SCMs - What are SCMs and how can you use them to your advantage?*, Adam D. Neuwald,
- *CIP30- Supplementary Cementitious Materials*, Concrete in Practice Series, NRMCA, Silver Springs, MD, USA,

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