



ALTERNATIVES TO PORTLAND CEMENT

AN INTRODUCTION

Cement, or some form of cementing material is an essential ingredient in most forms of building construction. Cement is the vital binding agent in concretes, mortars and renders, and is used for the production of walling blocks and roofing tiles.

Since its invention in the first half of the 19th century, Portland cement has become the most widely available cementitious material. Its dominance over alternative cements has been in part, due to successful, aggressive marketing. This is despite its clear technical disadvantages for certain applications. In addition Portland cement is relatively expensive to produce and is often in short supply in many developing countries. Typically, a rural African labourer may need to work for up to two weeks to earn enough money to buy one bag of cement. In comparison alternative cements can be produced locally, on a small scale and at much lower cost.



Figure 1: Participants at a workshop in Uganda visiting a very small traditional lime plant ©Practical Action/Simon L'epine Ekless

Alternative cements are not capable of replacing Portland cement totally, but they can be used in the many construction applications where they have advantages. These are as mortars, renders and non-structural concretes. Alternative cements are not normally considered suitable for structural applications such as reinforced concrete beams and columns.

The most common of these so-called 'alternative' binders is lime, to which other materials, known as pozzolanas, can be added to enhance strength and water resistance. Other binders such as gypsum, sulphur, bitumen, mud and animal dung have also been used.

Binding systems from history

The simplest, and possibly the earliest, binding material used was wet mud, and there are records of its use in ancient Egypt. Another example of a binder from the distant past is the use of naturally occurring bitumen by the Babylonians and Assyrians in their brick and alabaster (gypsum plaster) constructions.

Lime was known to the Greeks and was widely used by the Romans. The Roman architect and engineer Vitruvius published the first specification for the use of lime in building in his celebrated work *De Architectura*. The Romans also knew how to make a lime-pozzolana cement by adding materials such as volcanic ash or powdered bricks, tiles and pottery to lime.

That lime is an appropriate and durable binding material, especially when mixed with pozzolana, is well proven. The Pont du Gard at Nimes in France, a Roman aqueduct built in AD 18 with hydraulic lime-based mortar, is still waterproof; the excellence of the mortar is attributed to the selection of the materials and to the time spent tamping the mix into place during construction.

The rebuilding of the Eddystone lighthouse in the English Channel by John Smeaton in 1756 is a more recent development in 'lime technology'. It was achieved through Smeaton recognizing the hydraulic properties of lime that result from the burning of a clayey limestone. To make the highly water-resistant mortar needed for bonding the courses of stone, he thoroughly mixed this already hydraulic lime with an equal proportion of imported Italian pozzolana (so adding extra 'hydraulicity' to the mortar).

Why continue to use alternative cements

Major advantages of alternatives to Portland cement are that they are usually cheaper to produce, needing much lower or even negligible capital inputs to get started, and requiring far less imported technology and equipment. They can also be produced on a small scale to supply a local market resulting in greatly reduced transportation costs and a much greater degree of local accountability in the supply of building materials.



Figure 2: Medium-scale Portland cement plant, India
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From an environmental angle lime-pozzolana cements can be produced with lower energy input than either lime by itself or Portland cement – giving a half to one third consumption in use compared with Portland cement and about one fifth compared with lime by itself. Low energy consumption is particularly prevalent with naturally occurring pozzolanas, or those from waste materials, which might need little additional processing other than drying. The use of clay as a binder, of course, results in negligible energy consumption in production.

Lower production costs mean lower prices for the consumer, enabling those who could not afford Portland cement to purchase and use a quality binding material.

Pozzolanic cements additionally have numerous other technical advantages to the user:

- Improved workability
- Improved water retention/reduced bleeding
- Improved sulphate resistance
- Improved resistance to alkali – aggregate reaction
- Lower heat of hydration

In many large civil engineering programmes involving mass concrete works, Portland cement-pozzolana mixes are specified due to these technical advantages as well as to save money.

Social advantages of alternative cements to Portland cement include the potential for affordable quality housing and the opportunity for local employment generation.

The technical and economic advantages of alternative cements are not lost on architects and engineers from developed countries. Increasingly, architects, are becoming aware of the brittleness associated with Portland cement mortars, for example, and are now specifying blended lime/Portland cement mortars instead. As well as re-discovering the 'lost arts' of using alternative binders, recent research has enabled the properties of alternative binders to be thoroughly investigated and catalogued. A body of experience has built up on the appropriate application of traditional binders such as clay, lime and pozzolanas, not only in the repair and conservation of historic buildings, monuments and structures but also in adventurous and innovative new build applications.

In some developing countries traditional binders are still slighted, probably because they might be associated with poverty or considered to be low status materials. Their performance and technical specifications might, completely unjustifiably, also be considered inferior to Portland cement, they might not be widely produced or available, or the skills to produce and use them might well have disappeared. A good case can be made for disseminating the developed country experience to the South more widely. This would increase interest and awareness of alternative binders, allow producers and users to gain skills and confidence and determine the rightful place of alternative binders in appropriate building for sustainable development.

Types of alternative cements

Lime

There are two forms of lime: quicklime and hydrated lime.

Quicklime is produced by heating rock or stone containing calcium carbonate (limestone, marble, chalk, shells, etc.) to a temperature of around 1000°C for several hours in a process known as 'calcining' or sometimes simply 'burning'. It is an unstable and slightly hazardous product and therefore is normally 'hydrated' or 'slaked', by adding water, becoming not only more stable but also easier and safer to handle.

To produce dry powdered hydrated lime just sufficient water is added for the quicklime lumps to break down to a fine powder. This material would have a 'shelf life' of only a number of weeks, depending on storage conditions. 'Old' hydrated lime would have partially carbonated and become a less effective binder.

However, if quicklime is hydrated with a large excess of water and well agitated, it forms a milky suspension known as milk of lime. Allowing the solids to settle, and drawing off the excess water, forms a paste-like residue, termed lime putty, which is the form of lime which can be used in building applications to best effect. This will keep almost indefinitely and, in fact, improves with age. In most countries, though, lime is most widely available as a powder, due to its widespread utilisation in process and treatment industries rather than in construction. Lime putty, which needs a stiff bag or container for transportation, is more rarely produced.

Limes with high calcium content, often called 'fat' or 'white' limes are desirable for most industries, although the construction industry can use limes containing impurities. For instance, limestones containing a proportion of clay are often seen as an advantage in building as they produce hydraulic limes which will set under water and will produce stronger mortars.

In the construction industry, lime, in its hydrated or putty form, is mixed with aggregate and water to produce concrete or mortar in the usual manner. Lime putties generally produce mortars and renders of excellent quality and consistency.

Plain lime-sand mortars are quite weak; any early adhesive strength results from drying out, and longer term hardening occurs through the action of the air's carbon dioxide on the lime.

Traditionally lime renders and plasters were often mixed with animal hair to improve cohesion. Today the addition of gypsum or Portland cement and/or pozzolanas to increase durability and give faster setting times is usual.

Pozzolanas

Pozzolanas are materials which, although not cementitious in themselves, will combine chemically with lime in the presence of water to form a strong cementing material. They include:

- Volcanic ash
- Power station fly ash (usually known as pfa)
- Burnt clays
- Ash from some burnt plant materials
- Silicious earths (such as diatomite)



Figure 3: Hydrating of quicklime using a watering can Chenkumbi Limeworks, Malawi © Practical Action/Dave Mather

Materials not already in a fine powdered form must be ground, and some require calcining at around 600–750°C to optimize their pozzolanic properties.

Pozzolanas can be mixed with lime and/or Portland cement and can improve quality and reduce costs of concretes made from both materials.

In some countries (e.g. India and Kenya), pozzolanas are mixed with Portland cement and sold as blended cement, which in many respects is similar to Portland cement. In other countries (e.g. Cuba) lime/pozzolana/Portland cement blends are sold as an alternative to Portland cement. Lime-pozzolana cement by itself can make an excellent cementing material for low-rise construction or mass concrete and in some countries (e.g. Indonesia) is still produced extensively.

Pozzolanas can also be mixed with lime and/or Portland cement at the construction site but care must be taken to ensure the pozzolana is of a consistent quality and that the materials are

thoroughly mixed.

Gypsum plaster

Gypsum is a not an uncommon mineral, and needs only a low temperature, of around 150°C, to convert it into a very useful binding material, known as hemi-hydrate or plaster of Paris.

On its own, plaster of Paris sets very rapidly when mixed with water. To give time for it to be applied, around 5% of lime and 0.8% of a retarding material (such as the keratin glue-like extracts from boiling fish bones or animal hoof and horn) are added to the plaster.

Retarded plaster of Paris can be used on its own or mixed with up to three parts of clean, sharp sand. Hydrated lime can be added to increase its strength and water resistance. Gypsum plasters can be reinforced with various fibrous materials from reeds to chopped glass fibres.

technical brief

Gypsum plaster is not wholly resistant to moist conditions and so is normally used internally, except in the drier Mediterranean and Middle Eastern countries where it has traditionally been used as an external render.

Other alternative binders

Sulphur is used as an alternative binder in the Gulf region, where a million tonnes a year comes from natural gas plants in the United Arab Emirates. In some other locations, such as St Lucia, sulphur that accumulates around the vents of volcanic fumaroles is utilized.

A mixture of 15–25% molten sulphur, heated to around 130°C with 5% of organic additive, and 75–85% sand or other mineral aggregates which have previously been heated to 160–170°C, can be cast and de-moulded in only about five minutes. The additive is mainly used to impart durability. Sulphur concrete has applications which either exploit its quick curing and corrosion resistance or in situations where Portland cement concrete is expensive, unavailable or, for example in freezing conditions, impracticable.

Earth mixed with water to form mud has been, and continues to be, used over much of the world as a binding material. It develops quite a strong adhesion to fired clay brick and sun dried mud brick masonry and is satisfactory provided the mud mortar is protected from rainwater. A useful practice is to use mud mortar in the internal parts of the wall and do the external pointing in a cement or lime-based mortar. The best soils for building purposes contain both sands and clays and therefore it may be necessary to mix two different soils to obtain good results. Mud mortars have, traditionally, been improved by the addition of organic matter such as straw and cow dung.

A number of other alternative binders have been used in a number of applications, which generally relate to soil stabilisation, waterproofing, or the application of a waterproofing or wear resistant coating to vulnerable earth based constructions. Such binders include tars and bitumens (as by-products from petro-chemical industries), sodium silicate (produced from the heat activated reaction between silica and sodium hydroxide), casein (milk whey), oils and fats, molasses, and certain locally specific plant-based materials such as gum arabic, other specific resins and the sap, latexes and juices from specific trees and other plants.

References and further reading

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- *Lime Kiln Design: Small & Medium Scale Oil Fired Lime Kilns* Practical Action Technical Brief
- *A Small Lime Kiln for Batch and Continuous Firing* Practical Action Technical Brief
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- *Pozzolanas: Introduction* Practical Action Technical Brief
- *Testing Methods for Pozzolanas* Practical Action Technical Brief
- *Pozzolanas: Portland-pozzolana Blended Cements* Practical Action Technical Brief
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For further information please contact:

Practical Action
 The Schumacher Centre for Technology and Development
 Bourton-on-Dunsmore
 Rugby, Warwickshire, CV23 9QZ
 United Kingdom
 Tel: +44 (0)1926 634400
 Fax: +44 (0)1926 634401
 E-mail: inforserv@practicalaction.org.uk
 Website: <http://practicalaction.org/practicalanswers/>

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