EINDHOVEN UNIVERSITY OF TECHNOLOGY

Alternative 'cements' for application in developing countries

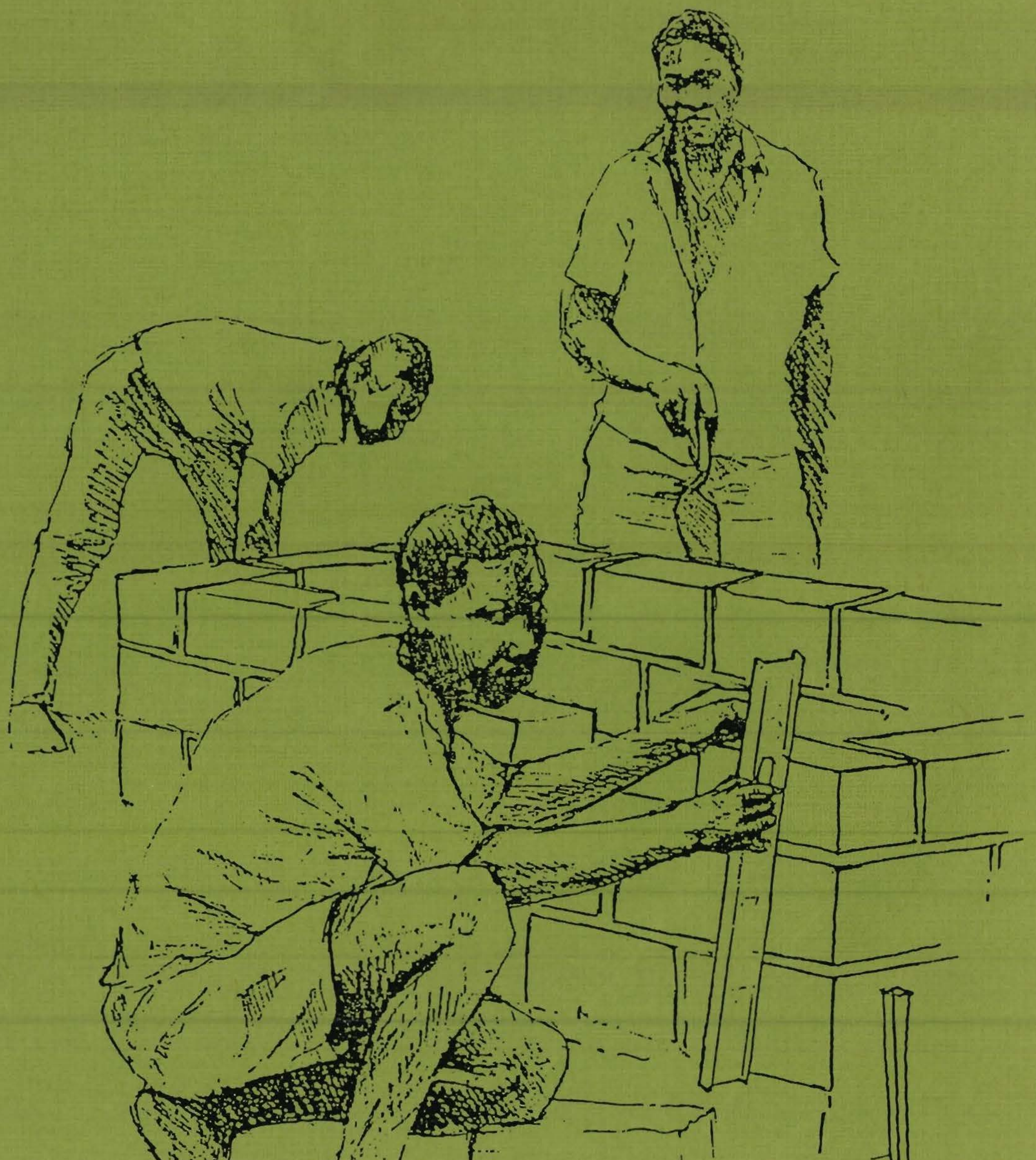

Illustration cover from; Construction Reference Manual, The Kitteredde construction Institute, Uganda

Alternative 'cements' for application in developing countries

Diane van Herpen
Id.nr; 327031
Tutors;
ir. A.Th. Vermeltfoort
dr.ir. J.J.A. Janssen
ir. H. Lamers

University of Technology, Eindhoven, January 1994

PREFACE

Students of the Faculty of International Technological Development Science (ITOK), who fulfil 60% of their study-programme with subjects given at the Faculty of Architecture, are supposed to carry out four study-projects in accordance with their technical speciality. I, fourth-year student of the faculty of International Technological Development Science, have construction and building-technology (BKO) as a speciality. This project should be seen as a T8-T9 BKO-research-project (50 sp) which implies 200 hours of study.

Since this is my last study-project, I preferred to choose a subject which was concerned with developing countries in order to make this as much as relevant for my study and future sphere of work. For the same reason this report is written in English as ITOK-engineers are generally working in an international framework. I considered it as a nice opportunity to get trained in writing in a foreign language and on the same time getting used to technical terms in English.

In terms of the views of development, I share the populist view, which means an emphasis on people themselves as agents of development, solving their own problems individually or through local organisations and networks. This in reaction against large-scale and 'alienating' industrialization. Consequently, the emphasis in this report is put on the 'appropriateness' of technologies and small-scale production. Secondly for rural areas in particular because there is often a limited access to urban factories and transportation facilities are scarce. The need for alternatives is felt the most in these areas. According to me upgrading of rural areas and employment-creation can contribute to a decrease in the tremendous migration and problems of urbanisation in developing countries. Availability of alternatives for Portland cement can make a big contribution to the improvement of housing standards.

This report can be seen as an attempt to integrate technological and social- economical- views as can be expected of a student of the Faculty of Technology and Society.

Diane van Herpen
Amsterdam, 1994.

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1 INTRODUCTION

More than three quarters of the world-population is living in the so-called 'developing countries'. Although these 'developing countries' are so heterogeneous and geographical even spread over different continents, they all have a couple of essential problems in common. They have to cope with a tremendous population growth, a massive and growing unemployment, a weak economy and position on the world-market, a lack of efficient infrastructures and often a lack of foreign currency. In these countries the building-sector has become of great importance. The high demand for building-materials and building-activities is predominantly provided by the informal building-sector. These small-scale informal production-units often take account for more than 50% of the total building-activities in the country.

The nature of the technologies that are being transferred from the industrialized countries to the developing countries are mostly capital-intensive, large-scale, and highly sophisticated. The need of developing countries is generally an appropriate technology, which is capital-saving, small-scale, and relatively simple. The crux of the problem is how to maximize the use of local skills and resources and how to minimize imported skills and goods in order to achieve self-reliance.
Remembering Gandhi's "Swadeshi" principal, "*we should be learning how to restrict ourselves to the use and service of our immediate surroundings, to the exclusion of the more remote*".

In the developing countries the masonry constructions are of special importance. The greatest part of the masonry is always made of soil blocks, produced in small-scale production units. In order to reduce costs, to make masonry applicable for low-cost housing projects, and to make better use of local available materials, an attempt to eliminate, or at least reduce, the need of the scarce and expensive 'Portland cement' is required. An attempt to find alternatives which would approximate the properties of 'Portland cement'. An attempt to fabricate "a substance which makes objects adhere to each other" with use of locally available materials. An attempt to develop an appropriate technology for masonry constructions in developing countries.

This report is the result of a literature-study concerning research for alternative 'binders' applicable in developing countries. As mentioned before, the developing countries are heterogeneous and represent an enormous variety of natural resources, cultures and architecture. Therefore different technologies and applications should be illustrated.

The succeeding chapter is about the history of cement manufacture, because when we search for alternatives for Portland cement we can learn a lot of our ancestors in the past. An other chapter is about the production and properties of

Portland cement and its short-comings for production in developing countries. The next chapter is about the building materials, techniques and conditions for masonry in developing countries and serves as a kind of scene in which the rest of this report should be placed. Six alternative binders and there appropriateness for developing countries will be described in specific chapters and will lead to a chapter with the general conclusions and a summary of the literature-study.

Finally this study is ended by a second part, namely the report of a narrow experiment with six different mortars of alternative 'binders', carried out in the 'Pieter van Musschenbroek' laboratory of the University of Technology, Eindhoven.

PART ONE; LITERATURE-STUDY

2 HISTORY OF CEMENT MANUFACTURE

The idea of using a form of cement or to induce adhesion between building components was first met at a relatively advanced stage of civilization.
Earlier structures were composed of earth, sometimes raised in the form of walls or domes by ramming successive layers, or of stone blocks, set one above another without the aid of any cementing material, as in prehistoric structures, and in the masonry of Greece. The stability of walls of the latter kind is derived entirely from the regular placing of heavy masses of stone without any assistance from adhesion.

The next stage of development is that found in the brick walls of ancient Egyptian buildings. The bricks are dried in the sun without baking, and each course is covered with a moist layer of the loam (Nile mud) used for making the bricks, with or without the addition of chopped straws. The drying of the layer makes the wall a solid mass of dry clay. The disadvantage of this method was of course the lack of resistance to water, but it produces quite satisfactory building for a rainless climate. Burnt bricks were employed by the Babylonians and Assyrians, and were cemented together with bitumen. Although this method was very effective, it was of course confined to regions where natural deposits of the material were found.

The first use of true mortar, in the sense of a mixture of sand and a cementitious material used to unite blocks and slabs of stone, is to be found in the massive masonry constructions of the Egyptians. While the typical Egyptian mortar was usually described as burnt lime, chemical examination has shown that the cementing material was always obtained by burning gypsum, probably because it requires a lower temperature and consequently less fuel for dehydration than calcination of lime.

Whereas the early Egyptians were not acquainted with the use of lime it was used at a very early period by the Greeks, and earlier still in Crete, and the Romans must have borrowed it from Greece. The mortar was prepared in the modern fashion by slaking the lime and mixing with sand, producing a mortar which hardened as the calcium hydroxide became converted to calcium carbonate. This was, however, a slow process, which often affected only the outside of the mortar layer.

By adding some form of siliceous matter, such as volcanic ash, or burnt clay, to lime mortar, a much more satisfactory produce was obtained, with the whole mass of mortar becoming more resistant to (rain) water. Both the Greeks and the Romans were aware that certain volcanic deposits, if finely ground and mixed with lime and sand, yielded a mortar which not only possessed superior strength, but was also capable of resisting the action of both fresh and salt water.

The material used by the Romans was a red or purple volcanic stuff found at different points on and near the Bay of Naples. The best variety of this earth was obtained from the neighbourhood of

Pozzuoli, and the designation "pozzuolana" or "pozzolana" has been extended to the whole class of mineral matters of this type. Vitruvius says of it:

> *'There is a species of sand which, naturally, possesses extraordinary qualities. It is found under Baiae and the territory in the neighbourhood of Mount Vesuvius; if mixed with lime and rubble, it hardens as well under water as in ordinary buildings.'*

If volcanic earth was not available, the Roman builders used powdered tiles or pottery. Vitruvius stated:

> *'If to river or sea, potsherds ground and passed through a sieve, in the proportion of one-third part, be added, the mortar will be the better for use.'*

[Ref; 2]

The advent of pozzolana mortars led to radical changes in building construction. Not only was it possible to erect more slender walls with the stronger mortar, but the construction arches and vaults became possible. The Roman used the pozzuolana mortars in position where it was impossible to prevent penetration of water and damp.

In post-Roman times there seems to have been a reversion to the use of non-hydraulic limes, which were not so durable, and in England it was probably not until the sixteenth and seventeenth centuries that imported pozzolana ('Dutch tarras' or trass) and lime mixtures were used. The Dutch tarras mortar was used extensively in Holland in the construction of harbours and sea defences. In 1756 John Smeaton was called upon to erect a new lighthouse on the Eddystone Rock following the destruction of the previous frame structure by fire, and proceeded to make enquiries as to the best building materials for work under such severe conditions. He found that usual mortar for work under water was composed of two parts slaked lime to one part tarras, and experimented with various limes.

Finding that lime from the siliceous limestone at Aberthaw, in Glamorgan, gave better results than ordinary lime; he compared the chemical behaviour of different limestones, and discovered that those which gave the best results as mortars contained a considerable proportion of clay. He deducted from these experiments that a good cement could be produced by deliberately mixing limestone and clay together and burning them.

Towards the end of the 18th century, the demand for cement in England was stimulated by the London Building Act of 1774, which encouraged the use of stucco as a facing for building, as well as the industrial revolution, which greatly stimulated the demand for the development of internal communications, canals, roads, bridges, tunnels, docks and harbours. In 1796 James Parker discovered that he could make hydraulic cement by calcining nodules of limestone found lying along the foreshore of the Thames. Parker called the product 'Roman cement', a misnomer, but one by which it came to be known.

Vicat, in 1813, did experiments on the effect of adding different clays in varying proportions to slaked lime, and then burning the mixture. The success of these experiments led other investigators to try artificial mixtures of clay and calcareous materials and in 1822 Frost brought out his "British cement," which was soon followed by Aspdin (1824) with "Portland cement". Aspdin was apparently the first to use the word "Portland" to define a particular type of cement that he patented. When set with water and sand, this cement resembled a natural lime-stone quarried on the Isle of Portland in England.

At about the same time it was discovered that an excellent cement could be made by pulverizing the nodules, which occasionally became sintered (that is, formed into a non-porous solid without melting) when hydraulic lime was fired. The resulting cement was of much higher quality than that obtained from the unsintered material. This fact was firmly established by the English cement manufacturer Johnson in 1845, and the term "Portland cement" has since been applied solely to the cement made from sintered material.

[Ref; 1] [Ref; 2] [Ref; 3]

3 PORTLAND-CEMENT

3.1 Introduction

As the objective of this literature-study is an attempt to find alternatives which would approximate the properties of 'Portland cement', a description of Portland cement and it's restrictions for use in developing countries can not be left unmentioned.

3.2 Brief description of the production process of Portland cement.

Portland cement is produced by making an artificial mixture of several raw materials: chalk or lime, clay and eventually iron (pyrites) and aluminum rich materials. This mixture is dosed very precisely, so that you get the following chemical structure;

65%	CaO
22%	SiO_2
5%	Al_2O_3
4.5%	Fe_2O_3

Starting from the morphology of the raw materials there are two kinds of production methods;

- Wet process; if the raw materials are soft, retentive of moisture and difficult to dry.
- Dry process; if the raw materials are hard, dry and suited to be ground to powder and easy to dry.

Both methods pass through four important stages;

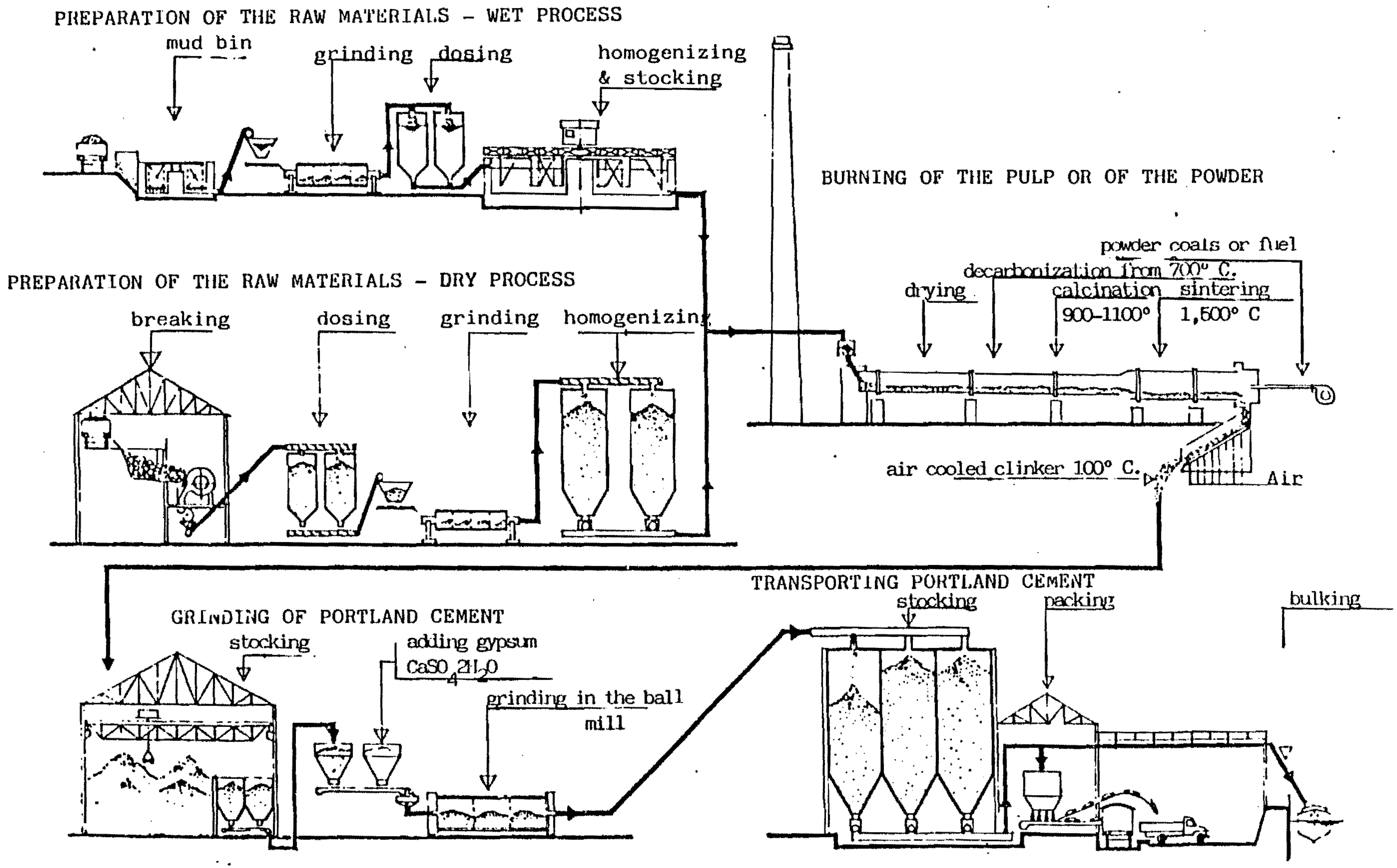
1) Preparation of the raw materials.

According to the wet process, raw materials are broken, when necessary even in their rough form. By adding water the raw materials there upon are mixed together in mud bins in the right proportion and remodelled to pulp. Then this pulp is ground in a ball mill. The dry process grinds the raw materials first in their rough form, dose them and this mixture is ground to very small pieces afterwards. It is very important to dose precisely: small changes in the chemical structure of the mixture of the raw materials have a great repercussion on the structure created during the burning process (hydraulic structure). Grinding the mixture is also important, because the degree of fineness coupled with the reactive surface, influences the process of the chemical reactions during the burning process.

2) Burning.

The pulp obtained by the wet process or the powder obtained by the dry process is conducted to the kiln and passes through the following stages;

- the stage of preheating;
- the stage of decarbonization and calcination (from 700° C). At this stage the $CaCO_3$ (limestone) is decomposed into CaO (calcium oxide or quicklime) and CO_2 (carbonic acid anhydride) and the CaO forms a chemical combination with the SiO_2, Fe_2O_3 and Al_2O_3.



Production process of Portland cement
Source; Binders; alternatives to Portland cement, ATOL Leuven, Belgium, March 1980.

- the stages of sintering (1,100-1,450^0 C). Small granules lute together to marbles with a diameter of 0,5 to 3 mm. These "marbles" are called clinkers.

This process of calcination and sintering is an essential stage, because the hydraulic components are formed there (hydraulic components have the property to harden under the influence of water). It is also a dangerous stage, because the CaO has to combine completely with Fe_2O_3 and Al_2O_3. Even a limited quantity of uncombined CaO will afterwards react upon the water and combine to $Ca(OH)_2$. This reaction involves a certain degree of swelling out and will cause fissures in the mortar or concrete.

3) Grinding the Portland Clinker.

The cooled clinker is ground in a ball mill. This stage is also very important, because the fineness degree of the ground cement strongly influences the quality.

4) Packing and transporting the cement.

3.3 Mortars of Portland cement

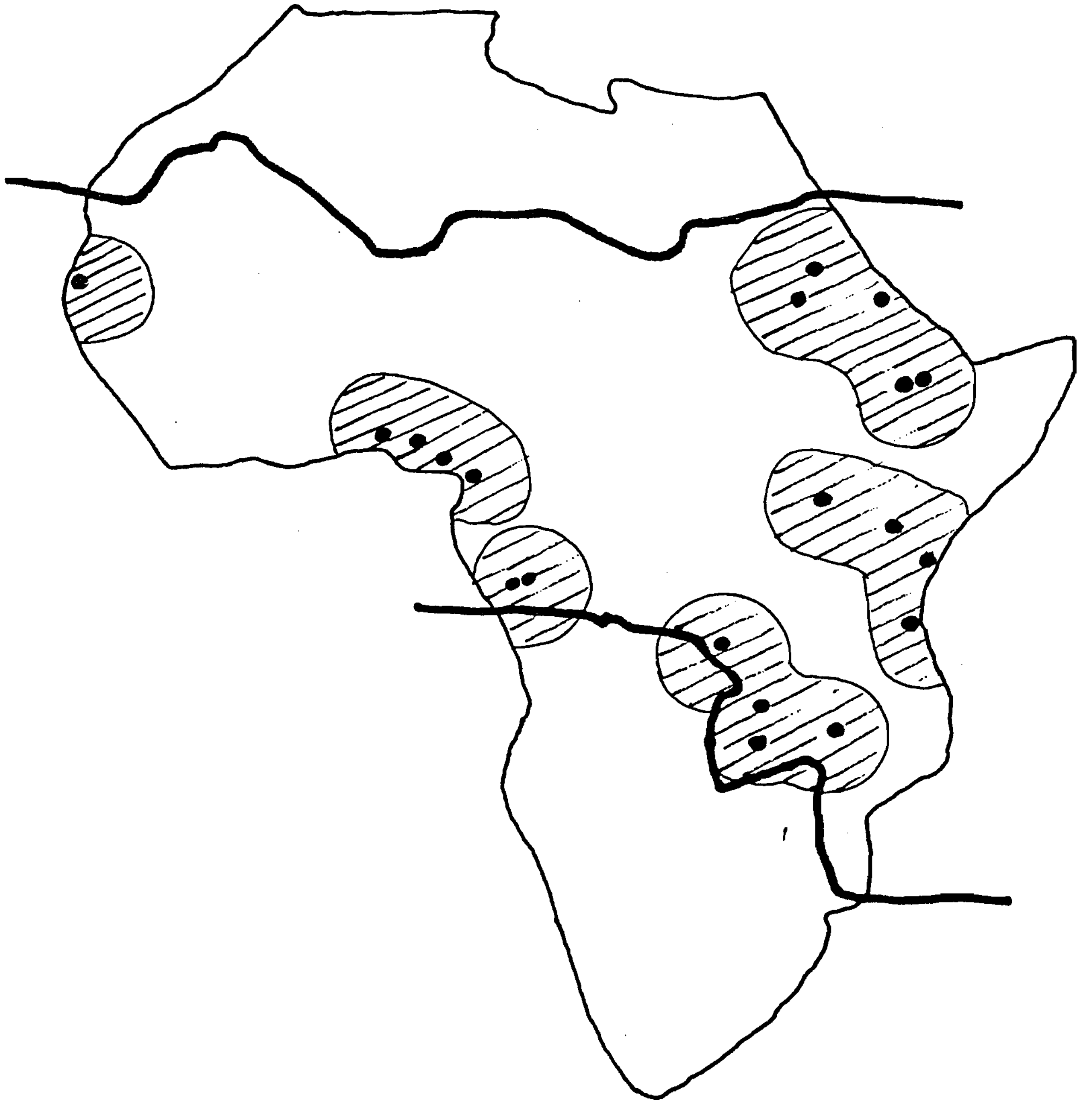
The invention, production and the qualities of Portland cement led to wide spread application in mortars, plastering and concrete in industrialized countries. The quick setting time, the high strength development and low shrinkage of Portland cement mortars offered a solution for the growing demand for building activities and the speed in which these building activities took place in the last century. The composition of the mortar-recipes depends on the kind of bricks used, the Haller-number of the bricks, the required workability of the mortar, the season etc.
Common used mixtures (in parts of volume) are;

Portland cement : lime : sand	1 : 1 : 5 or 6
and	1 : 0.5 : 4.5

but also a mixture without lime and a proportion Portland cement : sand of 1 : 3 satisfies. The use of additional (often chemical) products like retarders, plastifiers etc. can improve the quality.
The requirements of mortars are defined in norms and specifications and the minimum compressive strength of the mortars varies in between 2.5 N/mm^2 and 17,5 N/mm^2. [Ref; 15]

3.4 Portland cement and developing countries

"The binder" is the essential component in mortar, plastering and concrete. As we have seen in Chapter 2, various kinds of binders have been used in the course of time; earth, clay, trass, lime, pozzolana etc. The invention and improvement of the Portland-cement is the result of the unwearying search for an alternative and qualitatively better binder.
A network of cement industries has been set up in the industrialized countries. Convinced of the binder's quality, the developing countries also decided to set up Portland cement industries. 'The statistics of their annual cement production show this clearly. During the period of 1966-1975, the cement production doubled in Africa, Asia, South-America.' [Ref; 5]



AFRICA :

Centres of cement production, 1970
Shade areas are within 400 km. of a cement factory.
Source; World cement Directory, 1972.

Some countries already produce enough cement to be self-supporting in that matter. Others still have to import cement. This dependent position can sometimes have disastrous consequences. During the war between Uganda and Tanzania, the cement import to Rwanda was totally cut off. Due to that fact the building of any important construction was completely paralysed.

Setting up own Portland cement industries means mostly that, in imitation of the industrialized countries, large scale plants are built. This option however has the following negative results; [Ref; 4]

* The average production quantity of a cement plant varies from 600 to 3,000 tonnes a day. To keep this industry productive during a few decades, it is absolutely necessary to have a considerable reserve of raw materials in the immediate site. But the number of deposits is limited and not always situated near the consumers.

* Construction, transport and installation of the equipment (machines, kilns, etc.) becomes more complicated as the plant's capacity grows. This means essentially that the developing countries have to appeal to foreign experts and companies to draw up plans, to buy equipment, but they also need them for the installation, the experimental production stage and upkeep of the most important accessories.

* The infrastructure of the implantation region is more burdened as the plant's scale grows. The demand for energy increases (electricity for grinding, fuel or coals for the kilns); the demand for a better balanced transport system also grows (roads, rail- and waterways) together with the demand for specialized workers and workshops for the upkeep. A lot of plants are working under their capacity because the provision of coals leaves much to be desired.

* The investment costs are so high that foreign capital is often necessary.

* It takes a lot of time before the plant is planned and built.

* Transport and distribution of the finished product becomes more difficult as the production is more centralized.

At first sight, the savings in capital costs and energy costs resulting from an increase in size seem to constitute a clear case for the trend towards larger and larger kilns. But, whatever the advantages of the use of increasingly large-scale cement plants in the industrialized countries, their appropriateness for all situations in developing countries must be, and is being, seriously questioned.

Small scale production of Portland cement is not impossible, serious attempts were made by China and India. The production method is however rather complicated. The quality depends on the dosing of raw materials, on the good preparation of the raw materials before the burning process (grinding, mixing, granulating), and the good conduction of the burning process (temperature of 1,500° C and long enough, so that the reaction is complete), and also on the granulation of the clinker.

The need of;

- continuous quality control of the raw materials, before, during and after the production process;
- precise dosing;
- conscientious control of the kiln (leading a burning process to 1,500°C is not easy and requires skill and experience)

makes this process not the most appropriate (see Chapter 1; Introduction) one for application in developing countries. Alternative binders of similar quality, but to be produced with less complicated methods, do exist. In this report 'the small-scale production of Portland cement-option' is left out and the emphasis lays on the alternative binders.

4 MASONRY, BRICKS, AND MORTARS IN DEVELOPING COUNTRIES

4.1 Introduction

Before looking further into the 'alternatives' for cement and their use in developing countries, a clear picture of their application and the conditions for use in developing countries is required. The term 'masonry' might be all-embracing but masonry of industrial fabricated bricks in Europe is quite different from masonry of burned bricks in rural areas in Africa for instance. The type of bricks or stones used, influences the properties of the binder and the required width of the joints for example.

As mentioned in the introduction the building activities are predominantly carried out by the informal sector. In this chapter a brief description of types of masonry commonly used in rural areas in developing countries is given. Rural areas in particular because there is often a limited access to urban factories and transportation facilities are scarce. The need for alternatives is felt the most in these areas.

The following subjects will be enlightened;

- bricks or stones used
- definition and properties of mortar
- the requirements water and sand
- the conditions and technique of preparing and mixing the mortar
- bricklaying and thickness of walls.
- summary and conclusions

This chapter is not comprehensive but serves as a kind of scene into which the rest of the report should be placed.

4.2 Bricks and stones

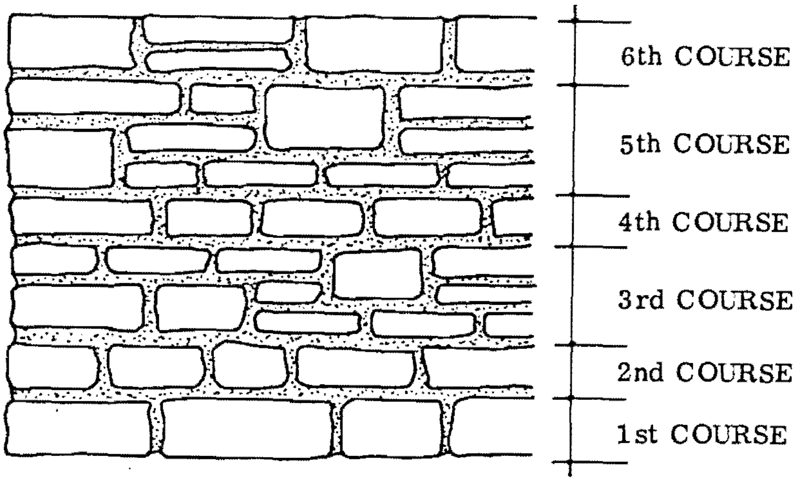
Of course the kind of bricks or stones used in construction is dependent on the local available materials.

Natural stones have been used for masonry for centuries. It is hardly necessary to enumerate the advantages of this type of construction. A stone wall is permanent, attractive and substantial. It may be a necessity where mud is unsatisfactory and where stone is relatively inexpensive and plentiful.

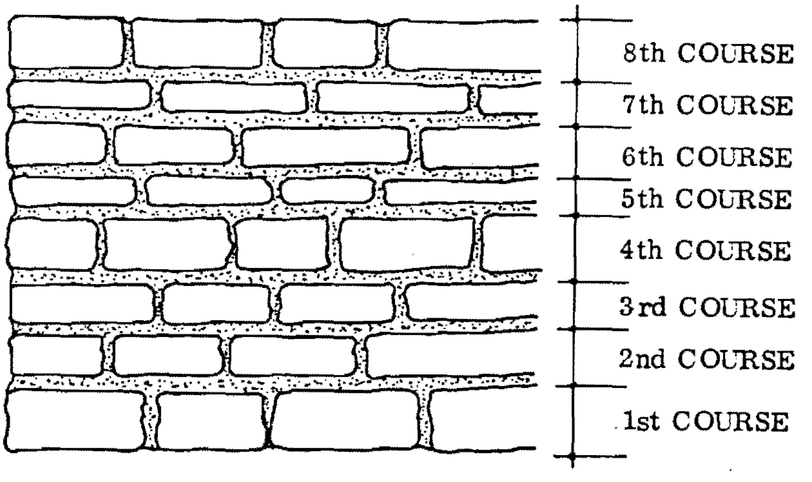
In this type of masonry the stones are 'dressed' before they are used in the structure. To dress stone means to cut and shape it, in order to make them better fit together. There are four different types of natural stone masonry, depending on how much dressing is done and how the stones are laid.

-Rough stone masonry

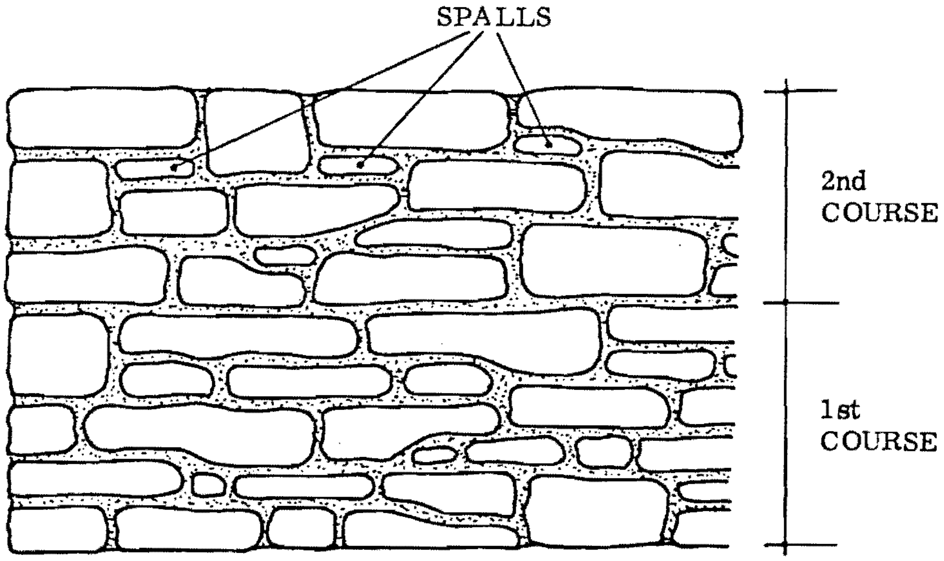
This sort of masonry consists of natural stones which are shaped only slightly along their bed faces, or not shaped at all. Regular courses are not seen because of the irregularity of the stones.



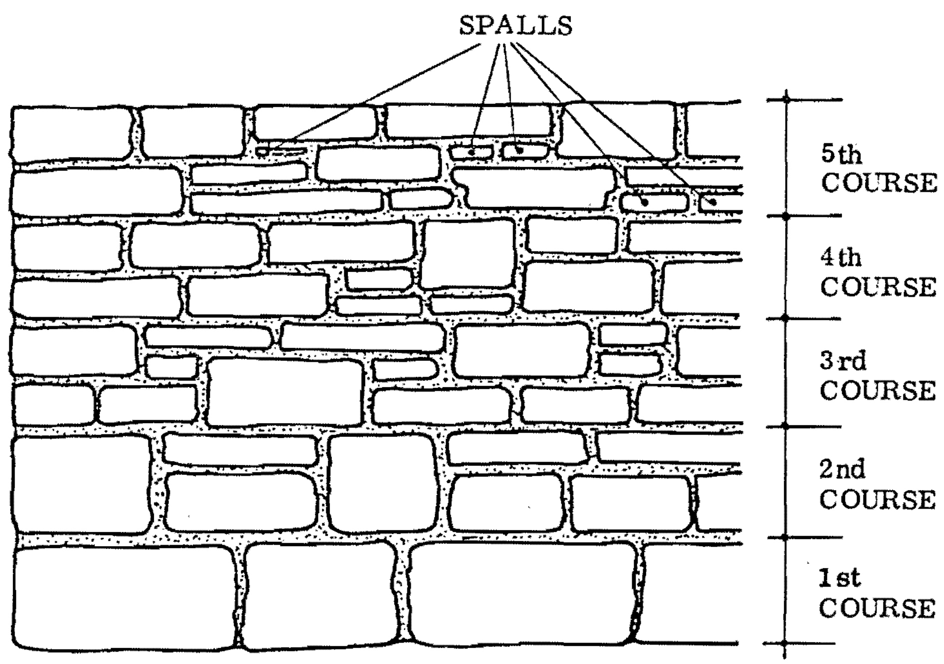
BROKEN RANGE MASONRY



RANGE MASONRY



ROUGH STONE MASONRY



HAMMER-DRESSED ASHLAR MASONRY

Masonry of natural stones
Source; Rural buildings, Construction, Stichting Kongregatie F.I.C., Maastricht.

-Hammer dressed masonry

As the name implies, the stones used for this type of masonry are roughly shaped with a hammer, so that the stretcher and header faces are approximately perpendicular to each other. The stones are laid in regular courses but the thickness of the stones may vary within one course.

-Broken range masonry

The stones of this masonry are accurately shaped with a hammer and chisel so that all the faces are perpendicular to each other. The bond should not contain joints more than 30 mm thick. The height of the stones may vary within a course, and the height of the courses may also vary, with the result that the courses are continuous for only short distances.

-Range masonry

The accurately squared stones are laid in courses, and each course is uniformly thick throughout its length. However, the courses are not all necessarily of the same thickness.

The following 'rules' have to be considered for all types of natural stone masonry, regardless of how much dressing is done on the stones.

* The stones should lay in the way it has "grown". This means horizontal layers should be laid flat.
* Bigger voids between stones have to be filled up with spalls, to save mortar.
* All natural stone masonry must be coursed and levelled at a height not exceeding 1.5 m and preferably every 0.5 m.

-Laterite rock

An other highly suitable building material is laterite rock. In structure and colour it appears similar to laterite soil, and although it is rather porous and comparatively soft when freshly dug from the earth, it gradually becomes hard and rock-like when exposed to air. Laterite stone has been used for many sorts of masonry because it is readily available, easily shaped, and strong. A disadvantage is the time it takes to excavate the stone and shape it into blocks. Although the stone can be given any convenient shape, the dimensions of blocks made from laterite stone should preferably be 140*300*460 mm, which allows proper bonding with all sorts of masonry. [Ref; 6]

An advantage of using natural stones instead of bricks is the fact that no firewood or fuel for baking is needed. Especially for environmental issues this is preferable. Stone walls not lend themselves to fine measures.

-Bricks

One of the world's most widely used building material is clay brick. Many countries have deposits of suitable clay, and good sources of local fuels, so that no foreign exchange is needed for the production of this well-proven building material.
In many developing countries, labour intensive production methods are more appropriate, and if care is taken in production, these methods can produce satisfactory bricks. Most bricks made in developing countries are moulded by hand, using traditional techniques which in some instances may have been in use for hundred of years.

-Mud or adobe bricks

Mud or adobe bricks have been found to be one of the most practical types of wall construction where the clay is suitable and there is enough dry, hot weather to bake the brick. Mud bricks are adaptable to almost all building requirements, except where conditions bring about constant washing or splashing of water. Mud bricks lend themselves to corners, jambs, arches and other awkward as well as straight wall work. On a proper foundation they may be classed as sound and permanent construction.

Earth in many tropical and sub-tropical countries has properties which, with a hot sun and dry air, are favourable for making durable mud bricks. Clay and sand are essential. Clay alone shrinks and cracks; sand mixed in with the clay in the right proportions will prevent shrinking and cracking, but too much sand will weaken the clay and also make it too soluble. Hence no more sand should be added to the clay than is absolutely necessary. If the bricks are too weak, chopped grass or straw is added to the mixture. No large lumps or stones are permissible in brick mud but small stones of not more than 16 mm are not objectionable, they may even be beneficial.

In literature practical sizes for hand-moulded bricks are given, like 80*180*390 mm [Ref; 7], or 3 1/2 * 5 5/6 * 12 inch (2.54 mm), which gives joints of 3/4 inch thickness [Ref; 8]. Bricks require to have a depth proportional to their length so that they will not easily break in two. Their length should work in well with building measurement and their width should always be a little less than half their length.

The greatest drawbacks are their inability, more in some locations than in others, to withstand rain, and their complete vulnerability to the ravages of the termite or white ant. The first problem has been overcome in some areas by waterproofing the mud with cotton seed tar, which, when dried, will hold lime plasters.

-Mud blocks

Many builders prefer mud blocks to mud bricks. They lay faster and on a good foundation may be regarded as permanent construction. They require special bonding at the corners to give strength, and they are definitely not as satisfactory as mud bricks in respect to odd measurements, awkward corners and special features.

Mud blocks should be moulded close to the job. More than bricks, they need chopped grass, straw or hemp to make them strong enough to handle without breaking. Blocks take longer to dry out than bricks.

-Burned bricks

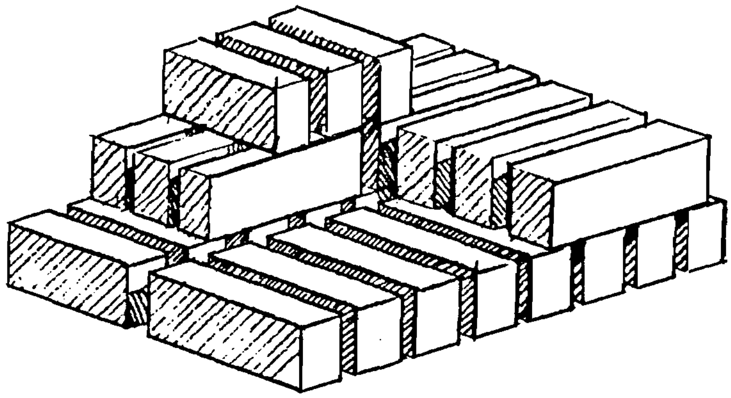
These have been used where the mud was of such poor quality that mud bricks were not satisfactory, or where for foundations, stone or concrete were prohibitive in cost. Considerable time and skill are needed to produce good fired bricks, they take longer to make than mud bricks, and often have to be transported for some distance from the clay source and kiln to the building site. Burned bricks are not always strictly waterproof. It seems that the clay lacks the properties necessary to an impervious product.

For the size of burned bricks the same principles applies as to mud bricks in connection with the relation between the width and the length.

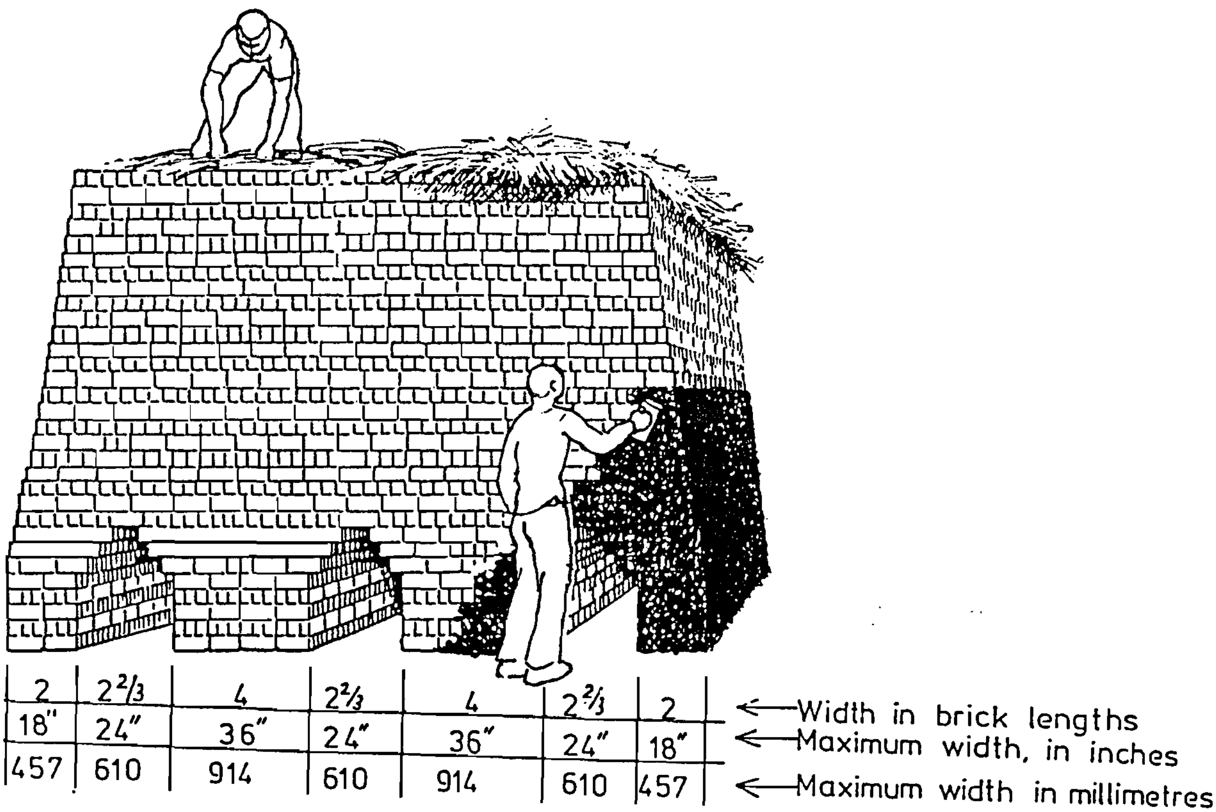
The bricks are burned in kilns which differ in type, size and fuel use all over the world but the principle is the same. The kiln is basically made up of a pile of stacked sun dried bricks arranged in rows in such a manner that the fire and heat can reach all the bricks and burn them as evenly as possible. According to the number of bricks required, one or more firing chambers are formed by arching the dry bricks to make a tunnel. The arch over the tunnels is formed by the process of 'corbelling' -stepping out the bricks until they meet in the middle. The outside of the kiln is covered by a layer of waste bricks, on top of which it is usual to plaster a coat of mud to reduce the escape of heat.

The fireholes or tunnels are lit at both sides of the kiln. As soon as the fire is burning freely, the openings are bricked up, leaving a small hole in each fireway for air flow. As fuel wood or coffee-rice husks, finely shopped straw, papyrus or other agricultural residues can be used.

During the first 24 hours of the firing process, it is very important to burn the fuel slowly. The purpose of initial slow burning is to cause the remaining moisture in the bricks to evaporate at an even rate rather than rapidly to avoid cracking and damaging the bricks. After this stage, when steam and vapour is no longer escaping from the kiln, the fireways are opened and a strong fire and high temperature should be maintained day and night for 2 or 4 days. The objective is to bring each brick to a level where it is red and hot for an extended period of time. The actual length of this intense burning process depends on kiln size, type of fuel and its degree of wetness or dryness, weather conditions, and the efficiency of the kiln.



BRICKS BEING PILED IN THE KILN.
LEAVE AT LEAST ½" SPACE AROUND
EACH BRICK.



Kiln construction for brick-baking
Source; Construction reference manual, The kiteredde construction institute, Uganda, 1985.

After this intense firing process, the fireholes are sealed up with bricks and mud and the kiln is left to cool down gradually for about 36 hours. After the burning process, the plaster is removed and when the bricks are cool enough to be touched and handled, they are carefully sorted out. The best burned bricks are used for the outer faces of main walls, and the least well burned bricks are for partition walls. If burned bricks are made for exterior walls only, the best ones are used for lower part of the wall, or that part which is most exposed to water.

Burned bricks are often more brittle and fragile than unburned mud bricks. Therefore they must be handled carefully. When the time comes to start building the walls, burned bricks should be drenched with water just before being laid in the wall, particularly because a dry brick soaks up the water in the mortar mix and causes the mortar to harden and set quickly.

Of course there are many other kind of materials for masonry work, like concrete blocks, corrugated iron, Pise or rammed earth but in the context of this report, the techniques are restricted to the ones given above.

4.3 Definition and properties of mortar

-Definition

A hydraulic mortar is a plastic paste, which gradually hardens, and which is obtained by carefully dry, or wet, mixing an aggregate and a binder.

Hydraulic mortar = aggregates + binder + water

The proportion of the different materials making up a mortar will vary depending on the use of which the mortar is to be put. There are several types of mortar depending on the part of the building where they are to be used and their particular intended function, like masonry or plastering.

In this report the application of mortar is restricted for use in masonry.

-Masonry mortar

In horizontal masonry joints, the function of the mortar is to:

* Spread the vertical loads exerted in the wall.
* Compensate for any deficiencies in laying.
* Compensate size-inaccuracy of the bricks.
* Improve stability of slender construction.

In horizontal and vertical joints, it serves to fill the voids between bricks or stones, preventing air and water from passing through.

At the foot of the wall, it has an additional function which is to prevent water rising form the soil by capillary action.

-Properties of mortars

The main properties of mortars are:

* Compressive strength; This depends on the nature and the properties of the binder and the grain size distribution of the aggregates. It should be noted that the optimum strength of masonry mortar is in the order of half the compressive strength of the units the wall is made of.

* Compatibility with the surface; The most common instances of incompatibility are linked to differences in moisture permeability (risk of drying out) and to mechanical performance.

* Impermeability; Water should not be able to pass through a mortar layer.

* Ability to withstand cracking; The mortar gives a certain amount of elasticity to the wall. Having a light bed of mortar between each brick course or layer, protect bricks from cracking due to settling or other causes.

* Workability; When it is still in a plastic state during application, a mortar should be workable, it should be easy to use.

4.4 Water and sand

-Water

A water source is important in planning any building and for the construction itself. The source can be a well, deep bore hole, spring, stream, or rain water collected from a roof and stored in a tank. The importance of water for constructions of masonry needs no explanation. It is worth spending both time and money to make sure water is available at all times. The water needed to make mortars does not need to be pure like drinking water but in general the better the quality of the water, the better the quality of the mortar. Impurities and contaminations should be avoided.

One way to improve the quality of water is to use a water filter. A simple design for a filter which can be made by anyone is a locally made pot which hangs from wires or ropes. The pot is partly filled with layers of fine sand, gravel and stones. The water sinks down through this and drains off through holes in the bottom of the pot. It is used for small amounts of water.

For construction purposes often a bigger amount is required. A built-up water filter can be used to purify larger amounts of water. The principle is the same as for the pot so further explanation is left out.

For mortars it is important that the water is filtered in one way or an other, but for this report is assumed that wherever building activities take place, there is water provision for people's daily activities and this will be of a sufficient quality to be used for mortars.

-Sand

A better term for sand in this context should be 'aggregate'. This is the mixture of different sized stones that could form the body of mortars. Ideally the stone should be graded so that the smaller sizes of stone fit exactly into the spaces between larger ones and no gaps or holes are left in the mass of mortar.

Sand itself is a mass of finely crushed rock. It is either crushed naturally as seen on the sea shore, in river beds or in deserts; or it is artificially produced in crusher plants near rock quarries, where rock is dug out of the earth.

Sand is classified according to the shape of its particles (which differs depending on where the sand came from originally). It is also graded according to the size of its grains. This is commonly done by sieve-analysis.

-Gravel

Gravel is the term commonly used for the larger sized stones of the aggregate, a mixture of sand and stones of all sizes which can sometimes be found all together in a natural deposit. The individual particles are rounded by the natural action of water and weather.

-Broken stones

These are the largest stones of the aggregate. They are found either in natural deposits or scattered on the ground surface; or they are artificially produced in crusher plants. The rural builder often must break up large stones with hammers, to make them a convenient size. For mortar the stones may not be larger than 5 mm.

Good mortar can never be made with poor materials. The sand and stones must all be of good quality and the correct type. Particle sizes, the shape and texture of the particles and their surfaces are all important factors in the strength and durability of the mortar.

-Grading

A graded aggregate is one that is made up of stones and particles of different sizes, ranging from large to very small. It sometimes happens that the size of particles differs from load to load. Depending of the required mortar, mixing of the two sands in different proportion may give a suitable aggregate. If the sand contains too many bigger particles it may be necessary to sift these out before using it to make mortar.

For making mortar or concrete, the rural builder has two types of aggregate; the fine one which is sand; and the coarse one which is broken stones. Both aggregates are classified according to their grain size and are each divided into two main groups;

Fine sand from 0-1 mm
Coarse sand from 1-5 mm

Fine broken stones from 5-25 mm
Coarse broken stones from 25-50 mm

[Ref; 10]

Only fine sand and coarse sand are suitable for mortars.

Another classification is made according to the shape and texture of the single particles. Some sands and stones have particles which are rounded, with relatively smooth surfaces. This sort of aggregate is found mainly in river beds, along shores of lakes and coasts, and in deserts. This weather- and water-worn sand is called "river sand" or, because of its properties and workability, "soft sand".

The other type of sand has fairly rough surfaces and is found mainly in deposits close to hills and mountains. Artificially made sand made from crushed rock is also classified as this "pit sand' or "sharp sand".

An important factor in the quality of an aggregate is its cleanliness. Clay, mud, or fine dust (silt) will weaken the mortar, while organic impurities may interfere the setting and hardening of the mortar and decrease the final strength.

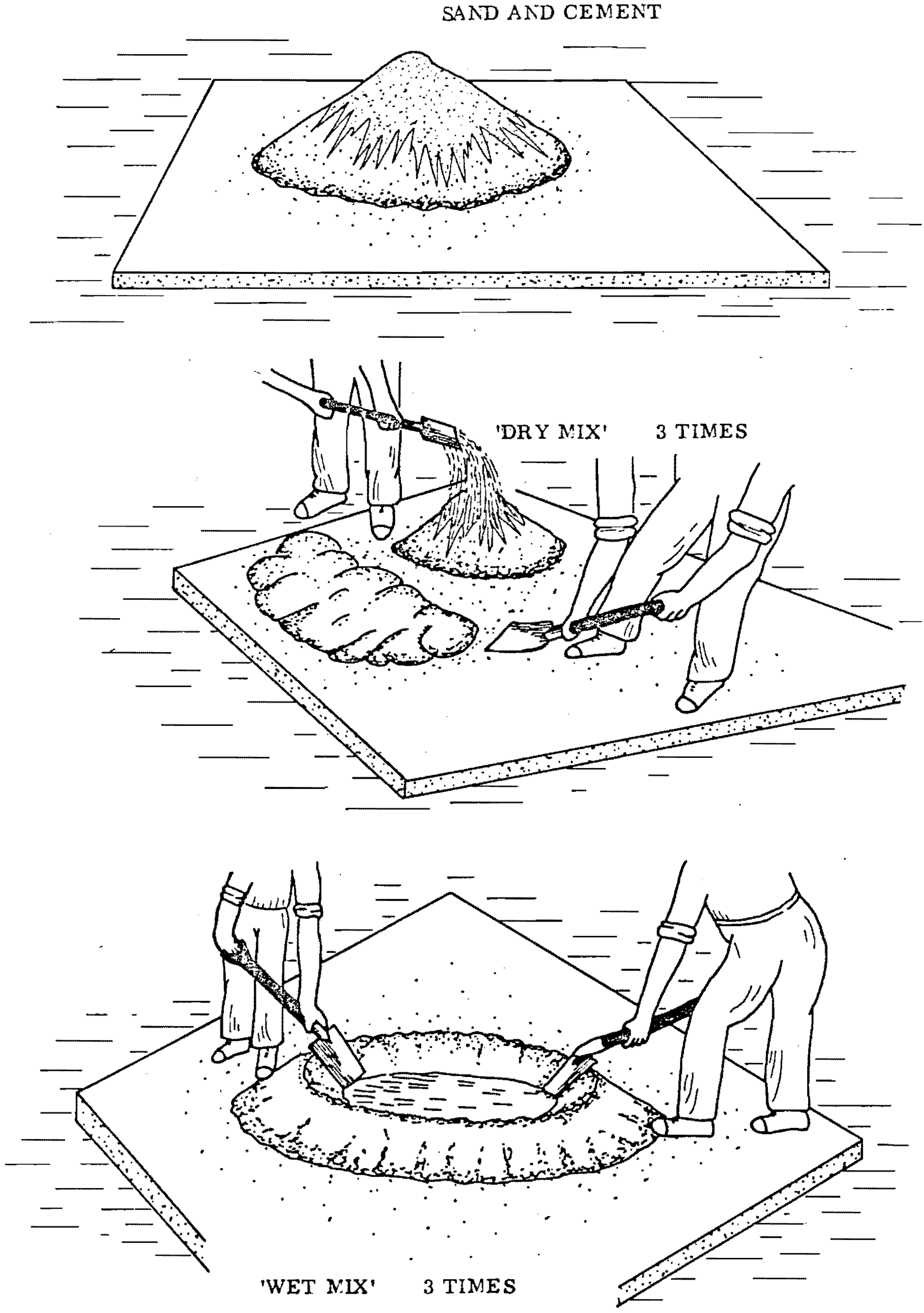
Simple tests can be carried out by a rural builder to check the quality of the sand like 'the hand test'; rubbing it between the hands and if the palms stay clean the sand is good, if not the sand may contain too much silt. Or 'the sink-test'; Put about 5 cm of sand loosely into a jar and pour some salt water on up to 2.5 cm above the sand. Close the jar, shake it firmly and leave it for 3 hours. The layer of silt on the top of the sand may not be more than 6% of the amount of sand. [Ref; 10]

Better sand can be found by removing the top layer, about 50 cm deep. The sand used for mortar should be well graded, sharp and not too fine if a strong mortar is needed. Of course this is dependent on the kind of mortar and recipe used. The more fine particles the sand contains the better the workability of the mix.

4.5 Conditions and technique of preparing and mixing the mortar

In rural areas the mortar is commonly mixed on the ground outside at a mixing platform of 1.5 by 2 m. The platform is first cleaned by sweeping for instance. Batching of the ingredients is mostly done by wooden boxes with the appropriate sizes; 'batching by volume'.

If the mortar contains sand and binder these are batched on one end of the mixing platform. Two men are facing each other across the pile, work their shovels together, turn the whole heap over once to form a pile at the other end of the platform. This turning is done twice and results in a 'dry mix'. The correct method for turning over is to slide the shovel along the top of the platform, pick up



Mixing the mortar

Source; Rural building reference book, Stichting Kongregatie, F.I.C., Maastricht.

a load and spill the load over the top of the new pile. The main point is that each shovelful runs evenly down the sides of the cone. All other motions should be eliminated. The dry mix is considered to be well mixed, when it has a uniform colour throughout.

The heap of dry mix is formed into a crater or pool, with sides drawn out towards the edges of the mixing platform. There should be no mixture left in the centre of the pool. Three quarters of the required water is poured onto the crater and with the shovels some of the dry mix is pushed into the pool. The water may not escape by breaking through the ring. When all of the dry mix has been heaped up in the centre of the platform, it should have taken up all the free water and have a rather stiff consistency (earth moist).In a second pool the remaining water is added and the procedure is repeated. To make sure the mixing is thoroughly done, the mortar is turned over a third time. The mixture will be covered to prevent it from drying out. [Ref; 10]

A simple test can be carried out to get a rough idea whether the consistency of the mortar is correct. A pan or basin is filled with mortar and the surface is smoothed. With the blade of a trowel a straight cut clear through the mortar to the bottom of the pan is made. The trowel is pushed flat under the mortar along the bottom of the pan, so that the cut in the mortar centres the length of the trowel.

When the trowel is lifted up 2 or 3 cm, the gap in the mortar must open into an oval shape along the outer edge but remain closed along the bottom. [Ref; 10]

4.6 Bricklaying and thickness of walls

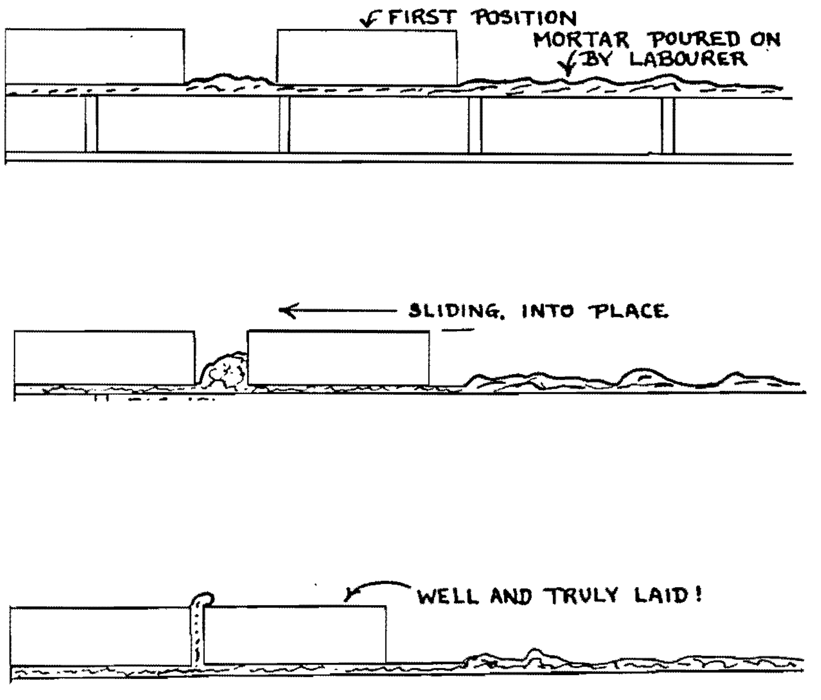
-Bricklaying

In laying bricks, it is customary to bed the bricks in mortar. The mortar serves several purposes (see 4.2). Using a mortar enables imperfections in laying to be rectified and allows each course to be in level. In general, the use of mortar when laying bricks or stones is recommended.

The thickness of the joint should depend upon the measure accuracy of the bricks and the smoothness of their surfaces. If these were perfect, a mere buttering would be enough.

Before using mortar, the dry bricks are laid from one corner to the other, leaving dry joints, and so is determined what the bond in the corners for the wall is to be.

In proper brick laying, a layer of mortar is first spread over the preceding course. This is generally done by pouring the mortar out of the a suitable can or if available by trowel. Then each brick is laid with both hands in place on the bed of mortar, and pushed up against the last one laid so that a header joint is gathered up and compressed between the two bricks. Before the mason's hands leave the brick it should be in position so that it will require no further adjustment. A common thickness of joints is 18 mm. [Ref; 8]

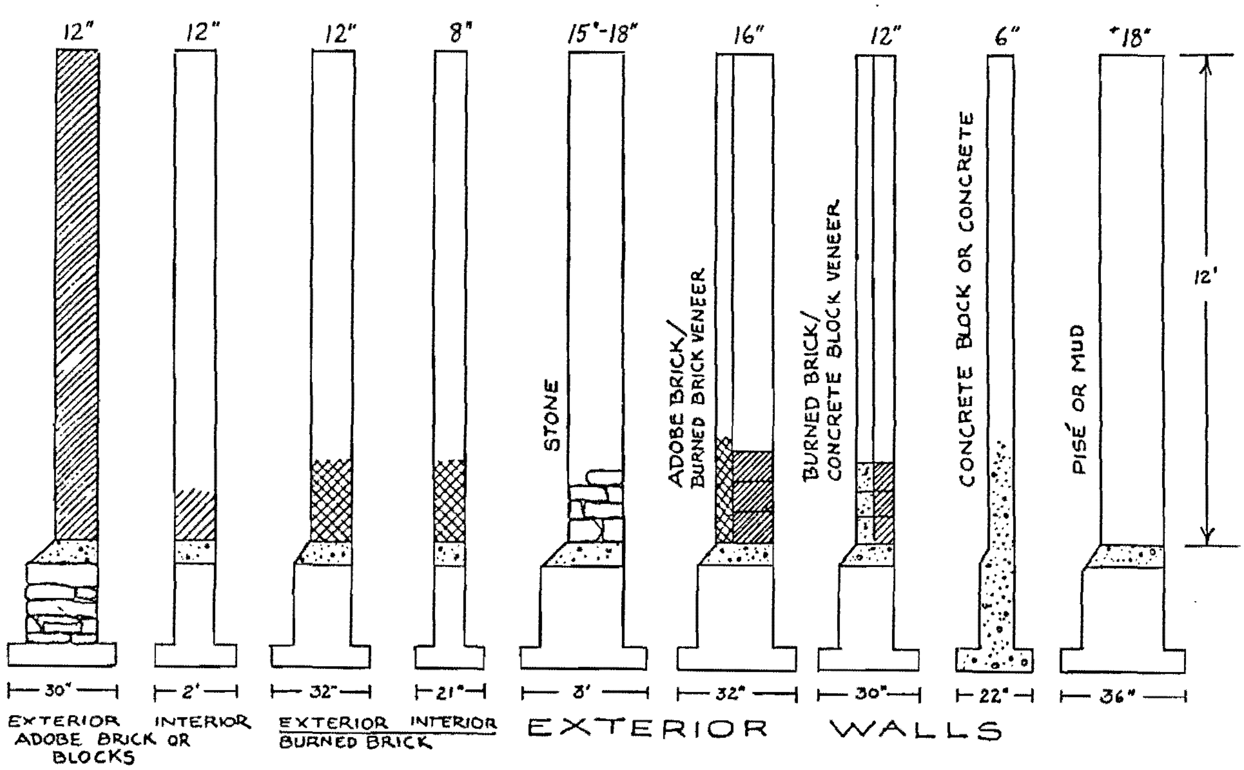


Brick laying
Source; A manual on building construction, Intermediate Technology Development Group, 1977.

A stretched line is used as an reference to the mason to keep the masonry work horizontal straight. A hanging line with a load on it should keep the wall vertical straight. All different kind of bonds are used in masonry in developing countries. The value and strength of masonry may be decreased by inferior bricks, inferior mortar, or by being laid by a bricklayer who does not understand his trade.

-Thickness of walls

The following designs are recommended for two storey building;



Measures in inches; 1" = 2.54 cm

Source; Construction reference manual, The kiteredde construction institute, Uganda, 1985.

4.7 Summary and conclusion

The objective of this report is a literature-study after alternative binders for application (in rural areas) in developing countries. With the content of this chapter a specification of the requirement for such a binder can be given and will be as follows;

* The alternative binder has to provide, when mixed with an aggregate and water, a mortar for application in masonry. The function of this mortar is spreading the vertical loads exerted in the wall, and compensate deficiencies in bricks and laying. The compressive strength of the mortar should be in the order of half the compressive strength of the units the wall is made of. The mortar should have a good workability, and should be compatible with the surfaces of the bricks or stones.

* The water used to make a mortar of this binder is to some extent filtered or cleaned. The aggregate added is graded and contains river or sharp sand with no more than 6% silt.

* The binder should be easily mixed into a mortar under the conditions given in this chapter; batching by volume, and mixed on a platform.

* A mortar made with this binder should be applicable for masonry either out of hammer dressed natural stones or burned bricks produced in a traditional oven. The joints should have an average thickness of 18 mm but may be thicker in masonry of natural stones. However they may not be thicker than 30 mm.

Beside the binder and mortars made with this binder have to be appropriate for developing countries with regard to the following aspects;

* availability and deposits of required raw materials
* sophistication of production technology
* required skill for production
* labour/capital intensity of production process
* investment costs of production unit
* required energy for production
* scale and
* physical behaviour (climates, drought, rainfall etc.)

5 ALTERNATIVE 'CEMENTS'

5.1 Introduction

In the following chapters the alternatives for Portland cement will be discussed, divided in six main-groups;

A) Lime
B) Natural pozzolanas
C) Burnt clay
D) Fly ash
E) Rice husk ash and
F) Gypsum

The structure of each chapter will be as follows;

The chapters begin with a general introduction and a description of the chemical composition and raw materials requirement of the alternatives, followed by the chemical reaction of the mortar. The properties of the alternatives in a mortar for application in masonry will be enlightened (hydraulic abilities, reaction time, and strength development). The common methods of production and their scale and fuel requirements will be described.

In the succeeding part of the chapters attention will be paid to the appropriateness for application in developing countries with regard to; availability of raw materials required, the production technologies, required labour/skill and capital/investment, fuel consumption and the physical behaviour (climates, drought, rainfall etc.). Further a comparison of 'the alternatives' versus Portland-cement will be made. At the end of the chapter conclusions will be drawn with on the background the out-lined situation given in Chapter 4.

6 LIME

6.1 Introduction

Before the development of today's cements, lime was used in many of the situations where cement is used now. The replacement of lime by Portland cement resulted in much more quick-setting mortars and plasters, and the consistency of the material gave the builder more confidence. Consequently wherever Portland cement has been available it has tended at first to replace lime altogether.

The significance of lime as alternative to Portland-cement in developing countries is that it can be manufactured by very simple processes suitable for village-scale technology. Lime is made by age-old technologically unsophisticated processes in most countries where limestones are available, in lime kilns of an enormous variety of shape and sizes.

6.2 Description and chemical composition of limestone

Limestone is a sedimentary rock composed mainly of calcium and magnesium carbonate. The most commonly source is formed by the deposition of the shells of marine organisms in seas or lake beds. Subsequently heat and pressure convert the deposits into rocks, limestones, dolomites or chalks, often in beds of several metres thickness. The thick-bedded limestones are very suitable for lime production. Thin-bedded limestones are also used, but are more likely to contain impurities.

In some parts of the world where sea shells are found in great abundance, these are used for lime burning. Coral is another very pure form of calcium carbonate which can be used.

Where neither rock limestone nor other forms of high-grade calcium carbonate are found, a form of limestone is sometimes found in nodules which have formed in the soil by solution and subsequent deposition of small quantities of carbonates in the soil. Such secondary limestones are often very impure, but the impurities can make them hydraulic, and consequently increase their suitability for use in building. Lime can also be made as a by-product of either sugar or acetylene manufacture.

-Chemical composition

Limestone is made up of varying proportions of the following chemicals with calcium and magnesium carbonate being the two major components:

Calcium carbonate	$CaCO_3$
Magnesium carbonate	$MgCO_3$
Silica	SiO_2
Alumina	Al_2O_3
Iron oxide	Fe_2O_3
Sulphate	SO_3
Phosphate	P_2O_5

The two main impurities are silica and alumina with iron as the third. The colour of most limestones is varying shades of grey and tan. The greyness is caused by the presence of carbonaceous impurities and the tan by the presence of iron.

We can classify limestone is different groups;
High calcium limestone is composed primarily of the minerals calcite or Aragonite ($CaCO_3$) with a total oxide ($CaO + MgO$) content of over 95%. It can be a fine to a coarse grained stone of varying porosity and hardness.
Chalk is a soft, fine grained, highly porous limestone. The pure, white chalks can have up to 99% calcium carbonate whereas the grey variety can have up to 20% impurities and only 80% $CaCO_3$.
Dolomitic and magnesium limestones in addition to the $CaCO_3$, contain a relatively large proportion of $MgCO_3$. Usually limestones containing 20% to 44% $MgCO_3$ are referred to as "dolomite" or as dolomitic limestone, and those containing between 5-20% $MgCO_3$, as magnesian limestone.

[Ref; 14]

6.3 Chemical reactions

Lime is normally produced by burning or calcining some form of limestone. The chemical reaction in the production of lime is as follows;

Calcination

A. High calcium limestones;
$CaCO_3$ + heat --> $CaO + CO_2$

B. Magnesian limestones;
$CaMg(CO_3)_2$ + heat --> $CaCO_3 + MgO + CO_2$
(at around 750°)
$CaCO_3$ + heat --> $CaO + CO_2$
(at around 1100°C)

Hydration
$CaO + H_2O$ --> $Ca(OH)_2$ + heat
(water)
$MgO + H_2O$ --> $Mg(OH)_2$ + heat
(water)

Simply stated, limestone plus heat produces quicklime and quicklime plus water produces lime hydrate.

The quality of lime-mortars depends on;
- the raw material used
- the control of the lime-burning process
- the composing components; lime, sand and water
- application and
- after-treatment

We can not determine a right mixture-recipe without information of the local used lime-stone, neither compressive strength can be predicted. A way of achieving the strength necessary for lime mortars is by addition of certain materials known as pozzolanas (see next chapter).

Some indications for mixture-recipes for lime and sand given in literature are;

250 a 300 kg lime (hydraulique lourde) and 1 m^3 sand.
Expected compressive strength ca. 4 N/mm^2 after 28 days.
or
1 part lime on 4 parts of sand.
Expected compressive strength ca. 1 a 2 N/mm^2.

[Ref; 11]

A higher share of lime in the mortar will lead to an increase in shrinkage during the hardening process.

In order to find the right mixture-recipe the characteristics of the raw material should be determined experimental.

The silica and alumina impurities react chemical with the water added to the mortar. The hydraulic abilities are determined by;

- The share of silica and/or alumina-compounds in the mortar.
- The structure of these compounds. An amorphous structure has more strength than crystalline structures.
- The fineness of the grains in the mortar. A fine grain gives more surface per weight.

As mentioned before, the hydraulic or binding abilities can be improved by adding, pozzolanas, trass etc.
The binding abilities of the lime can be examined by a relatively simple 'needle-test' of Vicat;

- Blend a dough by adding 32% water to the weight of the lime.
- Put this in a tray of glass or synthetic material, and press the dough firmly into the tray.
- Put the sample immediately under water of 17°C - 20°C.
- After 72 hours the sample should be charged with a needle (surface of 1 mm^2) and 300 grams of load.
- After removing the needle no visible print may be seen on the surface of the mortar.

[Ref; 11]

6.4 Methods of production

In a lime kiln, limestone is heated to a temperature at which dissociation will take place, and maintained at that temperature until all, or as much as possible, of the stone has been converted into quicklime. The quicklime is then cooled and discharged.
Control of the kiln process is very important, since if the lime is either underburnt of overburnt it is useless. Underburnt material, usually the core of the stone, cannot be converted to hydrated lime. Overburning leads to hard-burnt or dead-burnt lime; the stone shrinks and water cannot enter to complete the subsequent hydration process. Either a too high temperature or a too long retention time can lead to overburning.

There are a very large number of different kilns designs available, which differ considerably according to the type and size of stone burnt, the type of fuel used, the quality of the lime produced, the scale of production, the level of technology, the capital cost and the efficiency in terms of consumption.

Lime kilns can be classified according to the following types;

1) Batch or intermittent kilns
2) Vertical shaft kilns
3) Rotary kilns
4) Other kilns

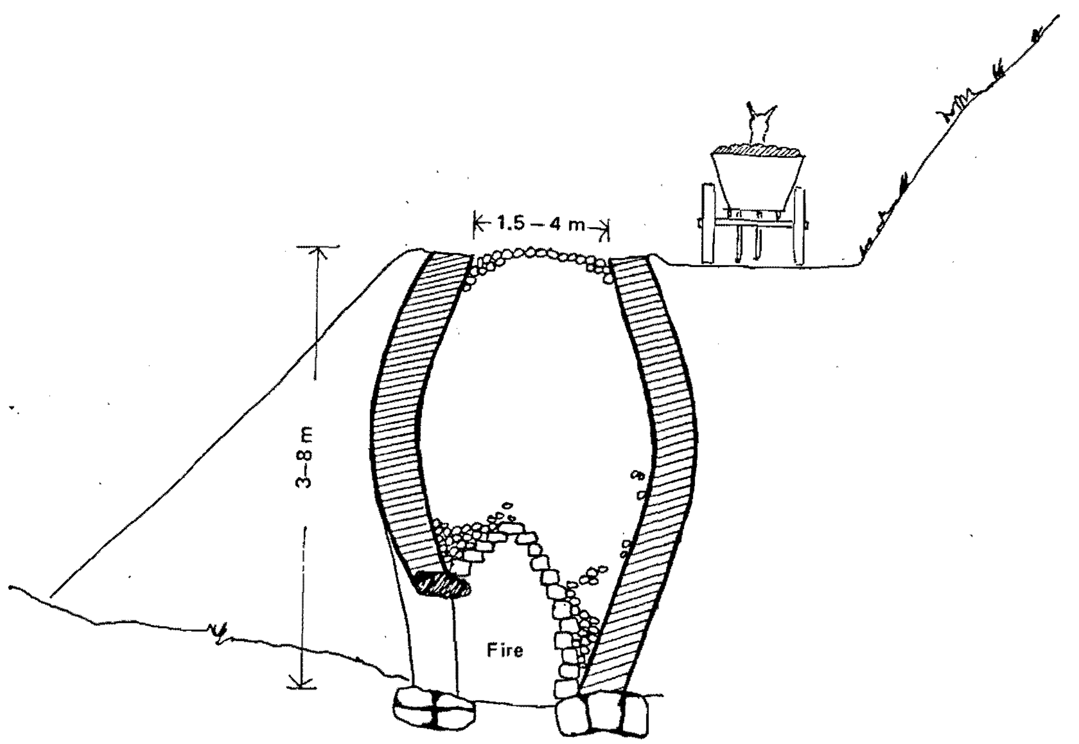
The first three types will be briefly described.

1) Batch or intermittent kilns

These are kilns in which one volume of stone is fired at a time and placed in an empty kiln. The stone is placed manually within the kiln, and a fire is created by burning fuel below and within the stone, until it is judged that all the stone has been converted to quicklime. The quicklime is then allowed to cool and is removed. Sometimes no permanent kiln at all is used and the stone and fuel are piled up in the open. The great advantage is that the kiln has extremely low or negligible capital costs and production can be intermittent or seasonal according to demand and labour availability. However the production is very wasteful of fuel, since none of the heat used to raise the stone to dissociation temperatures is recovered, and other heat losses are often considerable; and although a gradation of stone sizes is often used in order to attempt to achieve uniform burning, a high proportion of both underburnt and overburnt material is usually produced leading to a poor quality of lime.

We can distinguish two types of the batch oven; with or without grate. The type without grate is the most simple in both construction and operation. Disadvantage is the way of heating. The limestone is mixed with the fuel and this causes impurities in the lime. An other disadvantage is the produce of melt of the ashes of the fuel with the lime, which causes a tough solid mass and restrain a complete conversion.

The type with a grate has the disadvantage of pieces of limestone falling through the grate. To avoid this, bigger pieces of limestone should be used, which means on the same time a longer firing-time and subsequently more fuel-consumption. In order to achieve a good converting of the limestone into quicklime, a temperature of 500 a 600°C and good ventilation is required. The ventilation should lead the CO_2 gasses away. To improve the ventilation a longer chimney can be built, bigger pieces of limestone can be used (more space for air-transport) and air can be blown into the oven. The latter option needs a ventilator and leads to cooling of the oven and subsequently to a longer firing-time.



Honduran Type of batch kiln
Source; Small scale production of lime for building, Deutsches Zentrum fur Entwicklungstechnologien, Wiesbaden 1985.

The right way of heating the oven (time, fuel-use etc.) should be determined by experimenting (trial and error). In general can be stated; the right temperature in the kiln is reached after 24 hours, after which this should be maintained for two days more.
[Ref; 13]

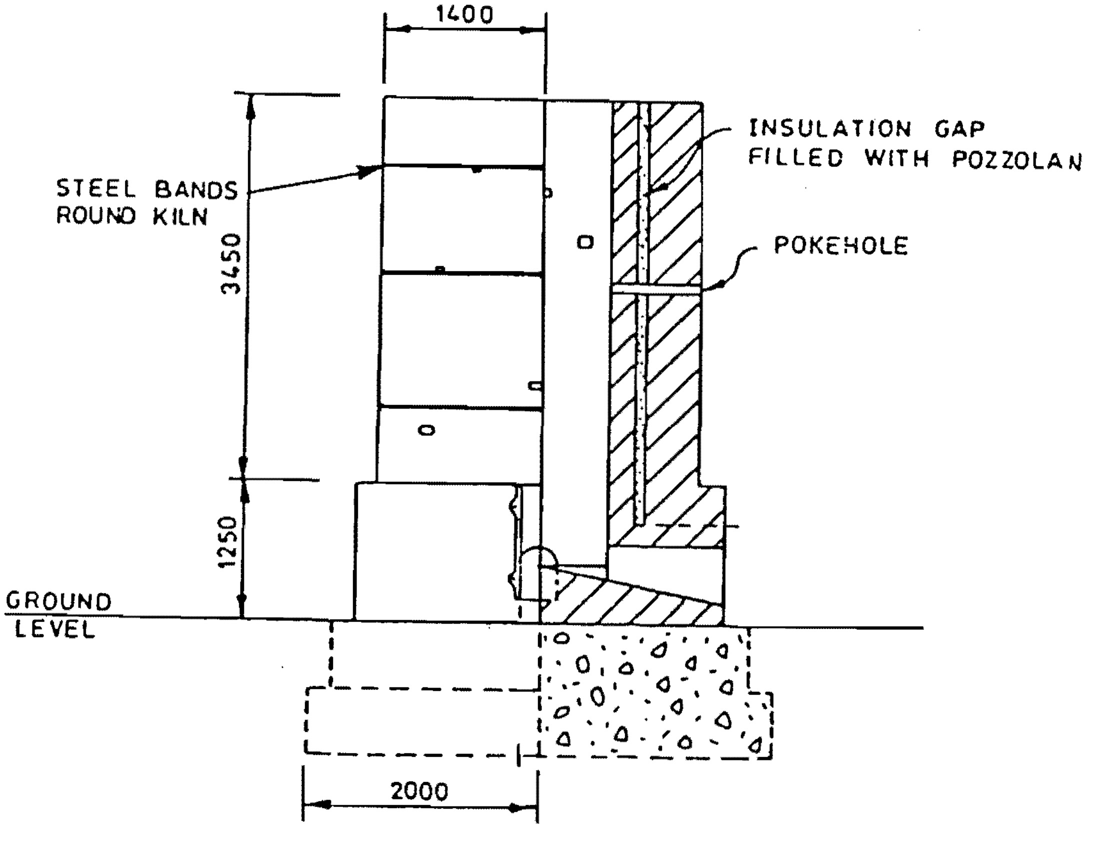
2) Vertical shaft kilns

Vertical shaft kilns are kilns in which the stone falls under gravity through a vertical shaft, in which it is heated up, burnt and cooled, and from which it emerges as quicklime. The crucial feature of such kilns is the counterflow principle; stone enters from the top of the kiln and flows downwards, air enters from the bottom of the kiln and flows upwards, and exhaust gases emerge from the top. By this means heat exchange occurs at two levels. The stone in the top of the kiln gains heat from the cooling exhaust gases and is therefore preheated before entering the hottest part of the kiln; the air entering the bottom of the kiln gains heat from the cooling stone, and is therefore also preheated before entering the hottest part of the kiln. This heat exchange serves to improve the thermal efficiency of the kiln, since most of the heat used to raise the temperature of the stone and the air can be reconverted.

A vertical shaft kiln can be considered to be divided into four different zones, known as the storage, preheating, calcining or burning and cooling zones. In practice, the boundaries of these zones are not distinct.

The storage zone serves primarily to ensure continuous operation even if the stone supply is irregular, and generally holds about two hours or more supply of stone. Some vertical kilns are open at the top, but this can make draught control difficult and expose the stone to rain, so most shaft kilns are covered, and provided with special doors for charging stone and with chimneys or flues to release the exhaust gases, or at least with a metal sheet roof. In the calcining zone the stone is maintained at the required temperature for dissociation. Methods of firing include mixed feed, in which the fuel is intimately mixed with the stone as it passes down the kiln, direct firing using fuel or oil, or indirect firing using gas or oil burners or gas producers.

At the bottom will be the discharge doors or openings through which the lime is removed either manually or by means of some automatic discharge device to a conveyer.



Indian small-scale vertical shaft kiln

Source; Lime in industrial development, a UNIDO guide to its uses and manufacture in developing countries, Sectoral Studies Series No. 18, 1985.

3) Rotary kilns

A rotary kiln is a long tube of large diameter lying nearly horizontal but with a slight incline and rotating slowly. The stone is charged at the upper end of the kiln and passes slowly down and along the kiln, being tumbled by the rotating action. The fuel, oil, gas or pulverized coal, is burned at the bottom of the kiln and the hot gases pass up the kiln making contact with the stone as they pass, and are then discharged to a chimney. Most of the kiln volume is filled with the hot gases, so heat exchange is be closely controlled, and can burn smaller sizes of stone; they are commonly used in the United States where fuel has been relatively cheap and a large productivity per worker is needed, but some very large capacity kilns are in use in other countries. [Ref; 12]

Hydration

The hydration (reaction with water) of quicklime produces an enormous heat. Precautionary measures are required. The simplest way of hydration is to dig a pit and to fill this pit for 3/4 up with quicklime. Sprinkle the quicklime with water. The water added should be carefully dosed (not too much at once). If it is done properly, the quicklime is bursting and breaking down into powder while steam is emitting. If the contents of the pit is well heated, more water can be added. The lime is then sieved through a fine screen to remove coarse material which is either unburned or unhydrated. Inevitably some finer pieces of unburned material will pass the screen, and lime made this way is not subsequently the best material for mortars and plasters unless it is subsequently ground in a mortar mill. By adding more water a thick putty is acquired which can be immediately applied for construction-purposes. [Ref; 13]

The water used in hydration may be drinkable or even brackish borehole water but water containing a large proportion of organic material can have a bad effect on the lime hydrate. The water required to slake quicklime to;
- a dry lime hydrate is around 550 litres per tonne quicklime,
- a lime putty around 1300 litres per tonne quicklime depending on the consistency preferred.

The exact quantities required will vary from one quicklime to another and can best be determined by trial and error. In general however, highly reactive porous type quicklime requires a greater proportion of water than dense or overburnt quicklime.[Ref; 14]

Dry lime-hydrate can be packed in plastic or paper bags but not be stored for long, as the CO_2 in the air will react and makes the lime useless for its purposes. [Ref; 13]

Comparison of alternative lime kilns

Type	Capacity (ton/day)	Stone size (mm)	Type of fuel	Fuel consumption	Control	Capital cost	Source of information
Batch[a]	1-3	50-100	Wood	2,250+	Low	Very low	Wingate (1985)
Continuous							
Shaft kilns							
KVIC mixed feed[a]	4-10	100-125	Coal	1,350	Medium	Very low	Spiropoulos (1985)
European MF	100-300	90-200	Coke	900-1,000	Medium/low	Medium	Boynton (1980)
Ring kiln	100-350	25-125	Oil or gas	1,040-1,140	High	High	Boynton (1980)
Double inclined	100-150	7-25	Varied	1,050-1,120	High	High	Boynton (1980)
Parallel-flow	100-600	25-150	Nat gas	880-920	High	High	Boynton (1980)
Rotary							
Simple	100-400	10-55	Varied	2,200-3,400	High	High	Boynton (1980)
Advanced	400-1,000	15-50	Varied	1,300-1,550	High	Very high	Boynton (1980)
Miscellaneous							
Fluosolids	100-125	0.2-0.5	Oil or gas	1,390 approx.	High	High	Boynton (1980)
Calcimatic	100-500	6-100	Oil or gas	1,570-2,100	High	High	Boynton (1980)

a/ The term small-scale kiln used in this report refers to kilns with capacities less than 20 tons/day.

Source; Lime in industrial development, a UNIDO guide to its uses and manufacture in developing countries, Sectoral Studies Series No. 18, 1985.

6.5 Fuel-consumption

The type of kiln used depends greatly on the fuel available. In many ways the ideal fuel for lime-burning is firewood, because the length and low temperature of the flame make for much more even burning of the stone than with other fuels. In parts of the world where firewood is cheap and abundant (the tropical forest areas) this may still be the best fuel. Of course environmental issues should be taken into account as there is deforesting, erosion etc. In most areas firewood is an increasingly scarce resource and alternative fuels must be found. Charcoal is not generally a good fuel. Where they are available coke or coal can be used; and they can be used in continuous mixed-feed kilns leading to improved fuel economy. Large kilns are usually fired by oil or gas. These fuels can also be used for small batch-operated kilns, and very low-grade oil can be used. But the cheaper, more primitive oil burners create a very hot concentrated flame which makes even burning difficult and a poor quality lime can result.

6.6 Appropriateness for application in developing countries

6.6.1 Raw materials

There are few countries or areas in the world where some form of calcium or magnesium carbonate suitable for lime production is not available. Limestone occurrences of any size are usually noted and mapped by geological surveys because of the mineral's importance as a raw material. But localised outcrops or occurrences of very little economic significance, and too small to be marked on maps, may nevertheless yield sufficient quantity of material to supply a village-scale industry for many years.

6.6.2 Production technology

Batch kilns are by far the most common types of small kiln in use in developing countries today. They are cheaper to build and easier to control; and they fit well with the patterns of intermittent production and demand which is commonly associated with rural industries.

The technology of lime production can be matched to the technological level of the region. For poor countries with a low technological infrastructure, simple kilns, like the batch kiln, and processing equipment can be used, which can be fabricated with only local available materials. Dependence on imported equipment or skills can be minimized.

6.6.3 Required labour/skill

At a simple level, lime production is labour-intensive and generates employment. Few trained or qualified people are required, and the skills required are learnt on the job. Employment in the production of lime teaches skills which can be applied to other, more sophisticated, industrial processes.

6.6.4 Required capital/investment

Lime production can be carried out efficiently and profitably at a small scale. The capital cost of establishing a lime production plant is low, permitting a high return on investment and rapid payback period.

6.6.5 Fuel consumption

As mentioned before, the best fuel for lime burning is firewood.
In developing countries even the use of coconut-shells, peat etc. can be considered as a proper fuel. Every fuel with a passable open structure and passable flammability suits for lime-burning.
Fine more tight structured fuels may lead to suffocation of the fire, as more fuel is needed. Prevention of this suffocation can be found in the use of brick of these fuels formed by pressing, so they will not fall easily to pieces in the fire.
Nevertheless is the fuel-consumption of low sophisticated lime-burning processes often highly inefficient.

6.6.6 Physical behaviour

For application in masonry-works you should be aware of the absorption of water out of the mortar by dry bricks or surfaces. For application in developing countries attention should be paid to the after-treatment and protection against a strong drying by wind and sun-shine. Wetting of the bricks on forehand is very important especially in tropical areas. After-treatment like covering by (palm)leaves, hay or branches of a tree during the drying process, may improve the quality of the masonry work remarkably.

6.7 Comparison of lime-mortar with Portland-cement

-Qualities

Lime is used in buildings in one of two forms, either as dry slaked lime powder or as putty. The choice of whether to use one or the other form depends on the preference of the builders, the availability of water at the production site and the available means of transport. There is little difference in terms of quality between the two.

The properties which make lime an excellent cementitious building material are the shape and fineness of the particles, which provide the plasticity necessary for good workable mortar, and its chemical properties which are the mechanical, strength giving characteristics. Lime mortar are more elastic than Portland-cement mortars are.

Lime especially in combination with pozzolanas (see Chapter 7) can be used as an alternative to Portland cement. This type of binder can be used successfully for most purposes other than structural concrete work.

-Disadvantages

The process of binding and hardening of lime-mortar is not as fast as mortars based on Portland-cement. Also the achieved compressive-strength of lime mortar is lower as of Portland cement mortars.
The attach of lime-mortars to baked and natural bricks and stones is less than the attach of Portland-cement.
The shrinkage of lime-mortars is higher than for Portland cement.

We may not forget that quality of bricks used in developed countries is not the same as bricks used in industrialized countries. Mortars made with Portland cement tend to be often much stronger than the country burnt bricks that they bond. This is extremely undesirable as it can be the cause of cracking in the masonry.

6.8 Conclusions

Lime can be seen as a good alternative for Portland cement in mortars for masonry. Some rudimentary knowledge both of the production and uses of lime usually exists, and can be built upon. Raw materials of sufficient quantity and quality for starting lime production are very wide-spread; there are numerous suitable deposits or reserves in almost every country.

A compressive strength of lime-sand mortars of 4 N/mm^2 can be achieved.

Disadvantages are the slow setting time and higher shrinkage compared to Portland cement, but both can be improved by the addition of pozzolanas (see Chapter 7). For application and production in (rural areas of) developing countries, lime can be considered as an appropriate alternative. The technology of lime production can be matched to the technological level of the region. The batch kiln can be used for production on village level. A weak point is the inefficient use of fuel in batch kilns.

Availability of lime can make a big contribution to the improvement of housing standards. Besides lime can be used in soil stabilization in road construction and for agricultural purposes as it neutralizes the acidity of the soil and can promote effective use of added fertilizers.

7 POZZOLANA

7.1 Introduction

The volcanic tuff found by the Romans near the town Pozzuoli, near Naples, became known as 'pozzolana'. Pozzolana is now used as a generic term to describe all materials which exhibit reactivity with lime and set, harden and develop strength in the presence of water. A wide variety of siliceous or aluminous materials may be pozzolanic. In practice, they are used either in combination with lime itself or with Portland cement. In the context of this report, the reaction with lime is interesting since both materials are amenable to production on a "village industry" basis.

Some pozzolanas occur naturally, others are artificial or semi-artificial, for example burnt clays, shales, fly ash and rice husk ash. Natural pozzolanas include trass, tuff ash and sand of volcanic eruptions and some specific earths.

The artificial pozzolanas: Burnt Clays, Fly ash and Rice-husk-ash will be amply described in succeeding chapters. This chapter is restricted to the natural pozzolanas.

7.2 Description and chemical composition of natural pozzolanas

It is hard to give an exact definition of natural pozzolanas, because pozzolana is a generic term, to describe a common behaviour of materials when mixed with water and lime. The materials can be extremely different of structure, and slightly different of chemical and mineralogical composition and geological origin.

Pozzolana is usually defined as;

"A silicious or aluminous material which in itself possesses no cementitious properties, but which in finely divided form and in the presence of moisture reacts with lime at ordinary temperature to form compounds possessing cementitious properties."

(G. Malquori)
[Ref; 16]

Natural pozzolanas may further be divided into two main groups;

* There are those derived from volcanic rocks in which the amorphous constituent is glass produced by fusion. These are, for example, volcanic ashes, and tuffs. They are amorphous with no defined structure and are usually chemically reactive. Natural weathering processes can convert volcanic glass to crystalline forms which are generally less reactive.

* The others are derived from rock or earth for which the silica constituent contains opal. Examples of these are earths containing substantial amounts of glassy components and clay which has been naturally calcined by heat from a flowing lava.

[Ref; 17]

In the case of volcanic glasses, reactivity derives from the high energy state of the liquid structure of the material frozen in by rapid cooling. It follows that the more rapid the cooling, the more reactive the pozzolana is likely to be. Reactivity it therefore linked to the way in which the volcanic material is formed. Reactivity will be diminished by conversion of the amorphous structure to a more stable crystalline state. This tends to occur as a natural weathering process with time and exposure to the elements. Reactivity can therefor be linked to age and environment.

In the case of clays, reactivity may be related to the type of mineral and the proportion of clay - the clay fraction - in the material. In general, the reactivity of clay as it occurs naturally is relatively low when compared to the volcanic glasses.

For a professional geologist, it may be possible to tour an area of interest and, with the benefit of the naked eye, identify potentially pozzolanic materials belonging to the above two categories. However, the most useful starting point to find pozzolanic deposits is the geological map. The common terms associated with volcanic materials are given below;

Basalt	Very heavy volcanic substance
Pyroclastic	Term for materials thrown into the air by a volcanic eruption
Ash	Small fragments from 0.06 to 4 mm. May be a mixture of amorphous glassy material and crystalline minerals
Tuff	Consolidated ash formed by thrown out volcanic material
Trass	Grounded tuff-rock
Pumice	Glassy honeycomb rock of low density, which can float on water, formed by liquid lava and usually particulate in form
Ignimbrite	A welded tuff

[Ref; 18]

Pozzolanic tuffs are found in many countries and as such are probably the most widely available natural pozzolanas.

-Chemical composition

As stated before, the chemical composition of pozzolanas differs from one type to another. In general they contain the following chemical components;

Silica	SiO_2
Alumina	Al_2O_2
Ferro Oxide	Fe_2O_3
Lime	CaO
Magnesia	MgO
Alkalies	Na_2O and K_2O

		Chemical composition (%)								
Pozzolana type	Location	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	L.o.I
Incoherent pyroclastic	Bacoli (Naples, Italy)	53.8	18.20	4.29	9.05	1.23	3.08	7.61	0.65	3.05
	Segni (Roman)	45.47	19.59	9.91	9.27	4.52	0.85	6.35	0.16	4.03
	Salone (Roman)	43.26	15.98	9.40	7.92	3.98	0.77	5.96	0.10	9.77
	Casteggio (Italy)	45.83	8.95	3.61	14.85	3.08	0.51	1.82	1.40	19.14*
	Vizzini (Italy)	49.01	16.28	11.25	4.72	5.09	0.84	0.17	0.15	12.30
	Santorin (Greece)	63.80	13.00	5.70	4.00	2.00	3.80	2.50	—	4.8
	Auvergne (France)	46.60	17.60	11.80	9.84	5.58	3.14	1.76	0.02	0.24
	California (USA)	70.76	12.85	1.38	1.08	0.43	—	—	—	n/s
Coherent pyroclastics	Yellow tuff (Italy)	54.68	17.70	3.82	3.66	0.95	3.43	6.38	—	9.11
	Rhenish trass (Germany)	52.12	18.29	5.81	4.94	1.20	1.48	5.06	—	11.10
	Trass (Indonesia)	60.02	17.76	6.80	4.49	0.96	3.88	2.62	—	2.62
Materials of mixed origin	Sacrofano (Italy)	89.22	3.05	0.77	2.28	—	—	—	—	4.67
Materials of organic origin	Washington State (USA)	85.97	2.30	1.84	—	0.61	0.21	0.21	—	ns
Naturally burned clays	Porcellanite (Trinidad)	56.79	25.79	7.61	0.06	0.28	0.10	0.42	0.57	7.60

*of which CO_2 = 11.5%
n/s: not stated

Chemical composition of some natural pozzolanas

Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

7.3 Chemical reactions

It is interesting to note that the lime-pozzolana reaction is still by no means well understood. One proposal suggested that the lime-pozzolana reaction was due to the presence of zeolites in the pozzolanas. It was considered that the zeolites absorbed lime through a base exchange mechanism. Sestini and Santarelli [Ref; 16] have shown that the exchange activity of the pozzolanas they examined was very low and the explanation could not be used to explain considerable amounts of lime combined in their experiments. Others have shown that zeolites do not occur in many pozzolanas and that the lime-pozzolana reaction produces new compounds which could not be explained by the base exchange mechanism.

The reactivity of pozzolana with lime is influenced by inherent characteristics of the pozzolana, such as chemical and mineralogical composition, morphology, the amount of glassy phase and fineness. It is also influenced by external factors such as the thermal treatments.

All pozzolanas have a high SiO_2 + Al_2O_3 content and have a glassy or amorphous structure, with the exception of the zeolitic tuffs. Experiments have shown for Italian pozzolanas that the long-term strength can be related to the SiO_2 + Al_2O_3 content but initially (within seven days), reactivity with lime is more related to the specific fineness of the pozzolana.

There is general consensus in the literature that the products of the lime-pozzolana reaction are as follows;

* Calcium silicate hydrate of the form C-S-H
* Calcium aluminate hydrate of the form C_4AH_x with a varying x from 9 to 13.
* Hydrated gehlenite C_2ASH_8
* Calcium carboaluminate $C_3A.CaCO_3H_{12}$
* Ettringite $3CaO.Al_2O_3.3CaSO_2.32H_2O$
* Calcium aluminate monosulphate $C_3A.CaSO_4.12H_2O$

[Ref; 18]

However, the presence of these products in the hydrate product depends on the chemical constituents of the pozzolana, the availability of lime, the extent or age of the hydration reaction and conditions of ambience during hydration.

-Properties of lime-pozzolana mortars

As we have seen, pozzolanas react with lime, with the reaction products consisting essentially of calcium silicate and calcium hydrates. For lime-pozzolana mixes, the presence of the pozzolana imparts hydraulic properties to the mix; it decreases the setting time, increases the strength and considerably improves durability.

Specifications for lime-pozzolana mixes require the initial set and final set to be 2h (minimum) and 24h (maximum) respectively, when measured using the Vicat needle (see 6.3). Where the final set time is not achieved, it is likely that the reactivity of the pozzolana is weak and the specified strength requirements may not be attained. [Ref; 16]

Most researchers have reported a recipe for lime-pozzolana mortar between 1:2 and 1:3 (in volume-parts) in order to get an optimum in strength.
Results obtained by Costa and Massazza [Ref; 18] are as follows;

Pozzolana*	Lime: pozzolana ratio	W/C	Compressive strength (MPa) 7 days	28 days	90 days
	1:5.67		2.8	9.6	15.8
Bacoli	1:2.33	0.5	2.5	7.7	14.8
	1:1.22		1.8	6.4	10.9
	1:5.67		2.4	7.6	11.2
Salone	1:2.33	0.5	3.3	8.9	13.5
	1:1.22		3.2	7.9	11.7
	1:5.67		1.9	5.8	6.8
Casteggio	1:2.33	0.6	1.3	4.7	5.7
	1:1.22		0.6	3.2	4.2
	1:5.67		11.1	11.5	9.9
Sacrofano	1:2.33	0.8	9.8	13.7	13.8
	1:1.22		5.6	9.9	10.8
	1:5.67		4.7	5.6	7.1
Vizzini	1:2.33	0.8	2.8	6.8	10.5
	1:1.22		2.3	5.4	9.1

Effect of the lime-pozzolana ratio on compressive strength
Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

It can be seen that there is some indication that at early ages a higher ratio yields higher strength, but the ratio 1:2.33 at 90 days is the optimum.

Rehsi stated in 'Appropriate Technology'; " *Masonry mortar consisting of lime and pozzolana both with and without sand has been in use in various countries since time immemorial. The mix proportion of mortars of grades (28-day compressive strength) 0.5-0.7, 1.5-2.0 and 2.0-3.0 N/mm² are 1:1:2 lime-pozzolana-sand, 1:2 lime-pozzolana and 1:3 lime-pozzolana, by volume respectively.*"
[Ref; 13]

As we have seen in the results obtained by Costa and Massazza [ref; 18] a much higher compressive strength can be achieved.

According to J. Apers in Vraagbaak vol.8, the norms for trass require the following minimal compressive-strength:

4.5 N/mm^2 after 7 days and
14 N/mm^2 after 28 days

for a mortar of;

trass : lime : sand
1.0 : 0.8 : 1.5 (share in weight)

(to compare the values of Portland cement are; after 7 days 16 N/mm^2 and after 28 days 30 N/mm^2).

[Ref; 4]

7.4 Methods of production

The production of pozzolana is very simple. It is recommendable to extract the pozzolana under expert supervision, otherwise a considerable part may get lost. Old natural pozzolana deposits are covered with layers of humus. When quarrying it, care must be taken to ensure no humus is mixed with the pozzolana.

The pozzolana may not be sufficiently dry for further processing. Removal of the moisture in the pozzolana has conventionally been done in Europe and the USA by gas-fired rotary kilns. This is a high sophisticated technology which is not needed. For most climates the pozzolanas can be exposed to air to dry.

In most cases the pozzolana is granulated and will need to be ground to a suitable fineness. This can be done in simple hand-mills or other grounding techniques. Illustrative in this context is the Dutch trass-mill "de Admiraal", preserved in Amsterdam which was in use in earlier days to ground the trass by using wind-energy.

An other example which has been applied in developing countries is a bicycle frame driven pair of rollers carrying a pot about 30 cm in diameter and 50 cm long. The pot contains the minerals mixed with old ball bearings or small basalt pebbles. A reasonably successful technology but not economically sensible for large quantities of materials.

Usually the material is ground by using 'animal power'. In Malawi, a renovation was made using a corn mill to grind the pozzolana.

This pozzolana-powder is mixed in a specific proportion depending of the qualities of the pozzolana variety with lime. Together they form the binder, ready to be used for making mortars by adding water and eventual sand. Some varieties are so active in the presence of lime, that they are also used in their granulated form.

7.5 Fuel-consumption

There is no fuel required to process natural pozzolanas except for the grinding. The grinding can be done in a simple mortar mill or hand mill. As pozzolanas are commonly used in combination with lime, the fuel required to produce lime-pozzolana mortar is given in chapter 6.5.

7.6 Appropriateness for application in developing countries

7.6.1 Raw materials

Natural pozzolanas can be found in many parts over the world, including various developing countries with areas of past or present volcanic activity. Unfortunately these countries are not always exempt of disasters caused by eruptions of these volcanoes but this is left aside.

Especially in Central-America the pozzolanas of volcanic origin are abundant and easily to win.

Natural pozzolanas occur in ash-falls, as sediments, as altered rocks and in other ways and have been overlooked quite often in the past. Geological maps should help to locate the deposits and new geological research should aim to investigate the usefulness of the resources as a pozzolana.

7.6.2 Production technology

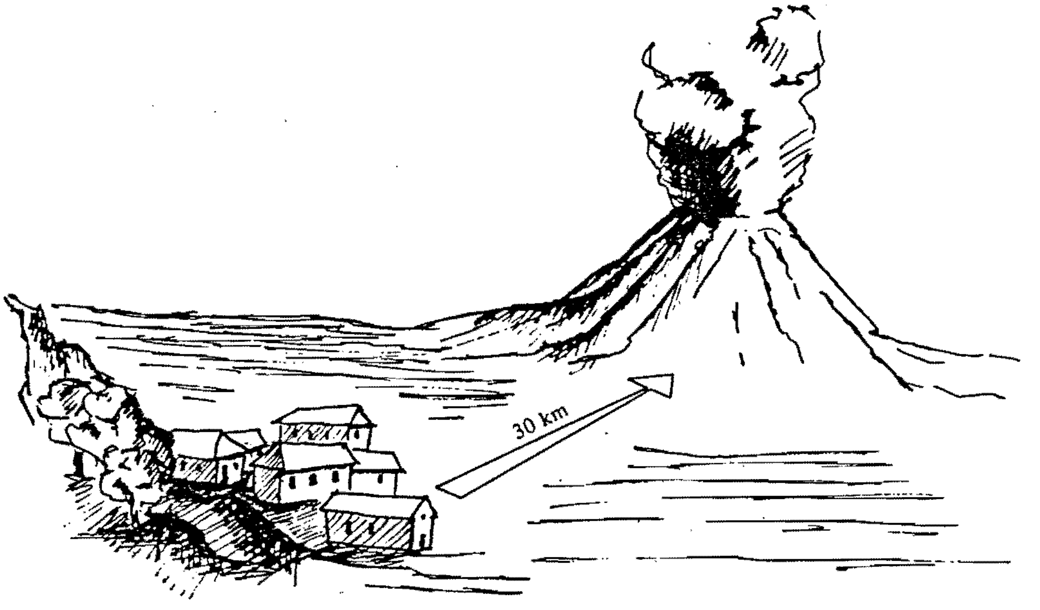
In most areas where the pozzolana occurs naturally, the material is won with pick-axes and shovels. The natural pozzolana does not need any further processing-technology. In some cases grinding is needed to get a suitable fineness. This can be done with relatively simple techniques on small-scale.

7.6.3 Required labour/skill

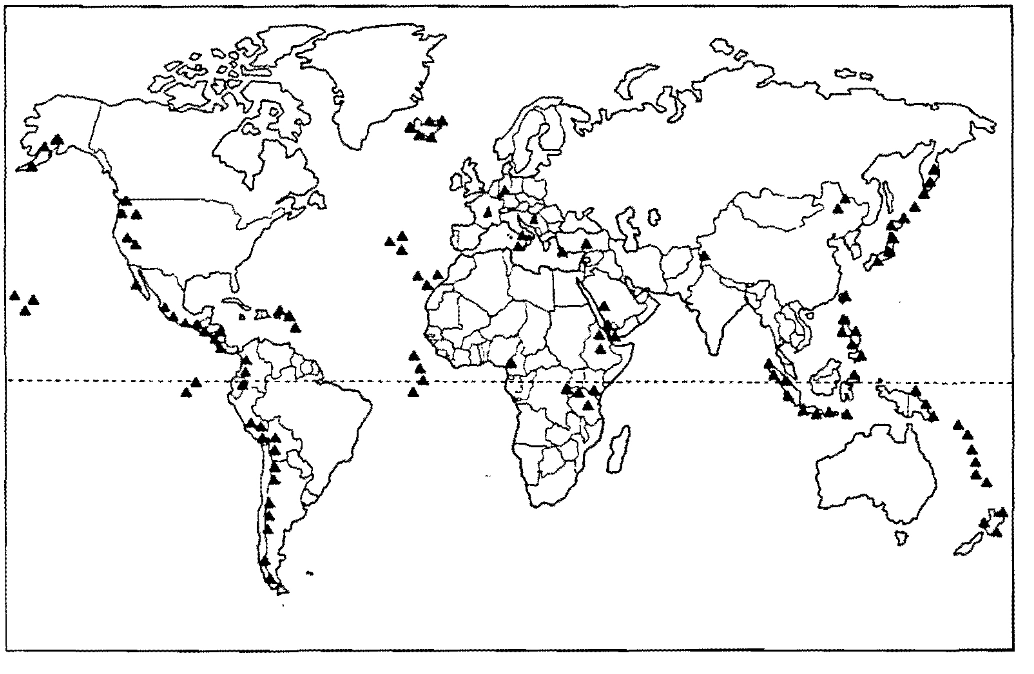
A few trained people are required for supervision of the extraction and proper grounding and batching of the pozzolana. The use and production of lime-pozzolana mortars is often based on a re-introduction of an old technology. Training in the proper use is often required. People lost their confidence in the quality of the binder, when Portland-cement has been introduced. In order to convince people of the properties and qualities of the binder, proper use can be learned by an on-the-job-training and regional field demonstration projects.

7.6.4 Required capital/investment

The investment-costs to set up a natural pozzolana production unit are very low. The major investment is a mill to grind the pozzolana into powder. As pozzolana is used in combination with lime, the same as is mentioned in chapter 6.6.4 applies for lime-pozzolana production units.



Natural pozzolana is often available in the vicinity of the place of construction.



Countries with extinct, dormant or active volcanoes.
Source; Building with Pumice, Deutsches Zentrum fur Entwicklungstechnologien, Wiesbaden, 1990.

7.6.5 Fuel consumption

No fuel is needed to process natural pozzolanas.

7.6.6 Physical behaviour

The addition of natural pozzolana to lime-mortars decreases the setting time, increases the strength and considerably improves durability. The pozzolanas contain silicious and aluminous constituents which improve the hydraulic ability of the mortar and as a result of this improve the strength. In chapter 6.6.6 attention is paid to the risk of drying by wind and sun-shine of lime-mortars. This risk is decreased by adding pozzolanas in the proper proportions.

7.7 Comparison of lime-pozzolana-mortar with Portland-cement

-Qualities

Compared to Portland cement, the lime-pozzolana binders in general impart greater plasticity, workability and ability to retain water in masonry mortars. Consequently, the extent of the bond between mortar and the masonry units is higher, and the masonry is more resistant to cracking, rain penetration and sulphate attack.

-Disadvantages

As stated before the process of binding and hardening of lime-mortar is not as fast as mortars based on Portland-cement, although this is improved by the addition of pozzolanas. Also the achieved compressive-strength of lime mortar is still lower as of Portland-cement mortars.

7.8 Conclusions

Lime-pozzolana mixes can be seen as competitive alternatives for Portland cement in mortars for masonry. Especially since the production of natural pozzolanas is often only a matter of quarrying and milling so the investment-costs are very low. Both materials are amenable to production on a "village industry" basis. The addition of pozzolana can notably improve the qualities of lime-mortars and lime-pozzolana-mortars can achieve a compressive strength of 4 or even 13 N/mm^2 after 28 days. The best results are obtained by lime-pozzolana ratio in between 1:2 and 1:3 (volume-parts).

The crux is the lack of (often lost) knowledge about proper use and research after the properties of the specific pozzolana. Two particular acts of official support could, however, give great encouragement to the pozzolana production. The first is that a number of promotion and demonstration projects could be established, to show the methods of quarrying and use, and prove its qualities. The second is that more research is done after potential deposits and the specific characteristics of the pozzolana.

8 BURNT CLAY

8.1 Introduction

Calcined soils, in the form of crushed pottery fragments, were the first artificial pozzolanas and have remained to this days as traditional materials in India and Egypt. Since ancient times it has been known that calcined clays can develop mechanical resistance if mixed with lime and water, that is they obtain binding properties similar to those of the natural pozzolanas. The durability of this type of cement can be seen in the many remains of Roman structures still present today.

Nowadays calcined clay face considerable competition from fly ash (see chapter 9), because fly ash (if available) is generally cheaper.

All clays are not equally capable of being transformed into artificial pozzolanas, nor are the best activation conditions always the same. The ability of each raw material to activate and the most favourable condition for activation must be determined.

8.2 Description and chemical composition of burnt clay

Clay and soils consist of small particles which are by definition less than 0.002 mm in size. Water molecules are attached to the surface of these particles. Clays are sedimentary deposits which consist principally of complex mixtures of characteristic minerals. They are usually denoted by the name of the mineral which is present in greatest proportion. The crystalline structure of clay minerals is fundamentally determined by the silicon, oxygen, aluminum or hydroxyl ions.

-Chemical composition

There are five main groups of clay minerals, there chemical composition is as follows;

	Composition (%)						
Clay mineral	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	$K_2O + Na_2O$	H_2O
Kaolinite	45	38	1	—*	—	—	14
Illite	53	25	1	4	1	8	6
Montmorillonite	50	20	3	6	1	2	15
Attapulgite	55	10	3	13	—	—	16
Chlorite	30	14	5	33	—	—	14

* < 1%

The clay minerals and their typical chemical composition.
Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

In tropical environments, clay deposits are subjected to a form of chemical weathering which leaches out the silica, and results in the accumulation of ferric and aluminium hydroxides. Subsequently, dehydration results in a process which produces iron minerals in predominantly iron-bearing residual clays or aluminium minerals in predominantly aluminium bearing clays. The soils produced are bauxite, which can consist of the aluminium-based mineral and lateritic soils which can consist of the iron-based minerals.
[Ref; 18]

Laterite soils (see 4.2 bricks and stones) are so-called because on exposure to air they harden to a brick-like form (the Latin 'later' means brick).

	Composition (%)						
Soil	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	$K_2O + Na_2O$	H_2O
Laterite	3	10	75	—	—	— —	10
Bauxite	1	52	18	—	—	—	28

Chemical composition of lateritic and bauxitic soils
Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

8.3 Chemical reactions

The reactive components of calcined soils and shales are formed by driving off the water molecules. This process results in the formation of a collapsed quasi-amorphous material which is reactive with lime.

Heating first removes the absorbed water and, as the temperature is increased, the interlayer and hydrate water.

The reactivity of the calcined soil and shale with lime depends on the quasi-amorphous nature of the collapsed structure. Hence an optimum calcination temperature exists for each soil or shale type; at temperatures beyond the optimum, recrystallization begins, while at temperatures below the optimum the clay structure is still in tact. Also the time of exposure to heat influences the reactivity of the pozzolana. It is apparent that prolonged exposure to high temperature promotes recrystallization and hence loss in reactivity. The optimum time of calcination is at 800°C is 40 minutes.

Also natural pozzolanas can be calcined but the calcination of natural pozzolanas destroys the original active ingredients and creates new pozzolanic constituent. Given the added cost of calcination it is unlikely that such treatment is practical for natural pozzolanas.

Summing up then we can expect a clay to be a potentially good pozzolana if it has a high silica content and can be dehydroxylated and disordered at a temperature sufficiently below a recrystallisation temperature for practical preparation.

-Properties of lime-burnt clay mortars

As for other types of pozzolana, the optimum lime-pozzolana ratio for calcined clay pozzolanas varies between 1:2 and 1:3 for long-term strength; at early ages a ratio of approximately 1:4 appears to give higher strengths. Gypsum can be used to accelerate the setting and hardening of lime-burnt clay mixes. Results obtained by the Central Road Research Institute in India indicated that for a burnt clay pozzolana, an addition of 3% by weight of gypsum was optimum in accelerating early strength.

[Ref; 18]

As mentioned in 8.3 the reactivity of the calcined clay with lime depends on the calcination temperature. A table with the strength development of lime calcined bauxite mortars found by Hammond is given below. The ratio of the mixture was not given;

Calcination temperature* (°C)	Compressive strength (MPa)		
	7 days	28 days	90 days
300	2.8	3.2	2.4
400	3.0	3.4	2.8
500	3.4	3.6	2.9
600	4.5	4.8	6.9
700	8.7	9.9	12.5
800	6.7	7.4	9.3
900	7.4	7.3	7.2
1000	4.7	5.1	2.6
1100	2.5	1.8	1.2

*for 8 h

Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

The optimum is 12.5 MPa (N/mm^2) after 90 days. The water requirement, consistency and strength development are related to the fineness of the clay and lime. It may be expected that the reactivity of the pozzolana would increase with fineness, the water requirements to achieve normal consistency will also increase. As for lime-natural pozzolana mixes, the presence of the calcined clay in lime-calcined clay mortars imparts hydraulic properties to the mix; it decreases the setting time, increases the strength and considerably improves durability.

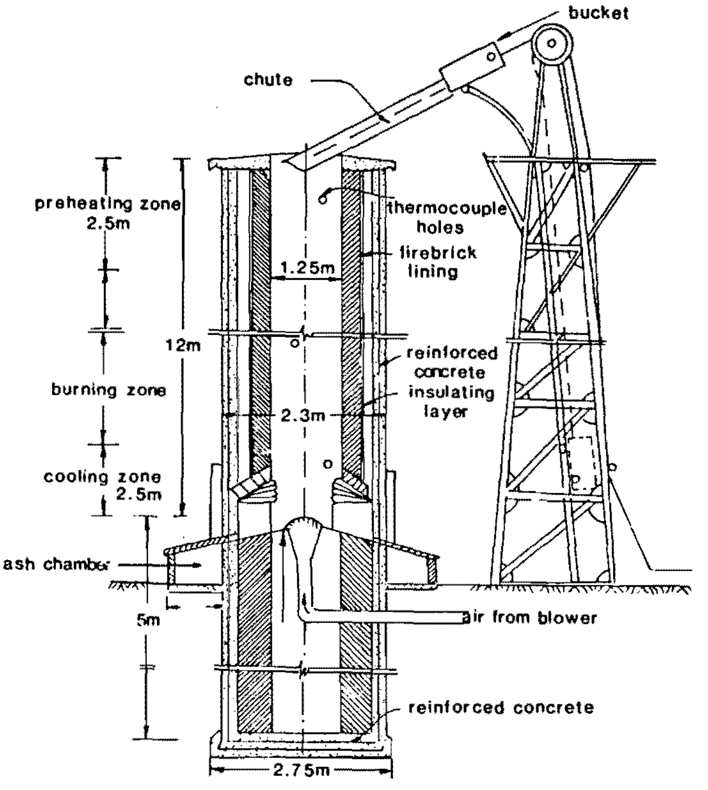
8.4 Methods of production

Burnt-clay pozzolanas have traditionally been produced by pulverizing and grinding reject fired clay bricks and tiles. This practice is still prevalent in India and Indonesia and no doubt in other developing countries. The resulting pozzolana, however, has extremely variable pozzolanicity and the production is thermal inefficient.

The most common means of calcination has been the rotary kiln. This method has been extensively used in the USA and Brazil and for various dam projects in India. Although there are obvious differences, the kilns used have varied in length from 6.5 to 40 m and in diameter from 1 to 3 m. The daily output varied from 12.5 to 100 tonnes depending on the size of the kiln and the conditions of calcination. The length of time for calcination appears to have been around 1 hour.

Considerable research has been undertaken in India to improve the thermal efficiency of calcination and to develop methods appropriate to Indian conditions. Three processes were evaluated. The first was the down-draft kiln commonly used in the ceramics industry. This kiln was designed for intermittent operation and a mixed feed of coal and rough shaped bricks of sun-dried clay. The temperature inside the kiln was controlled with thermocouples by adjusting the feed-rate of the coal in the fire box. Each batch took 1 to 2 days for the completion of the firing and 4 days for the entire cycle. The process was best suited to rural areas as a considerable amount of unskilled labour was required and labour is less expensive in these areas. Although plants were designed with capacities of 5 and 10 tonnes per day, no details are available to whether this process was developed beyond the pilot plant stage.

An other process for the production of burnt-clay pozzolana is by using the vertical shaft kiln. The feed consisted of mixture of clay lumps and coal slack. The conditions of calcination were 700°C for 3 hours, this was also monitored by using thermocouples and controlled via the air blowers and feed input. The plant shown on next page has a capacity of 10 tonnes per day.



Vertical shaft kiln for calcining clay
Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

The National Buildings Organisation in New Delhi has developed a fluidized bed process for the production of burnt-clay pozzolanas. In this process, the soil to be calcined is sun-dried, then pulverized and fed into the top of the kiln. As the material falls, its progress is impeded by fins attached to the side of the kiln which allow intimate contact with the updraft of hot flue gases generated by oil burners. The calcined material passes through the burning zone and exits the furnace where it is allowed to cool. The contact time with the hot gases is extremely short, of the order of a few minutes, but apparently was sufficient to calcine the clay feed. A pilot plant to produce 20 tonnes per day was constructed, but details of commercial development are not available. Despite of the costs of using oil, the cost per tonnes of production was competitive with other methods. [Ref; 18]

All methods of production have in common the requirement to grind the pozzolana once it has been calcined. This is conventionally done in either ball or hammer mills. Some calcined materials are very soft and require minimal grinding, calcined kaolin for example. Other soils, because they have constituents which are not affected by the calcination temperature, may take several hours to produce material of adequate fineness.

8.5 Fuel-consumption

Natural gas, coal or oil have been the most commonly used fuels for the kilns. Also energy requirements for ball milling normally constitute about 25 to 30% of the cost of producing calcined clay pozzolanas and they should be minimized where feasible. [Ref;18]
As we have seen in previous chapters the milling can also be done by other means. (see 7.4)

8.6 Appropriateness for application in developing countries

8.6.1 Raw materials

The literature contains a considerable number of references to research work with the evaluation of raw material for burnt clay pozzolana, particularly in Indian publications. The approach to these studies, however, has been largely empirical and deals mainly with optimisation of particular preparation techniques for a given raw material and its assessment in terms of lime reactivity. Little effort has been expended in relating type of clay to pozzolanic behaviour and consequently the assessment of a deposit, considerably hampering the use of geological criteria in the search for new or better deposits. Simple field or laboratory techniques may be used as means of determining whether the clay is an useful, an essentially poor or worthless raw material. Chemical analyses may already be available for those clay deposits which are been exploited for brick making operations, but these may be not sufficient to assess the potentially active elements.

As the active ingredient in burnt clay is the amorphous material obtained from the clay constituent, the potential quality of the raw clay will depend on the amount of clay present in the first place, this is generally more important than the actual type of clay. As the inactive constituents such as quartz and silt occur largely this should be removed by (wet) sieving. In a small non-industrialised operation for making burnt clay pozzolana the softer and more easily extracted clay deposits might be more readily accepted than harder materials requiring the use of mechanised power to extract.

One obvious approach arises form the nature of clay deposits used for making heavy clay ware. Broken or reject bricks and tiles have been a common source of pozzolana in the past. Such operations usually require a plastic mouldable material and generally speaking, in any deposit the more plastic the raw material the more clay it will contain.

In developing countries, especially in tropical environments, clay is widely available. The crux is the determination of its reactivity and the optimum calcination temperature.

In this context it is worth to mention that extraction of clay has not always been without risks. In Egypt where fertile land for agricultural purposes is becoming more and more scarce and urbanisation and desertification are still increasing, it has been forbidden by law to extract clay for building purposes like baking bricks, etc. Since the extraction of clay destroyed the top-layer of the soil and led to a further decrease of fertile land.

8.6.2 Production technology

Examples of production-units given in literature were often still in a pilot plant stage. The rotary kiln commonly used in the USA and Brazil varies in output, but this technology does not seem to be appropriate for production on village-scale. The attempts made in India to make the production more appropriate for intermittent operation and rural areas seem to be promising, but it is too early to draw conclusions. The production by pulverizing and grinding reject fired clay bricks and tiles has several short-comings as the production is thermal inefficient and the pozzolanicity is extremely variable.

8.6.3 Required labour/skill

The production of burnt-clay by using a rotary kiln needs skilled labours and know-how. The down-draft kiln production requires a considerable amount of unskilled labour which implies that this technology can contribute to employment-creation in rural areas.
As stated above, the information is too concise for drawing conclusions. No feasibility study is executed.

8.6.4 Required capital/investment

Nothing was mentioned in literature about the investment costs, but as a rotary kiln for lime production required high investments (see chapter 6.4), it can be presumed to be about the same for a rotary kiln for production of burnt clay.

8.6.5 Fuel consumption

The most commonly used fuels for the kilns, natural gas, coal or oil are not always available in rural areas of developing countries. Low-sophisticated technologies for production of burnt clay are thermal inefficient and require relatively much fuel.

8.6.6 Physical behaviour

The addition of burnt clay to lime-mortars improves its qualities for application in masonry, as this decreases the setting time, decreases shrinkage and increases the strength like natural pozzolanas do (see 7.6.6).

8.7 Comparison of lime-burnt clay-mortar with Portland-cement

-Qualities

The lime-burnt clay binders impart greater plasticity and ability to retain water compared to Portland cement, like other lime-pozzolana binders. Secondly, masonry made with these cements is more resistant to cracking.

-Disadvantages

The quality of a lime-burnt clay binder is dependent on many factors, like the kind of clay used, the temperature of calcination of the clay, if recrystallization occurred etc. Due to this the quality of the mortar made with this binder is not as much predictable as mortars of Portland cement. The general disadvantages of lime-mortars (mentioned in 6.7 and 7.6) are of course the same for lime-burnt clay mortars.

8.8 Conclusions

Lime-burnt clay mixes can be seen as an alternative for Portland cement in mortars for masonry. When properly used and with optimum conditions for production, the quality of these mortars satisfies for application in developing countries. The compressive strength of these mortars (after 28 days) can be in between 4 and 10 N/mm^2. The optimum lime-pozzolana ratio for calcined clay pozzolanas varies between 1:2 and 1:3 for long-term strength.
Nevertheless the production of burnt clay needs to be well controlled and requires know-how, and research of the raw material. Production with low sophisticated technologies is highly inefficient in fuel use and gives extremely variable pozzolanicity of the burnt clay. Production methods with more sophisticated technologies (like rotary kilns, dawn-draft kilns and vertical shaft kiln) require natural gas, coal or oil as fuels and are relatively more expensive than the production of natural pozzolanas, fly ash and rice husk ash (see chapter 7, 9 and 10).

The use of burnt clay as the pozzolanic constituent in lime-mortars can be an option if other alternatives are not available. More research, dissemination of knowledge, and publications can contribute to more efficient and proper use.

9 FLY ASH

9.1 Introduction

Fly ash, also known as pulverized-fuel ash, is the residue of the combustion of finely ground coal used in generating electric power. Coal-burning electric utilities annually produce millions of tonnes of fly ash as a waste by-product worldwide.

Only in 1937 an American researcher published the results of his investigations and stated for the first time that fly ash could be transformed from a waste product to a useful by-product in the cement industry due to its pozzolanic properties. In the beginning fly ash was only used in the USA but in 1954 profound research resulted in the ASTM-norms for the use of fly-ash. Since the oil crisis the use of coal combustion in electricity generation and industrial applications has rapidly increased in many countries. Most of the combustion residues are disposed. However, these disposal increasingly are felt as a burden for society, especially in heavily populated areas. The direct economic benefits that can be obtained, the increasing awareness of the need to protect the environment and conserve scarce energy resources have all contributed to the worldwide attention on the use of fly ash. However the rate of utilisation of fly ash rarely exceeds 50% in any country.

9.2 Description and chemical composition of fly ash

In general terms fly ash can be divided into two distinct categories;

* Low-lime fly ash; Possesses truly pozzolanic properties, and needs an activator to undergo reaction and thus produce cementitious properties.
* High-lime fly ash; Possesses some cementitious properties itself, in addition to pozzolanic properties.

This grouping is generally associated with the type of coal used at the power station.

-Chemical composition

Traditionally, oxide analysis is used to describe the chemical composition of fly ash. An indication of the order of oxide values for both low and high-lime fly ash is as follows;

	Mass percentage	[m/m] * 100
Oxides	Low-lime fly ash	High-lime fly ash
SiO_2	50	40
Al_2O_3	28	18
Fe_2O_3	9	8
CaO	3	20
MgO	1	4
SO_3	1	2
Others	8	8

Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

In general Low-lime fly ash contains less than 10% CaO and High-lime fly ash contains more than 10% CaO.

Apart from the chemical composition the nature of its phase composition is important. The potential reactive constituent is the amorphous phase (commonly known as glass). In the low-lime fly ash the glass is of siliceous or alumina-silicate composition, whilst in the high-lime fly ash it is of calcium-aluminate composition. Other active compounds that may be present in high-lime fly ash, which imparts its self-cementing character, are free lime (CaO), anhydrite ($CaSO_4$), tricalcium aluminate ($3CaO.Al_2O_3$), and calcium sulphaoaluminate ($4CaO.3Al_2O_3.SO_4$). As a general rule, the glass content in high-lime fly ash is lower than in low-lime fly ash, but it is of a more active nature. From this it would appear that the reactivity of fly ash depends upon the nature and proportions of the glass phase present, which in turn, for a given type and source of coal, is generally determined by the operating temperatures within the furnace (see 9.4 methods of production).

9.3 Chemical reactions

Fly ash has the ability to react with calcium hydroxide ($Ca(OH)_2$) at ordinary temperatures to form a water-resistant bonding material which accounts for the pozzolanic characters of fly ash. Lime or Portland cement are the source of calcium hydroxide. A calcium-silicate-hydrates-gel is formed and is the main bonding constituent.

Calcium sulphate, calcium sulphite and alkaline substances may have a positive effect on strength development. If calcium sulphate is applied ettringite ($3CaO.Al_2O_3.3CaSO_2.32H_2O$)(see also 7.3; chemical reactions lime-pozzolanas) will be one of the reaction products and will contribute to early strength development.

-Properties of lime-fly ash mortars

The quality of fly ash for application in binders is found in its pozzolanic nature and in the rounded shape of the particles. Fly ash is applied in binders in combination with;

* Portland cement with more than 30% of fly ash
* Lime
* Lime plus gypsum and
* Slag and alkaline activators.

The binders are applied with or without additional fillers or aggregates. One of the main general criteria in the choice of cement, lime or lime plus gypsum will be the strength development, in particular early strength which is higher for Portland cement mixtures. The amount of cement or lime or lime plus gypsum required to achieve a certain strength depends further on the amount of free lime available in the fly ash. Lime alone with fly ash shows a very slow strength development. Higher strengths are possible when gypsum is added as a third component. Regarding the use of lime plus gypsum attention is paid in literature to the destructive formations of expanding ettringite.

The addition of fly ash to lime-mortars results in an increased workability and greater water retaining capacity.

9.4 Methods of production

Fly ash is produced by the combustion of finely ground coal, injected at high speed with a stream of hot air into the furnace at electricity generating stations. On entry into the furnace, where the temperatures are usually around 1500°C, the carbonaceous content of the coal in suspension is burnt. The remaining matter present in the coal, such as shales and clays (essentially consisting of silica, alumina and iron oxide), melt whilst in suspension, and then on rapid cooling, as they are carried out by the flue gases, form into fine round particles. About 80% of the coal ash is eventually carried out of the furnace with the flue gases and must be removed before the flue gases are discharged to the atmosphere. This is the material which is called pulverized-fuel ash, and more commonly fly ash. The remainder of the coal ash falls to the bottom of the furnace where it sinters to form a coarser material called bottom ash.

Fly ash is removed from the flue gases by a variety of methods and this can result in a variable quality of fly ash being produced at power stations. As a general rule fly ash extracted at the mechanical collectors (like cyclones) is coarser than that collected at the electrostatic precipitator; it is the latter material which is normally selected for use in concrete.

If we compare this with the production of Portland cement (see 3.2) we can see that both Portland cement and fly ash are produced from finely-ground rock by burning at about the same temperatures and consist essentially of oxides of silica, alumina, calcium and iron. There are, of course, differences between their composition and physical characteristic but the ability of fly ash to replace partially Portland cement is obvious.

The fineness, grain size distribution, amorphous fraction, particle shape and fraction of unburnt carbon determine the quality of the fly ash. A good quality fly ash can be produced if the milling of the coal, the coal and air supply through the furnace, the excess air factor and the flame temperature are kept at a good and constant level. Measurements of flue gas composition and temperature are required to control proper firing conditions.

9.5 Fuel-consumption

In fact fly ash is a residue of the combustion of coal used in generating electric power. No extra energy is needed for its production. If fly ash is used in the cement industry to replace partially Portland cement it has to be packed in bags or containers and transported to cement industries. Cement industries are located in areas of appropriate limestone deposits and not often in the vicinity of power plants.

9.6 Appropriateness for application in developing countries

9.6.1 Raw materials

The use of fly ash in binders is restricted to countries which have excess to coal-reserves or at least make use of the combustion of coal in generation of electric power on large scale. From the developing countries both China and India make partially use of the properties of fly ash.

A considerable amount of fly ash still has to be disposed of in ash dump areas worldwide. Apart from the claim on land close to large cities, serious environmental problems may occur at these ash dump areas. First, there already exists a dust problem at ash dump areas which are being used over a longer period, as a result of evaporation and ash transport by water. Wind blows away ash particles to villages and cover houses and crops with a layer of dust.

Secondly, problems may occur due to leaching of toxic elements, contaminating groundwater or surface water being used for preparation of drinking water. For these countries the economic use of fly ash can be a viable solution for refuse and environmental problems.

9.6.2 Production technology

The production technology of fly ash is quite sophisticated. It is directly linked to the combustion of coal used in generating electric power. The production is centralized and only feasible on large scale. On the other hand is fly ash a waste product so for the already existing electricity industry relatively simple to produce. To put it briefly it can be stated that fly ash production is not appropriate for developing countries on a lower state of development, without a well developed infrastructure for distribution, transport etc., with a small national market and without an already existing electricity-industry. For larger countries like India or China the use of fly ash can even solve many environmental problems like dumping the wasted fly ash.

9.6.3 Required labour/skill

For the realisation of fly ash production of a sufficient quality for use in mortars, it is considered to be essential that a transfer of knowledge is started and maintained in the field of fly ash quality measurement and control, utilization techniques and environmental chemistry. This means essentially that the developing countries have to appeal to foreign experts and companies and will be more dependent.

9.6.4 Required capital/investment

For the production of fly ash investments are needed to obtain the knowledge (foreign currency) of a proper production-technology, for packing the fly ash, for storing, and for transport. The investments for dumping sites of the waste of fly ash can be saved.

9.6.5 Fuel consumption

The fuel needed for the production of fly ash is negligible as fly ash is a by-product of electricity generation by coal combustion. The production is centralized and therefor fuel is needed for transport.

9.6.6 Physical behaviour

The addition of fly ash to lime-mortars increases the workability and water retaining capacity against suction. The fly ash contains silicious and aluminous constituents which improve the hydraulic ability of the mortar and as a result of this improve the strength.

9.7 Comparison of lime-fly ash-mortar with Portland-cement

-Qualities

Compared to Portland cement, as already mentioned for lime-pozzolana-binder, the binders impart greater plasticity, workability and ability to retain water in masonry mortars. Consequently, the extent of the bond between mortar and the masonry units is higher, and the masonry is more resistant to cracking.

-Disadvantages

Although the binder can have a similar strength as Portland-cement some disadvantages are mentioned in literature, namely;
* Loss of tensile strength in drying
* Irritation of the skin due to high alkalinity
* Increased danger of alkaline-aggregate reaction

9.8 Conclusions

In a technical view, fly ash can be seen as an alternative for Portland cement when used in lime-fly ash binders. Fly ash is even much cheaper in production as it is a waste product in generating energy by coal-burning.

However in the context of this report it is rather doubtful if fly ash is really a good alternative for application in masonry in rural areas of developing countries, as much of the short-comings in the production of Portland cement (mentioned in 3.4 Portland cement and developing countries) are the same for the production of fly ash.

The use of fly ash is a relatively new and for equipment, know-how, and research, developing countries still need to appeal to foreign expertise. Specialized and skilled people are needed and the production is not labour-intensive. Bagging, transport and distribution of the fly ash becomes more difficult as the production is more centralized.

On the other hand fly ash is a waste product and its use can (if well-controlled) be an option to reduce disposal and environmental problems. Due to the dense population of the Netherlands for instance, strict laws regarding dumping of waste materials have been made. Products containing waste materials also have to meet certain leaching requirements before they may be used. Products containing fly ash often meet these requirements, especially as toxic element are present. Although those laws will not be directly applicable in developing countries, these methods of leaching tests and determination whether the material is hazardous and contaminating groundwater should be embodied in technology-transfer activities.

As in developing countries more people are dependent of bore-holes and springs to collect their daily drinking water and as specific laws and regulations, knowledge and control-mechanisms are often lacking, the use and distribution of fly ash may imply higher risks than it does in industrialized countries.

Fly ash can be well used in the production of Portland cement, in the production of lime-fly ash bricks, in concrete, in road construction and other applications, but precaution is recommended. For application in lime-fly ash mortars for masonry in rural areas of developing countries, fly ash can not be considered as a good alternative for Portland cement.

10 RICE HUSK ASH

10.1 Introduction

Utilization of agricultural residues in housing and construction has been investigated for many years. Throughout the world eighty million tonnes of husk become available each year during the processing of rice. Some is used as fuel, as fertilizer, or as feed for animals but the greatest proportion is dumped as a waste causing pollution and problems with disposal.

Several institutes have investigated the properties of the ash of the burnt husk, which contains a high proportion of silica, and there has been some commercial exploitation of its pozzolanic reaction with lime to form a cementitious material of potential use in building and construction. Rice husk ash offers as a readily available agricultural waste material, the attractive prospect of providing a low-cost alternative cement, by simple, village-scale technology concentrated on rural areas in developing countries where the husks are produced. Utilization of rice husk ash as a pozzolana to any significant extent is relatively new, although literature cites investigations as far back as 1924. [Ref; 21]

10.2 Description and chemical composition of rice husk ash

The rice husk is the woody sheath surrounding the rice-grain and must be physically removed from the grain after harvesting. This is done by hand threshing or by milling. Hence the husk is a by-product of the process of obtaining grain. The large piles of husk which accumulate near to rice mills constitute a major disposal problem. A small proportion of husk waste from mills does find a use already as a fuel, stabilizing the ground or as food for animals. Usually the pile is near the mill and, if alight, forms a fire hazard to the mills itself. Sometimes the husk is carried to a remote corner of the site for burning.

Rice husk consist of crude fibre, cellulose, lignin, water, and small amounts of crude protein and crude fat. It should be noted that silica has been shown to be an essential soil constituent in the growth of rice. Ash remaining after rice husks have been burnt consists very largely of silica. The combustion process removes the organic matter and leaves a silica rich residue. However such thermal treatment of the silica in the husk results in structural transformations that influence both the pozzolanic activity of the ash and its grindability.

-Chemical composition

The typical chemical analysis of rich husk ash is as follows;

Constituent	Percentage by weight [m/m %]
SiO_2	93.1
Al_2O_3	0.4
Fe_2O_3	0.2
CaO	0.4
MgO	0.5
Na_2O	0.1
K_2O	2.3

Source; Cement replacement materials, Reader in civil and structural Engineering, University of Sheffield, 1986.

Differences in composition can occur due to influences by season, temperature, growing methods, particular type of rice and location. The major impurity is carbon, especially prevalent if the organic constituents have not had sufficient time of sufficient supply of air to enable them to burn off completely.

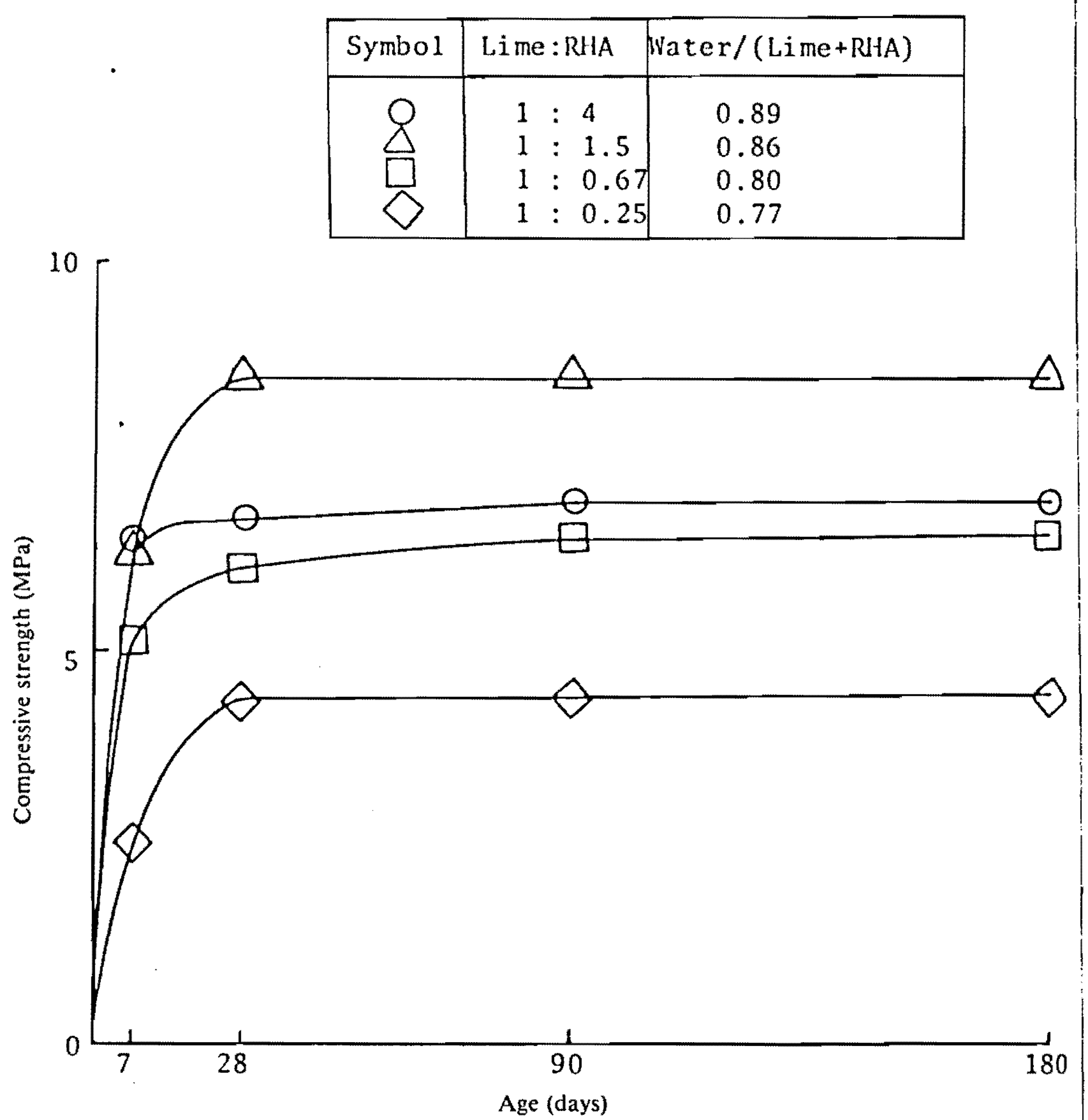
10.3 Chemical reactions

The silica in the rice husk ash is the component which may react, as a pozzolana, with lime, so a high silica and a low carbon content is desirable. The carbon content decreases the reactivity if it exceeds 15 percent of the total weight, the influence of lower proportions is negligible. Further is the form in which the silica in the rice husk ash occurs of importance. The reactivity of the silica is related to the degree of amorphousness of the silica. The pozzolanic reaction is that between lime and silica, to form calcium silicate hydrates. This reaction is influenced by the nature (amorphousness) of the silica and the fineness of the ash. The compressive strength increases as the fineness increases and decreases as the ash becomes more crystalline.

-Properties of lime-rice husk ash mortars

In literature there is consensus of an optimum in strength of lime/rice husk ash mixes with a ratio of around 1:2. A final compressive strength of 8.5 N/mm^2 can be achieved. In generally the shrinkage of the mortar decreases if the lime:rice husk ash ratio decreases. As would be expected the reactivity of the ash is related to its surface (read fineness). Ash reactivity has to be balanced against water demand as the high specific surface of the rice husk ash will significantly increase the amount of water required to produce a workable mortar.

As lime-mortars in general have a very slow strength development, the same as for lime/fly-ash mortars this can be improved with the addition of gypsum as an accelerating third component.



Compressive strength development of lime/rice husk ash mortar
Source; Properties and behaviour of rice-husk ash, Cook D.J. and Suwanvitaya.

The addition of rice husk ash to lime-mortars results in an increased workability, greater water retaining capacity against suction, and the hydraulic or binding abilities and final strength can be improved.

The bulk density of cements based on rice husk ash and lime is lower than that of conventional cements. In India, for example, ash cements are currently sold in 40 kg amounts in second-hand 50 kg Portland-cement bags. Since most mixes are batched on a volume basis (see 4.5; Conditions and technique of preparing and mixing the mortar), it is important that the end user adjust the mix quantities to ensure that the correct amount of cement is used. This can be ensured by distributing leaflets on mix proportions with each bag and by field demonstrations. Problems with illiteracy in rural areas obviously limit the value of printed information.

10.4 Methods of production

Rice husk is a (waste)product obtained by threshing or milling rice for consumption. The production of rice husk ash is a matter of successively burning and grinding the rice husk. The way in which this is done differs from region to region and varies enormously in sophistication of the technology, scale and control. Some examples will be given below;

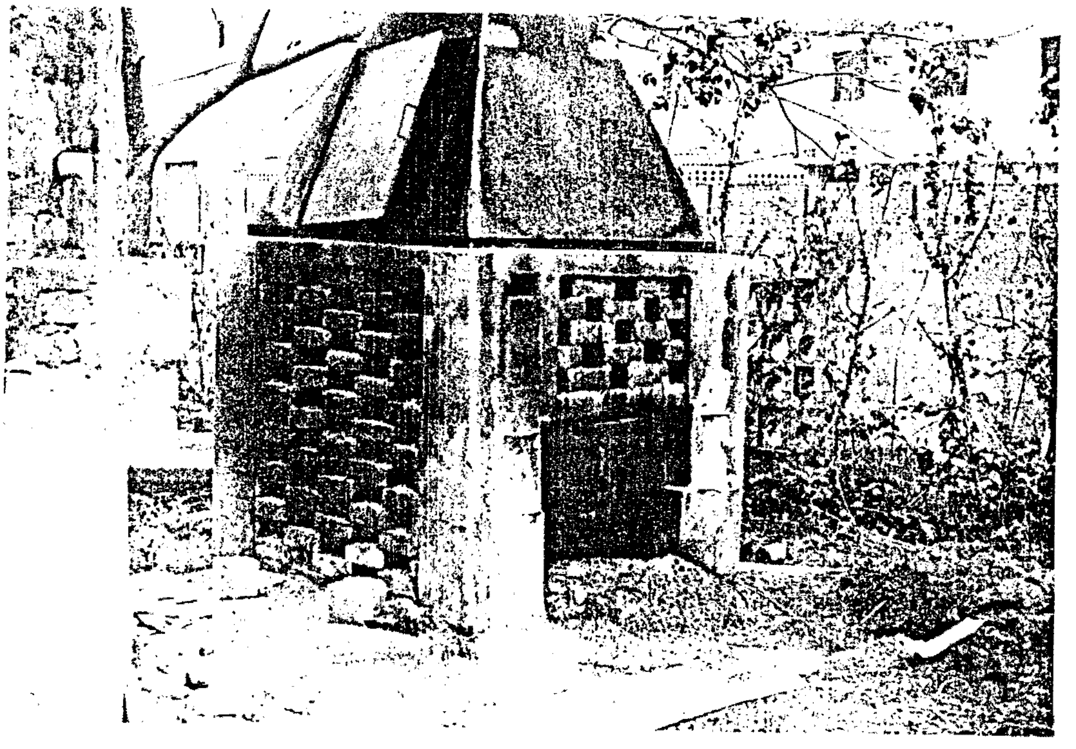
-Burning

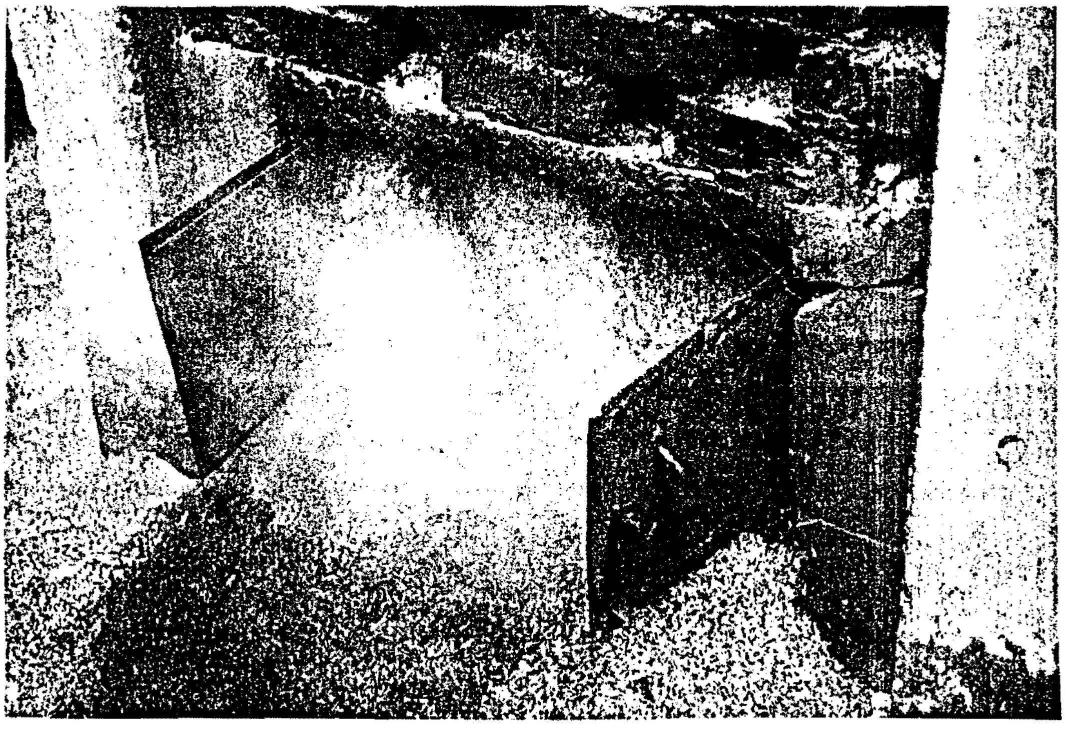
In Surinam the waste husk is usually blown out of a pipe from the rice mill, and it deposits in a large conical heap which is burning continuously, as it is deposited. The temperature of combustion is not subject to any form of control in the heap.

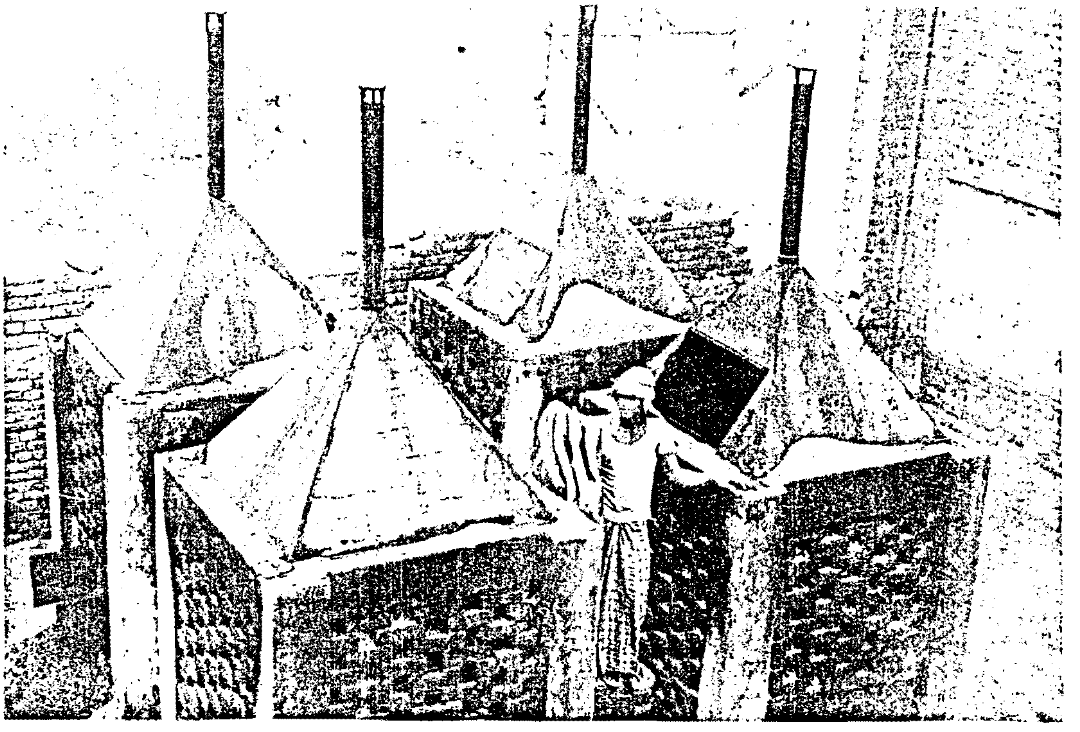
In India husk and clay are mixed, moistened with water and shaped into hand-made balls or cakes which are dried in the sun and then fired in an open clamp. After combustion the material is ground with hydrated lime in a ball mill to produce a cementitious material. No control of combustion is attempted. The process no doubt converts the clay to a reactive form (see Chapter 8) but the contribution of the rice husk ash is somewhat variable.

An other process in India, is the use of lime sludge, a waste from the sugar and paper industries instead of the clay. The cakes or balls again are hand-made and fired in a bench type kiln out of bricks. It is claimed that the temperature of combustion is sufficient to calcine the lime sludge. As this temperature is approximately 850°C, it is likely that the rice husk ash will be converted to a crystalline, and hence low reactivity, form. Strength results, however, were quite reasonable, a mortar consisting of one part binder to three parts sand had a compressive strength after 28 days ranging of 3.9 to 7.8 N/mm^2.

[Ref; 20]







Single brick incinerator
Source; Rice-Husk ash cements; their development and applications, UNIDO in co-operation with the Government of Australia, 1984.

In Malawi a steel basket incinerator was used. It can only produce 2.5 kg of rice husk ash in one batch. The costs of the incinerator was high in relation to the weight of ash produced. Therefor an alternative was found in a incinerator of cheap locally-made bricks, laid without mortar. The openings between the bricks allows air supply and metal mosquito netting retain the husks and ash. The ash is manually added through the top inlet and consolidates and settles as it burns, where it is removed through the bottom door.
[Ref; 21]

A round brick-built incinerator with little ventilation is also used but has the disadvantage of a lower temperature through the absorption of heat by the mass of the bricks.

In Nepal a group of local people collect the ash remaining from the burning of husks to roast rice grains for sale to the public. The ash was taken by wheelbarrows, stored and milled.

In Thailand a medium-size incinerator, holds the ash in a wire basket, surrounded by metal sheeting to exclude rain and excess wind; while a gap between basket and sheeting allowed adequate access of air for combustion. Other incinerators are made out of oil-drums.
[Ref; 20]

An other technology is heap-burning where an enormous heap surrounded by brick-walls is burning. Apart from the pollution problems by wind etc., the heap-burnt ash is also variable with respect to the silica structure produced. The external layers of husks in the heap burn vigorously but cover the interior mass. Combustion in the interior occurs in a predominantly carbon dioxide atmosphere and high temperatures result due to the fuel value of the husks. If the temperature does not exceed 650°C, it is likely that the ash will be amorphous. Temperature control can be achieved by having a small husk volume in the heap so that it can be quenched if the temperature rises too quickly.
[Ref; 21]

For large-scale industrialized burning operations a furnace is designed which looks like an inverted cone into which rice husk is sucked due to negative pressures maintained by an exhaust fan.
From the furnace the hot gases containing ash are taken to a boiler, and finally to a multicone separator which removes the ash from the gases. Thus the heat produced by combustion of husk is usefully recovered in the form of steam.
[Ref; 20]

In general more amorphous ash is produced when smaller quantities are burnt with plenty of air. Weather conditions like rain and wind may influence the burning process or even lead to interruption of the production.

After burning, the ash is collected in piles and left to cool. During this period, most of the remaining carbon in the ash is oxidized and the ash becomes whitish grey in colour, although a black crust usually remains on the outside of the pile. As far as possible the ash should be kept under cover prior to grinding since a high moisture content produces problems during grinding.

-Grinding

Common to all methods is the necessity to grind the husk to a particle size compatible with the required ash reactivity. It is commonly done in conventional ball mills, either electric or working by hand. The grinding media are steel balls or rods. Due to the weight and replacement cost of the steel, sometimes ceramic balls are used. The use of a pestle, mortar mills or maize mills will satisfy to. Other grinding techniques are mentioned in 7.4.

In general sufficient reactivity can be achieved by grinding the ash for 30 minutes then placing the required amount of lime in the mill and grinding for a further hour.
It will be apparent that the necessity for grinding has a significant influence on plant capacity since it reduces production to a batch process. As a result, if long periods of grinding are required either the production output will be limited or larger ball-milling capacity will be required, the latter obviously resulting in higher capital costs for the plant. In addition, in developing countries, electricity is comparatively expensive and frequently intermittent in supply. Hence, it is desirable to produce ash that requires as short grinding time as possible.

-Packing

The dry lime/rice husk ash mix can be packed in either plastic or paper bags, but can not be stored for long. To facilitate bag filling, the ball mill can be mounted on a frame to enable the cement to be discharged into a hopper.

10.5 Fuel-consumption

Rice husk itself has a fuel value of approximately 14 MJ/kg which means that the energy content of one tonne of rice husks is equivalent to that of 0.48 tonnes of coal or 0.36 tonnes of fuel oil. The rice husk is often used as a fuel for several purposes among like cooking. Heat generated by combustion of ash should be usefully employed, for example for drying foodstuffs. In India it is used to dry citrus pulp. The energy required to produce rice-husk is found in the grinding-process and eventually transport. The grinding can be done by using electricity, by hand, or by animals. For application in mortars, rice husk ash is mixed with lime. So the same as mentioned in 6.5 fuel-consumption for lime production goes for lime-rice husk ash mortars.

10.6 Appropriateness for application in developing countries

10.6.1 Raw materials

The production of rice worldwide has increased steadily over the years. Many developing countries are contributing in the world-production of rice. China and India are the world's biggest suppliers of rice. Utilization of rice husk ash for building purposes is attractive, because rice and rice husk is produced in rural areas which are the areas often most deprived of Portland-cement. In many situations, utilization of the ash for mortar will assist in reducing pollution, since after combustion the ash may have been simply dumped.

Rice husk ash is not readily transportable. Geographical distribution is a factor which has to be considered. In a small region there may be significant husk production but transport cost would need to be taken into account in the economical feasibility of any planned utilization, for instance in case the capacity of mills is insufficient.

A further difficulty with the utilization of an agricultural residue is its seasonal availability, a problem that can be aggravated by the mill size. A large mill will require larger capital investment or storage area than a small mill.

The weather can play an important role in the production and availability of rice husk also. For the burning process the rice husk has to be dry and for proper burning it may not rain.

Changing pollution control requirement in many (mainly industrialized) countries mean that disposal by heap burning in the field is no longer acceptable and strict emission laws control disposal in furnaces. This can lead to a saving in costs if a suitable method of utilization can be found.

Of course for use in mortars the availability of lime is a requirement of the same importance.

10.6.2 Production technology

The production process of rice husk is relatively simple and is recommended on small scale instead of large scale, in order to facilitate the control of the burning process. Rice husk ash taken from a burning pile at the rice mill can be satisfactory for use in making mortars, if the husk is burning evenly and continuously near the surface of the cone formed as husk is ejected from the mill. Incinerators for burning of the rice husk can be built with relatively cheap and local available materials. A ball mill is recommendable for the grinding but even the grinding can be done by other means. The production can be easily carried out on village level.

10.6.3 Required labour/skill

The number of employees working in rice husks ash production units varied from 2 to 15 depending on the scale. Rice husk ash production is labour-intensive and generates employment. Few trained or qualified people are required, and the skills required are learnt on the job. The most important is the quality control of the burning process and the right grinding time. With experienced workers, visual checks can be sufficient. The problem with the production of rice husk ash for utilization in building activities is relatively new, and worldwide there is a lack of specific literature, manuals etc. The United Nations Industrial Development Organization (UNIDO) made in 1984 a state-of-the-art assessment and reported several cases all over the world. More investigations and publications should contribute to a further development of the potential use of rice husk ash.

10.6.4 Required capital/investment

Bruce R. and Garg M.K. have carried out a feasibility study in 1978 and have proposed that the fixed capital investment including a lime-kiln, rice husk incinerator, buildings, land, ball mill, packaging equipment etc. for a 25 tonnes/day mini-cement plant would be $33.6 per tonne, while for large-scale cement production, it is in excess of $100/tonne. So small scale production units are more viable and can be financed with local capital.

A comparison of costs in India, Nepal and Pakistan, when lime/rice husk ash cement was being produced at several centres during 1982, showed that the cement was significantly cheaper than Portland-cement. The selling price of lime/rice husk ash binder is in general 30% of the price of Portland cement and the internal rate of return varied from case to case and turned out to be in between 10% and 65%. [Ref; 21]

The production of rice husk ash cement can be made feasible using simple technology like heap burning, but also as a commercial venture producing many tonnes of product per day.

10.6.5 Fuel consumption

The only problem in the production of rice husk ash in developing countries can be the relatively expensive and intermittent supply (particularly in rural areas) of electricity needed for a ball mill. However the grinding can be done by other means as stated above. In fact the burning of rice husk can be seen as a loss of fuel. Efforts should be made to make use of the heat generated by combustion of ash.

10.6.6 Physical behaviour

Time required for lime/rice husk ash mortar to reach its first set can be sufficiently long to permit easy use of the material. In order to increase the setting time gypsum can be added. The good plasticity of the mortar containing rice husk ash has considerably enhanced market acceptance. Like the other pozzolanas, the addition of rice husk ash to lime-mortars increase the workability and water retaining capacity against suction. It decreases the risk of drying out.

10.7 Comparison of lime-rice husk ash-mortar with Portland-cement

-Qualities

Lime/rice husk ash cement is much cheaper than Portland-cement (30% of the selling price of Portland-cement). [Ref; 21]

And as we have seen in previous chapters, compared to Portland cement, lime-pozzolana-binders impart greater plasticity, workability and ability to retain water in masonry mortars. Consequently the masonry is more resistant to cracking.

-Disadvantages

The water content required to achieve the same consistency is higher for cement containing rice husk ash than conventional masonry cements with Portland-cement. As a result, for mixtures of the same consistency, the strength will be less for those containing rice husk ash because the water:cement ratio will be higher.

The rice husk ash cement in general is darker than Portland-cement and can in some instances be almost black. The colour of the cement is reflected in the mortar. There appears to have been little consumer resistance to the colour of the cement.

The process of binding and hardening of lime/rice husk ash-mortar is not as fast as mortars based on Portland-cement.

10.8 Conclusions

A binder of rice husk ash in combination with lime can be seen as a good alternative for Portland cement in mortars for application in masonry. A compressive strength of a lime-rice husk ash mortar can be 7.8 N/mm^2 which is much lower than for Portland cement mortars. This is also due to a higher water requirement to achieve a good consistency and workability. As already stated in 6.4, we may not forget that quality of bricks used in developing countries is not the same as bricks used in industrialized countries. Mortars made with Portland cement tend to be often much stronger than the country burnt bricks that they bond. This is extremely undesirable as it can be the cause of cracking in the masonry.

The use of rice husk ash is attractive as it is a waste product and relatively cheap in production. Its use can even solve disposal problems. The production can be executed on village-scale with different (labour-intensive) technologies matched to the technological level of the region. The investments for setting up a production unit can be very low. Rice husk ash is in particular suitable for application and production in rural areas because the rice husks is available as agricultural waste material.

More research can improve the use of the heat liberated by the combustion of rice husk. More promotion and dissemination (through field demonstrations for instance) should encourage the use and production of rice husk ash. Even on larger scale the production can be a viable economic activity.

11 GYPSUM

11.1 Introduction

Gypsum is one of the most common materials, occurring in every continent of the world, and it has been exploited for various purposes for many centuries. Six thousand years ago, the Egyptians were making mortar from gypsum, it was used by most early Asian civilizations, and it was much used in Europe during the Middle Ages. The name 'gypsum' is derived from the Greek, meaning 'earth' and 'cook'. This is due to the fact that when gypsum is heated to about 165 degrees Celsius, approximately 75% of the water is driven off.

Gypsum is in previous chapters mentioned as an additional constituent in mortars to accelerate the setting.

11.2 Description and chemical composition of gypsum

Gypsum occurs naturally, as rock gypsum, in beds which may be up to 30 metres thick, though beds less than about 100 mm in thickness are of little commercial value. The colour is often white, though impurities may give a pink or grey shade. A quick test to distinguish gypsum from calcite (calcium carbonate), which is similar in appearance, is to test with a finger nail; gypsum is so soft that it can be scratch-marked, whereas calcite cannot.

-Chemical composition

Gypsum is the name given to calcium sulphate, when in the crystalline form which has two molecules of water combined with every one molecule of calcium sulphate, and it has the chemical formula

$$CaSO_4.2H_2O$$

Calcium sulphate with no water of crystallisation simply has the formula $CaSO_4$
and is known as anhydrite. It occurs naturally as a white mineral, sometimes with a blue or grey shade. Anhydrite is both harder and denser than gypsum.

Often gypsum and anhydrite can both occur in the same quarry, but as far as possible the two types of the mineral are kept apart for separate processing and use, since they have different properties.

A particle form of gypsum, having a marble-like appearance is known as alabaster, and this too has been used through the ages, frequently because of its attractive appearance, especially since it is a soft rock, and is therefor easily carved for statuary and ornaments.

11.3 Chemical reactions

As mentioned in the introduction of this chapter when gypsum is heated to about 165 degrees Celsius, approximately 75 per cent of the water is driven off. This dehydrated product, which is still calcium sulphate, but with less water attached, as indicated by the formula $CaSO_4.0.5H_2O$, is known as hemi hydrate, or 'Plaster of Paris' (due to the long-famous deposits at Montmartre, in Paris). Addition of water to this hemi hydrate causes re-hydration back to $CaSO_4.2H_2O$, the material setting hard in a short time, accompanied by a slight increase in volume. The time of set may be controlled by use of retarders.

The dehydration of gypsum can take place at temperatures very much lower than 165 degrees, especially if sufficient time is allowed and the environment is very dry. There can also be interchange between the two forms if the environment changes, and this interchange with the accompanying volume change, together with the slight solubility of gypsum in water (approximately 2 g/l) can be significant in its effect upon the long term durability as a building material.

If the heating process described above for producing hemi hydrate from gypsum is continued to approximately 200 degrees Celsius, the remaining water is driven off, and the resulting material is artificially-produced anhydrite. Hydration of anhydrite to gypsum takes place, when water is added, but the process is very slow, so that anhydrous building plasters, made from anhydrite, requires incorporation of a suitable accelerator such as alum or other salts, usually sulphates. [Ref; 18]

A large proportion of the gypsum produced in the world is used in the manufacture of cement. After the mixing cement with water, the gypsum addition dissolves and then reacts forming Ettringite (see also 7.3; reaction lime and pozzolanas).

-Properties of gypsum mortars

Gypsum is probably best known for its use for plasters and plasterboards in the building industry. If water is added to "Plaster of Paris" it hydrates back to the original mineral, setting hard in a very short time. The quick-setting property of "Plaster of Paris" makes it very useful for a variety of building purposes, but it is soluble in water, which makes it unsuitable for external use except in arid climates and where well protected, sufficiently frequent inspection, maintenance and repair schedules can be undertaken. For this reason its use in most industrialised countries today is limited to internal plasters and plasterboard, though in some countries it is used for blockmaking.

R. Otte of Magdeburg has conducted a large number of experiments. He stated that gypsum offers possibilities of many different uses for load-bearing and non-load bearing internal and external wall elements. [Ref; 19]

Although gypsum was used by the Egyptians in true mortar, in the sense of a mixture of sand and gypsum as a binder to unite bricks or stones in masonry, the use of gypsum mortars for masonry in more recent applications is not mentioned in literature.

11.4 Methods of production

Quarrying and mining are both used for the extraction of the mineral rock, depending on the thickness of the beds, upon the overburden covering the deposits, and on local features. Quarrying is used where possible, and is appropriate where beds are near the surface and approximately horizontal. If mining is necessary, pillars of the mineral are usually left to support the roof if the bed is near-horizontal. The pillars must be of sufficient size and frequency so that they are not crushed under the load imposed from above when the intervening material is removed, and they may be located so as to include the least pure deposits within the pillars.

The rock is subsequently broken into lumps of manageable size, cleaned by washing etc, and ground to required size. Because the low temperature (165^{0}C) required in calcination, the processing techniques for producing hemi-hydrate are very simple. Calcination takes place in some form of pan, kettle or kiln.

After subsequent grinding, the material must be kept dry before use.

11.5 Fuel-consumption

As outlined above, the hemi-hydrate is produced by calcining gypsum at about 165^{0}C in some form of pan, kettle of kiln, a process which requires only about one fifth of the fuel required for the same volume of Portland cement. Several kinds of fuels can be used.

11.6 Appropriateness for application in developing countries

11.6.1 Raw materials

Gypsum occurs, usually together with anhydrite, often in extensive beds in various sedimentary rocks, especially in limestones, shales, and clays, and it is often associated with deposits of common salt. It may occur in rocks of any geological age, but is often associated with rocks from which petroleum is recoverable. Generally gypsum is the form found at the surface, while anhydrite is the more stable form at great depth.

Among the developing countries, India, Mexico, United Arab Republic, Argentina, Brazil, Turkey and Jamaica produce large amounts of gypsum. In many other developing countries gypsum deposits can be found.

11.6.2 Production technology

The production process of gypsum is relatively simple and can be done in some form of pan, kettle of kiln. Although dust is produced during manufacture and handling, working with calcium sulphate does not appear to constitute a hazard to health.

11.6.3 Required labour/skill

The production of gypsum is not high sophisticated and can be done by unskilled or low skilled people. The quarrying is relatively labour-intensive. Technologies for production were not explicitly mentioned in literature.

11.6.4 Required capital/investment

Nothing was found in literature about the investments to set up a gypsum production unit. As the technologies for production are not high sophisticated, the investments are presumably low.

11.6.5 Fuel consumption

Different kind of fuels can be used, depending on the availability in the vicinity of the production unit. Due to the low temperature for calcination, the process has an energy requirement less than one fifth that for producing Portland cement.

11.6.6 Physical behaviour

The solubility of gypsum in water restricts its external use to areas in arid climates.

11.7 Comparison of gypsum-mortar with Portland-cement

In the context of this report gypsum-mortar can not be well compared with Portland-cement, because it is more commonly used as a plaster and not as a mortar for application in masonry like the other alternatives given in this report. An import disadvantage of gypsum is its solubility in water.

11.8 Conclusions

We can not consider gypsum as an real alternative for Portland-cement in mortars for application in masonry. But firstly, as we have seen in the chapter about the history of cement manufacture, it were the Egyptians who used in the past gypsum as a binder in masonry and secondly because gypsum is mentioned a several times as an additional constituent in lime-pozzolana mixes, this chapter could not be left out.

12 GENERAL CONCLUSIONS

The production-technology of Portland cement seems not to be appropriate for developing countries. Import of Portland cement requires foreign currency, which is often scarce in developing countries. The quality of country burned bricks used in developed countries is not the same as bricks used in industrialized countries. Mortars made with Portland cement tend to be often much stronger than the country burnt bricks that they bond. This is extremely undesirable as it can be the cause of cracking in the masonry. Rural areas have often a limited access to urban factories and transportation facilities are scarce.

There is a need of alternative binders for application in masonry wich can be produced by low-sophisticated technologies on village-scale. Lime is such an alternative binder, which especially in combination with a pozzolana can replace Portland cement in mortars. Pozzolanas contain in general SiO_2 and/or Al_2O_2 or Al_2O_3. The chemical reaction of pozzolanas with lime is not entirely understood up to now. Anyway does amorpous structures contribute to the properties of pozzolanas.

The process of binding and hardening of lime-mortars is not as fast as mortars based on Portland-cement. Also the achieved compressive strength of lime- and lime-pozzolana-mortars is lower varying from 4 to 14 N/mm^2. Masonry with lime- and lime-pozzolana-mortars is more resistant to setting and cracking and these binders impart better workability and ability to retain water in mortars for masonry. The extent of the bond between mortar and the masonry units is higher.

Some pozzolanas have been in use for centuries like; trass, burnt clay, and volcanic ash. Other pozzolanas are relatively new in their application like; rice husk ash and fly ash. Natural pozzolanas seem (if available) to be the best pozzolana since the natural pozzolana does not need any further processing-technology after grinding. Rice husk ash is also a good alternative as this is a readily available waste material in rural areas and its use can prevent disposal problems. Both can be produced by low-sophisticated technologies on village-scale. Burnt clay is an other option but requires fuel for production, know-how (of optimum calcination temperatures) and monitoring of the production process. This makes burnt-clay more expensive in production and less suitable as a pozzolana. Fly ash can also replace Portland-cement in combination with lime, but the short-comings in the production and use of Portland cement are more or less the same for production and use of fly ash. The production is centralized, needs an energy-generating industry by using coals, needs skills and besides can be a hazard for the environment and indirect for health if not well controlled.

Gypsum can be a third component in lime-pozzolana and can function as an accelator in the setting. Gypsum can also easily produced on village-scale with simple technologies.

Lime- and lime-pozzolana-mortars are viable alternatives for application in mortars and can make a big contribution ot the improvement of housing standards. The lime and pozzolana production can be self-promoting, can create employment and need little investments. Official support could give encouragement to the industry. Demonstration projects could be established, to show the methods of lime- and pozzolana production and use, and prove that is can be profitable at a small scale. More research after the properties of the raw materials, the deposits and improvements and innnovations of the production technologies should be promoted.

13 EXTRACT

Since early days many kind of binders are used in mortars for masonry. Research of Vicat and Aspin led to the invention of Portland cement in the begin of 19th century. The high qualities and fast setting of this cement led to wide-spread production and application of Portland cement in industrialized countries. Convinced of the binder's quility, the developing countries followed and also decided to set up Portland cement industries. However the production of Portland cement appeared to be not appropriate for all situation in developing countries.

Particularly in rural areas where buildings of masonry are generally made of burnt bricks produced in country kilns and stones, the need for a more appropriate binder is felt. The mortar is in these areas in general prepared at a platform, where the ingredients are batched by volume and the mortar is mixed with a showel.

Lime is an alternative and more appropriate binder which especially in combination with pozzolanas can replace Portland cement in mortars for masonry. Natural and artificial produced pozzolanas can be used. In this report six groups of alternative ingredients for mortars are described namely; lime, natural pozzolanas, burnt clay, fly ash, rice husk ash and gypsum. Natural pozzolanas and rice husk ash seemed to be the best suitable for production and use in masonry in rural areas of developing countries.

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DEFINITIONS IN THE CONTEXT OF THIS REPORT

Adhesion; the capacity of a substance to stick fast.

Alkali; any substance that reacts with or neutralizes hydrogen ions.

Appropriate; suitable or proper, in the context of this report 'appropriate for developing countries'; Labour-intensive, capital-saving, relatively simple, and small-scale.

Binder; 1. a substance that acts cohesively. 2. a substance that fasten or hold together bricks or stones in masonry works.

Bitumen; a black sticky substance of hydrocarbons obtained from petroleum.

Calcareous; of or containing calcium carbonate; chalky.

Calcination; reduce, oxidize, or desiccate by strong heat, or reduce to calcium oxide by roasting or burning.

Calcium carbonate; a white insoluble solid occurring naturally as chalk, limestone, marble, and calcite, and used in the manufacture of lime and cement.

Calcium hydroxide; a white crystalline powder used in the manufacture of cement; slaked lime

Carbonization; converting into carbon by heating.

Cement; 1. a powdery substance made by calcining lime and clay, mixed with water to form mortar or used in concrete. 2. any similar substance that hardens and fastens on setting.

Chalk; a white soft earthy limestone (calcium carbonate) formed from the skeletal remains of sea creature, or a similar substance (calcium sulphate).

Clay; a stiff sticky earth, used for making bricks, pottery, ceramics etc.

Cohesion; the act or condition of sticking together.

Granule; a small hard particle of salt, sand etc.

Grind; reduce to small particles or powder by crushing or smooth by friction.

Gypsum; a hydrated form of calcium sulphate occurring naturally and used in the building industry

Lime; a white caustic alkaline substance (calcium oxide) obtained by heating limestone.

Limestone; a sedimentary rock composed mainly of calcium carbonate, used as building material and in the making of cement.

Lute; clay or cement used to stop a hole, make a joint airtight, etc.

Masonry; building of bricks or stones.

Marble; limestone in a metamorphic crystalline (or granular) state

Mortar; a mixture of lime with cement, sand, and water, used in building to bond bricks or stones.

Nodule; a small rounded unshapely mass.

Portland cement; cement manufactured from chalk and clay. It was patented in 1824 by Joseph Aspdin, a bricklayer of Leeds, who fancied that it bore some resemblance to the limestone of the Isle of Portland in Dorset.

Pozzolana; a volcanic ash used for mortar or hydraulic cement or substance with the same properties.

Pulp; any soft thick wet mass.

Pulverize; reduce to fine particles.

Rice husk; the dry outer covering of rice.

Quicklime; see lime.

Sinter; to forme into a non-porous solid without melting.

Slake; disintegrate (quicklime) by chemical combination with water.

Soil; the upper layer of earth, consisting of disintegrated rock with an admixture of organic remains.

Stucco; plaster or cement used for coating wall surfaces or moulding into architectural decorations.

Tarras; a light-coloured tuff used as cement-material.

Tuff; rock formed by the consolidation of volcanic ash.

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PART TWO; REPORT OF EXPERIMENTS

1 INTRODUCTION

Apart from the literature-study, this project contains a more practical second part in which experiments with six different mortars are executed and reported. The experiments are executed in the 'Pieter van Musschenbroek Laboratory' of the University of Technology, Eindhoven. The objectives of this second part are;

* To get more 'feeling' with what is found and written in literature.
* To get some experience in the execution and reporting of experiments.
* To make some comparisons between the properties of the different mortars and to draw conclusions.

Of course the conditions in which the experiments are carried out, are completely different from the conditions in which mortars are prepared and applied in developing countries. For instance the use of clean tap-water and industrial fabricated bricks and the lack of climatical influences like rain, heat and wind may have great influence on the qualities of the mortars and thus the masonry. However with the results obtained by these experiments, some general conclusions can be drawn about the properties of the alternative mortars prepared under less severe conditions and a comparison between the six different mortars can be made.

2 SET-UP OF EXPERIMENTS

The ingredients of the six different mixes are batched by weight (in contrast with what is stated in Chapter 4.5; batching in developing countries is done by volume). The mortar is mixed by an electric mortar-mixer, whereby the ingredients are firstly mixed dry and successively water is gradually added during mixing. The mixing-process is stopped when the mortar has achieved a good workability according to the opinion of the bricklayer, who builds upon his experience and judges with the naked eye.

Of each of the six mortars, six prisms-samples of 160*40*40 mm and three wall-samples of five bricks and six joints of 15 mm are manufactured. The samples are packed in plastic to prevent them from drying out.

The following matters will be investigated;

- The water-content of the six mortars.
- The workability and consistence after mixing.
- The consistence after 30 minutes.
- The visible shrinkage of prisms after ± 28 days.
- The flexural-tensile strength of the prisms after ± 28 days.
- The compressive strength of the mortar-samples after ± 28 days.
- The compressive strength and the E-modulus of the entire wall-samples after ± 28 days.

For the time-schedule and planning of the experiments see Appendix A.

3 MATERIALS

3.1 Bricks

The bricks used for the experiments are 'Hagens bricks' of circa 211*100*50 mm. These bricks are used, because their relatively low strength approximate the best the strength of the burnt bricks used in developing countries (see literature-study Chapter 4.2). Mean compressive strength 30 N/mm^2. For further specifications see Appendix B.

A recommendation for mortar containing Portland cement is given in Appendix B as well.

The Haller-number of the bricks used in wall-samples of mortars A and B, differs from the wall-samples of mortars C, D, E and F and are respectively 11 and 41 (see Appendix C). This is due to the fact that a new parcel was ordered after the manufacturing of the samples of mortars A and B. Unfortunately this second parcel has been stored outdoors (exposed to the rainy Dutch climate) and could not be dried before application in the samples. This has to be considered in the interpretation of the results of the experiments, but could not be avoided.

3.2 Aggregates

Two types of aggregates for application in mortars were available in the laboratory; a fine and a more coarse sand. Both aggregates are sieved according to a sieve-analysis NEN 2560 in order to determine whether they are well graded. As can be seen in Appendix D, do both aggregates meet the general requirements of NEN 2560. The coarse type fits in the recommended area of the diagram. However is, in deliberation with the brick-layer, chosen for the fine type of sand.

3.3 Cements/binders

For the 'alternative cements' is chosen for lime, a natural pozzolana and an artificial pozzolana. The natural pozzolana is German Trass. Although in the general conclusions of the literature-study (Chapter 12) is stated, that fly-ash can not be considered as a good alternative for Portland cement for applications in rural areas of developing countries, this artificial pozzolana is used in the experiments. Reason for this is the fact that burnt-clay and rice-husk-ash may be appropriate for application in developing countries, but not for experiments in a Dutch laboratory. Both are not local available in the Netherlands and hard to obtain. As the objectives of these experiments are more of educational than of scientific importance, fly ash could serve very well as the artificial pozzolana.

3.3.1 Lime

The lime used in the experiments is MEKAL 'luchtkalk'. It contains min. 70% active lime-hydrate and a mortar-stabilizer (?). It has a fineness of 90% $\leq$ 0.2 mm. The MEKAL lime is commonly used with

Portland cement in mortars.

3.3.2 Trass

The trass used is TUBAG 'Trasmehl' (Rhenish trass see literature-study Chapter 7.2). A natural pozzolana of high quality (according to DIN 51043), which is ground to fine particles and hardens hydraulic when used together with Portland cement or building-lime. Trass is not an independent binder, but is according to DIN 1045 an additional constituent in concrete. The recommended recipe for applications in mortars with lime-hydrate is given on the bags. For masonry-works made with these mortars, sprinkling of water and moistening is recommended as an after-treatment in windy areas.

3.3.3 Fly-ash

The fly-ash used in the experiments is an additional constituent in concrete according to DIN 1045. An 'EFA-filler' (?) for concrete and mortars. This is a low-lime fly ash (see literature-study Chapter 9.2).

3.3.4 Water

The water used is tap-water of ± 20° C.

3.4 Mortars

Of the six different mortars, two consist of only lime-sand-water, two of lime-trass-sand-water and two of lime-fly ash-sand-water in different proportions. Of each mortar is ± 10 litres prepared in an electric mortar-mixer. The recipes are given below;

Recipes	**lime**		**trass**		**fly-ash**		**sand**
A parts of volume	1	:	0	:	0	:	2
B ,, ,,	1	:	0	:	0	:	4
C ,, ,,	1	:	1	:	0	:	3
D ,, ,,	1	:	4	:	0	:	7.5
E ,, ,,	1	:	0	:	1	:	4
F ,, ,,	1	:	0	:	3	:	8

(See for further specifications Appendix E)

3.4.1 Mortar A

A recipe for mortars with a ratio of lime:sand 1:4 is often given in literature. A higher share of lime will lead to an increase in shrinkage according to many researchers. In order to be able to make a good comparison of mortars with a higher lime-content is chosen for this mixture. No indication of expected strength of this mortar is found.

3.4.2 Mortar B

The mortars of lime:sand 1:4 are recommended in literature [Ref; 11]. The expected compressive strength varies in between 1 a 4 N/mm^2 (see Chapter 6.3)

3.4.3 Mortar C

This recipe is recommended and printed on the trass-bag. Most researchers have reported a recipe for lime-pozzolana mortar between 1:2 and 1:3 (in volume-parts) in order to get an optimum in strength. Rehsi stated that a compressive strength of 0.5-0.7 N/mm^2 could be expected where Apers stated that the norms for trass require for a comparable mortar of trass:lime:sand a compressive strength of 14 N/mm^2 after 28 days (see Chapter 7.3).

3.4.4 Mortar D

This is the recipe recommended by J. Apers [Ref; 4]. The binder:sand ratio is kept the same as for mortar E. Only the lime:trass ratio is different. The expected compressive strength is in between 4 and 14 N/mm^2.

3.4.5 Mortar E

This recipe is chosen to determine the effect of the pozzolana as 50% of the lime in mixture A is substituted by fly ash, so mortars A and E can be well compared.

3.4.6 Mortar F

This recipe is chosen in order to be able to make a good comparison with the effect of a natural and an artificial pozzolana since this recipe can be well compared with mortar D as the lime/pozzolana/sand ratio in weight is almost the same.

4 DESCRIPTION OF EXPERIMENTS

4.1 Determination of Haller-number bricks

The specific Haller-number of the bricks gives an indication of the ability of the bricks to suck water out of the mortar into the bricks. This Haller-number varies in between 10 and 60 g/dm^2 per minute. This number is determined after 7 seconds immersion for both parcels according to NEN 2489 (see Appendix C and Appendix F).

4.2 Determination of required quantity of water

The quantity of water which is added to the mortar is measured by determining the begin and end weight of the measuring cup where the water is poured out of into the mortar during mixing.

4.3 Determination of consistence

The consistence of the different mortars is determined with use of a shock-table according to NEN 3534. The consistence is determined two times, first time direct after mixing and second time 30 minutes later (see Appendix G).

4.4 Determination of shrinkage of prisms

The shrinkage is determined by measuring the volumes of the prisms after $\pm$ 28 days with a vernier callipers. This shrinkage is not determined very precisely, but is only an indication whether significant shrinkage occurred or not.

4.5 Determination of flexural-tensile strength

The flexural-tensile strength of the prisms is determined according to NEN 3835, whereby the prisms are laying on two point (50 mm out of the centre) and loaded in the middle of the upper side till they are breaking. Two assumptions are made;

- The validity of the hypothesi of Bernoulli
- The material/prism is homogenous

[Ref; 15]

The flexural-tensile strength is determined with the formula;

$$\sigma = \frac{0.25\ F\ L}{0.67\ B\ H^2} \qquad (N/mm^2)$$

F = force on prism
L = distance between two supporting point (2 * 50 mm)
B = width of prism (40 mm)
H = Height of prism (40 mm)

With these tests the prisms are broken in two parts and of each half the compressive strength is determined.

4.6 Determination of compressive strength of prisms

The two halves of the prisms are compressed between two steal plates of 40*40*5 mm till they break according to NEN 3835. The conditions of hardening of the prisms is different from the conditions of hardening of the mortar in joints of masonry-work. The load in masonry work is different and the suction of the bricks influences the properties of the mortar. These experiments give an indication of the potential strength of the mortar, but not the quality of the mortar in masonry-work. [Ref; 15]

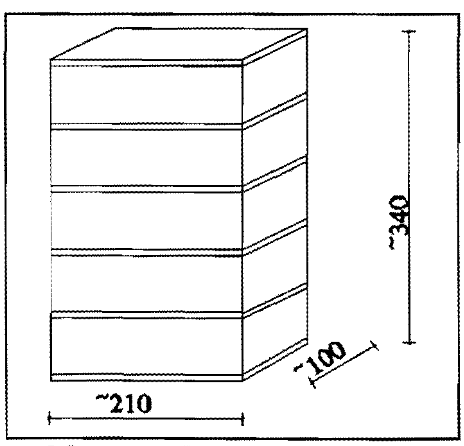
The compressive strength is determined by the quotient;

$$\sigma = F/A \quad (N/mm^2)$$

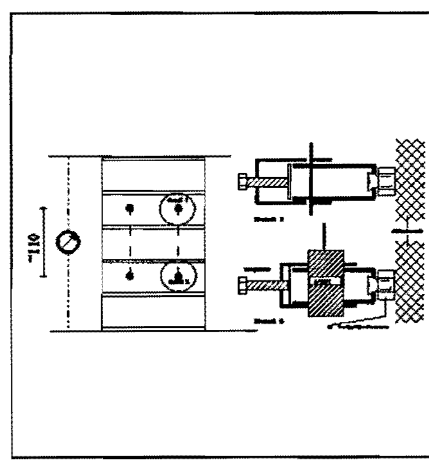
F = Compression force on half prism
A = Surface of steal plates (1600 mm^2)

4.7 The compressive strength and determination of E-modulus of the wall-samples.

Four sensors are attached (glued) on the wall-samples. Two at each side. The wall-samples are placed in a compression-installation and four other sensors are placed at the corners of the compression-table. The sensors are gauged and connected to a computer. The digits recorded by the computer can be translated in respectively the deformation of the wall-samples on four different places and the movement of the corners of the compression-installation. The wall-samples are compressed till they collapse.



Wall-sample



Attach of sensors

The relation between the force of compression and the deformation of the wall-samples can be converted to the E-modulus of the entire wall-samples (principle of Hooke). The theory of Haller stated that precaution is required with the application of principle of Hooke in masonry work (see Appendix H).

In the TGB Norm EC 6 the assumption is made, that there is an arithmetical relation between the strength of masonry and the strength of the bricks and the mortar they bond. Empirical research has proved that there is no relation, between the compressive strength of the bricks, the compressive strength of the mortar and the compressive strength of the masonry-work made out of these two materials. At the University of Technology, Eindhoven research has been done in order to find an empirical test-procedure to determine the mechanical behaviour of masonry-samples. The results of the research are translated in computer-programmes like DIANA and UDEC. These experiments are known as B50 compressive-strength experiment.

[Ref; 15]

Data obtained by these experiments with alternative mortars will be used in this more comprehensive research in the 'Pieter van Musschenbroek laboratory' (see Appendix H).

5 OBSERVATIONS AND REMARKS

Originally the prisms and wall-samples were planned to be packed in plastic during the hardening-process to prevent them from drying out. This appeared to be a mistake as lime-mortars harden in reaction with CO_2 in the air. The prism-samples of mortars A and B, did not achieve any significant strength during the first week of hardening. Apparently due to insufficient access of air and CO_2 under the plastic. Consequently the samples are unpacked after the first six days, where after the hardening-process accelerated. In order to be able to make a good comparison between the six different mortars, the conditions of hardening are kept the same for the six mortars and mortars C, D, E, and F have been packed in plastic for the first six days as well.

The attach between mortar and bricks proved to be weak. This was about the same for the six different mortars and did not make any difference for the parcels of bricks with different Haller-number (respectively 11 and 41). In Chapter 6.7 of the literature-study is stated that the attach of lime-mortars to baked and natural bricks and stones is less than the attach of Portland-cement.an for Portland cement. In Chapter 7.7 of the literature-study is stated that the extent of the bond between mortar and the masonry units of lime-pozzolana mortars is higher than for Portland cement mortars. This difference was not proved by these experiments.

A colleague who was working with masonry-samples made with Portland cement met the same problem. This is a general weak point in masonry and not specific for lime-mortars. C. Groot of the University of Technology, Delft has investigated the water-transport in masonry and found that this has an important influence on the attach of mortar and bricks (see Appendix I). The interaction between brick and mortar at the contact surface in still subject of study. [Ref; 15]

6 RESULTS OF EXPERIMENTS AND INTERPRETATION

6.1 Required quantity of water

The required quantity of water to get a good workability of ± 10 litres of mortar varied in between 2.1 and 3.2 litres. This is very common as the average quantity of water used in ± 10 litres mortar is in between 2.6 and 3.2 litres. [Ref; 15].

For the six different mortars the water requirement was as follows;

Mortar A	3.1 litres
Mortar B	3.1 litres
Mortar C	2.4 litres
Mortar D	3.2 litres
Mortar E	2.5 litres
Mortar F	2.1 litres

The differences in the mixes do not seem to have great influence on the water requirements. To achieve a same consistence, mortars A and B required the same quantity of water. Mortar D (trass) required 0.7 litre more water as mortar E (fly ash) to get the same consistence. The result are rather arbitrary as the criteria of a 'good workability' is judged by the naked eye of the brick-layer. The consistence of the different mortars with good workability varies, and restrains a good comparison (see Appendix E).

6.2 Consistence of different mortars

The consistence is determined by the diameter (spreading) of a specific volume of the mortar after shocking on a table (see Appendix G).

The spreading of the six different mortars with a good workability (according to the brick-layer) varied in between 165 * 166 mm^2 and 180 * 180 mm^2. These are common spreading-measures for masonry mortars (between 150 and 170 mm).
[Ref; 15]

For the six different mortars the spreading after mixing was respectively;

	(0 min)	(30 min)
Mortar A	165*166 mm	140*145 mm
Mortar B	165*166 mm	150*145 mm
Mortar C	170*170 mm	135*125 mm
Mortar D	175*175 mm	155*155 mm
Mortar E	175*170 mm	150*155 mm
Mortar F	180*180 mm	150*155 mm

The lime-mortars with pozzolanas appeared to have a little more spreading as the lime-mortars A and B without pozzolana. The difference between trass and fly-ash is not significant, but fly ash mortars has a little more spreading as the mortars containing trass. Considered the differences in quantity of water added, the comparison is difficult to make.

The spreading of all the six different mortars was remarkably decreased after 30 minutes. The spreading of mortars A, B, D, E and F was decreased by ± 25%. The decrease of 42% in spreading of the mortar C after 30 minutes is striking.
(see Appendix E)

6.3 Shrinkage of prisms after ± 28-days.

Only the prisms of mortar A appeared to have a visible shrinkage of ± 1%. The shrinkage of lime-mortars was mentioned in chapter 6.7 and 6.8 of the literature-study and it was already stated that this could be prevented or improved by the addition of pozzolanas. Therefor these results could have been predicted. The fact of no visible shrinkage of the prisms of mortar B, suggests that more sand in the lime-mortar decreases the shrinkage.

6.4 Flexural-tensile strength of prisms after ± 28-days.

The average flexural-tensile strength of the prisms after 28-days is as follows;

	N/mm^2	
Mortar A	0.05	
Mortar B	0.05	
Mortar C	0.33	
Mortar D	0.40	
Mortar E	0.32	
Mortar F	0.38	(see also Appendix J)

Of both lime-mortars A and B, two prisms were already broken before they could be tested. The mortars A and B proved to have almost no flexural-tensile strength. This strength was considerably improved by the addition of pozzolana to the lime-mortars. There is no significant difference in the strength achieved with mortars containing natural pozzolana (trass) and the mortars with the artificial pozzolana (fly ash). The mortars D and F, which were containing relatively more pozzolana as the mortars C and E and the same quantity of sand, did achieve a higher strength.

6.5 Compressive strength of prisms after ± 28-days.

The average compressive strength of the prisms after ± 28 days is as follows;

	N/mm^2	
Mortar A	0.45	
Mortar B	0.34	
Mortar C	2.50	
Mortar D	3.23	
Mortar E	1.29	
Mortar F	1.53	(see also Appendix J)

In general the achieved compressive strength of the prisms of the six different mortars is lower as was expected from data obtained by the literature-study (see 3.4 mortars). The first six days (± 20% of hardening-time) that the hardening process was hindered by the mistake of packing them in plastic, could have contributed to a lower strength-development. However the pozzolanas imparted hydraulic properties to the mixes and the influence of the packing should be less for mortars C, D, E and F. Other hardening conditions can be due to these lower strength-developments as well (temperature, moisture in lab. etc.).

We can clearly distinguish different strength-developments for the three groups of mortars. Mortar A and B without pozzolana appeared to have the lowest strength-development. The pozzolanas did significantly improve the strength of lime-mortars as was already found in the literature-study. The mortars containing trass appeared to develop the highest strength. The strength development of the fly ash mortars E and F was half as high as the strength-development of the trass-mortars C and D. Further can be seen that the more pozzolana in the mixes, the higher the compressive strength development.

A mixture of 1 part lime on 4 parts of sand (mortar B) was suggested to be the best recipe for lime-mortars in literature. Mortar A with 1 part lime on 2 parts of sand proved to develop a higher compressive strength but more shrinkage as well. Precaution is required as the tests with prism-samples of mortar A yielded a high deviation. This was the same for the prisms of mortar D.

Mortar D yielded a higher strength than mortar C, where the recipe of the latter was recommended and printed on the bag of the trass.

6.6 The compressive strength of the wall-samples after ± 28 days.

The average compressive strength of the wall-samples after ± 28 days is as follows;

	N/mm^2	Deviation N/mm^2	
Mortar A	4.0	0.4	
Mortar B	3.3	0.4	
Mortar C	7.4	0.2	
Mortar D	5.8	0.9	
Mortar E	6.3	0.6	
Mortar F	6.3	0.6	(see Appendix J)
Average	5.5		

The deviation of the tests with the wall-samples of mortar D is quite high, so precaution in the interpretation is required.

The conclusion can be made, that a higher compressive strength of the mortar does not automatically lead to a higher strength of the masonry-work. This was already found by research of the BRS, London [Ref; 15]. The strength of masonry depends on the attach of mortar and bricks.

The samples of mortars containing pozzolanas achieved a considerably higher strength as mortars A and B without pozzolana. Mortar C of which the recipe was given on the bag of the trass, yielded the highest strength.

The differences in strength of the samples of mortars A and B, suggest that a higher content of lime results in a higher strength of the masonry. A higher content of pozzolana leads to a higher compressive strength of the mortar but not automatically to a higher strength of the masonry.

The lower strength of the samples of mortar A and B could be explained by the higher Haller-number of the bricks used (41 versus 11). This is not very probable to be the cause of the lower strength, as lime hardens with CO_2 in the air and the suction of the bricks would not have such a crucial influence on the strength-development. The lower strength of the prisms of mortars A and B substantiates the assumption that the differences in Haller-number may not be seen as the cause for a lower strength of the samples of mortars A and B.

6.7 E-modulus of wall-samples

The data obtained by the tests will be used in a more comprehensive research as mentioned in 4.7. The data recorded by the computer are translated in a Lotus-computer-programme and in Appendix K a compression-force/deformation diagram of a wall-sample with mortar F is given. For more detailed information see the research of ir. A.Th. Vermeltfoort of the section: masonry of the Faculty of Architecture, University of Technology, Eindhoven.

7 GENERAL OBSERVATIONS AND CONCLUSIONS EXPERIMENTS

Since the conditions and the environment in which the experiments were executed, are completely different from the conditions and environment in which the mortars would be applied in developing countries, no real conclusions with regard to the application of the mortars in developing countries can be drawn.

Some general observations and conclusions are;

* The six alternative mortars with lime and pozzolanas as substitute for Portland cement do not require considerably more or less water as Portland cement mortars.

* The consistence of the alternative mortars is not very different from more common mortars. The more pozzolana in the mortar, the more spreading on the shock-table.

* Masonry with lime-mortars should not be packed in plastic during the hardening-process as this restrain the access of air and consequently CO_2 required for setting.

* In mortars without pozzolana, a higher content of sand leads to a decrease in shrinkage, but decreases the strength-development as well.

* Lime-mortars without pozzolana do not have any considerably flexural-tensile strength. This strength is significant improved with pozzolana in the mortar.

* The achieved compressive strength of the prism-samples in these experiments are generally much lower as could be expected from data found in the literature-study (see pages 89,90).

* Pozzolanas in lime-mortars do considerably improve the strength of both prism- and wall-samples, and decrease shrinkage.

* The mortars containing trass yielded the highest compressive strength of the prisms.

* The more pozzolana in the mortar, the higher the strength of the prism-samples. However this appeared not to be the case for masonry-samples.

* A higher compressive strength of a mortar does not lead automatically to a higher strength when applied in masonry.

* Mortar C, containing trass, yielded the highest strength in the masonry-samples (not in the prism-samples). Striking is the fact that this same mortar proved to have the highest decrease in consistence 30 minutes after mixing. There is no proof for a relation between these findings.

* The strength of the wall-samples deviated with an average of 15% from the strength calculated by the formula EC 6;

$$f'_k = 0.4\ (f'_b)^{0.75} * (f'_m)^{0.25}$$

f'_k = strength of masonry
f'_b = strength of bricks (30 N/mm^2)
f'_m = strength of mortar (mean compressive strength of prisms)

Maybe other parameters should be used for lime-mortars.

* The strength of the wall-samples deviated with an average of 21% from the strength calculated by the formula of Hermann;

$$f'_k = 0.45\ \{(f'_b)^2 * f'_m\}^{1/3}$$

f'_k = strength of masonry
f'_b = strength of bricks (30 N/mm^2)
f'_m = strength of mortar (mean compressive strength of prisms)

[Ref; 15]

* These experiment do substantiate a deviation of what can be calculated by the formulas and what is empirical found, maybe other parameters should be used/calculated. The deviation can be either positive as negative and subsequently the code is not satisfying for application. (This is not relevant for application in developing countries since there is a general lack of building codes and control-mechanisms)

In the literature-study was stated that natural pozzolanas together with lime could be seen as a good alternative for Portland cement. These experiments proved that masonry of reasonably good quality can be made, with the natural pozzolana: German Trass.

8 FINAL WORDS

In this last chapter of the report, I would like to give a brief personal evaluation of this project.

The available amount of literature and publications concerning the subject of this study exceeded my expectations. Especially in the libraries of the KIT (Royal Institute of the Tropics), TOOL (Organisation of Technology Transfer for Developing countries), CICAT (University of Technology, Delft), and Faculty of Architecture Eindhoven, enough information could be found to carry out this literature-study. Maybe I even gathered too much literature, as I often lost the overview. Above all the books about building-technologies and manuals for building in developing countries were a pleasure to read. They gave me the feeling of 'back to the basics', and remind me of what this whole study is about.

The time I have spent on this project exceeded the planned 200 hours of study, but this does not matter as long as you have the impression of 'really learning something'.

With regard to the second part; the experiments, I think the objective of getting more 'feeling' with what is written in literature is achieved. It is remarkable that you can leave the 'Faculty of Architecture' without having touched one brick ever in your life. Especially ITOK-students should get some more practical training according to me, since they are supposed to carry out some field-work in the future and not to sit only behind their computer. For this reason I really appreciated the opportunity I have got during this project.

Last but not least I would like to give my special thanks to the people working in the 'Pieter van Musschenbroek Laboratory'. Especially for the assistance, time, patience and perfect cooperation of H. Donders as brick-layer and of C. Naninck during the execution of the experiments.

I enjoyed this project and hope that I or other people will ever make use of this literature-study,

Diane van Herpen,
Amsterdam, 1994.

APPENDICES

TIME-SCHEDULE EXPERIMENTS 'ALTERNATIVE MORTARS'

prp = prepare
man = manufacture
unp = unpack/remove plastic
tst = test
kal = gauge

Prisms

Week	**49**	**50**		**51**	**52**	**1**				**2**		
Day	**tue**	**mon**	**thu**	**wed**		**tue**	**wed**	**thu**	**fri**	**mon**	**wed**	**fri**
A	6 man						6					
B	6 man						6					
C			6 man									6 tst
D			6 man									6 tst
E			6 man									6 tst
F			6 man									6 tst

Masonry/wall-samples

Week	**49**	**50**		**51**	**52**	**1**				**2**		
Day	**tue**	**mon**	**thu**	**wed**		**tue**	**wed**	**thu**	**fri**	**mon**	**wed**	**fri**
A	3 man	3 unp		3 prp		kal	3 tst					
B	3 man	3 unp		3 prp		kal	2 tst	1 tst				
C			3 man	3 unp					3 prp	kal	3 tst	
D			3 man	3 unp					3 prp	kal	3 tst	
E			3 man	3 unp						3 prp		3 tst
F			3 man	3 unp						3 prp		3 tst

Hagens steenfabrieken bv

Kruispunt 26 - 5441 PB Oeffelt Holland - Telefoon 08856-1444 - Fax 08856-2747

Morteladvies

N.B. Dit advies geldt voor normaal gevelwerk, behalve bij Verblend- en geglazuurde steen.

Metselmortel dient te voldoen aan de eisen van morteltype II vlgs. NEN 3835.

Essentieel is dat:

- het luchtgehalte kleiner of gelijk is aan 15%;
- de volumieke massa minstens 1850 kg/m^3 bedraagt;
- bij natte (vertraagde) prefab-mortel bij voorkeur een verwerkingstijd van 12 à 14 uur wordt aangehouden;
- in bepaalde gevallen (klein werk op grote afstand van de centrale) kan de vertragingstijd volgens de norm maximaal 30 uur bedragen.

Voegmortel dient 3 à 4 delen zand op 1 deel bindmiddel te bevatten. Voor het bindmiddel Portland-cement met enige kalk te gebruiken.

Een normale samenstelling is bijvoorbeeld:
1 Portland cement : ½ lucht- of schelpkalk : 4½ zand.

Afwijkende cementsoorten geven een groter verwerkingsrisico, doch bij zorgvuldige uitvoering voldoende resultaat.

Het borstelen van voegen raden wij af.

Korte beschrijving (C)

Hagens metselbakstenen zijn warmrode vormbakstenen in Waalformaat voor al dan niet dragend (schoon)metselwerk.

Samenstelling (E)

Systeemopbouw Metselbaksteen uitgevoerd als vormbaksteen in één formaat, kleur en oppervlaktebehandeling voor toepassing als buitenmuursteen:

- Formaat: Waalformaat
- Kleur: warmrood (licht genuanceerd)
- Oppervlak: bezand.
- Toepassing: Buitenmuursteen (hardgrauw)

De stenen zijn aan één platte zijde voorzien van 4 nopjes en geschikt voor alle soorten metselverbanden.
Door de keuze van het voegwerk (kleur, vorm en afwerking) kan het uiterlijk van het metselwerk beïnvloed worden.
Elementopbouw Volle steen.
Materiaal Maasklei met een homogene samenstelling waardoor stenen ontstaan met een vrijwel konstante kwaliteit en kleur.
Fabrikagemethode Na het mengen van de klei vervaardiging van de stenen in een vormbakpers, drogen in een kamerdrogerij en bakken in een tunneloven bij 1100°C.
Oppervlaktebehandeling Bezanden tijdens het vormen.

Vorm, afmetingen, gewicht (F)

Vorm Waalformaat.
Afmetingen Ca. 211 x 100 x 50 mm.
Gewicht Ca. 17,5 N/steen; ca. 1700 N/m^2 halfsteens metselwerk (74 stuks).

Uiterlijk (G)

Oppervlaktestruktuur Bezande vormbaksteen.
Kleur Warmrood (licht genuanceerd).
De kleur en de vorm van het voegwerk zijn van invloed op de totale kleurindruk van het metselwerk.
Neveneffekten Alle soorten voegwerk en metselverband mogelijk.

Mechanische eigenschappen (J)

Produktsterkte Gebruiksklasse volgens NEN 2489: B2/B3.
Materiaalsterkte Gemiddelde druksterkte, 30 MPa (N/mm^2).
Gemiddelde splijtsterkte: 1,5 MPa (N/mm^2).

Vuur, explosie (K)

Brandbaarheid Onbrandbaar.
Brandwerendheid Halfsteensmuur: ≥ 90 min.; steensmuur: ≥ 360 min. mogelijk.

Gassen, vloeistoffen, vaste stoffen (L)

Diffusie Waterdampgeleidingskoëfficiënt: 1-3·10^{-6} m^2/s.
Vochtopname Maximaal: Ca. 12 gewichtsprocenten.
Veranderingen Maat- en volumevast.
Bestandheid Bestand tegen alle weersinvloeden, luchtverontreiniging, micro-organismen en de meeste chemicaliën.

Thermische eigenschappen (M)

Uitzetting Lineaire uitzettingskoëfficiënt metselwerk: 5-6 ·10^{-6}K^{-1}.
Geleiding Warmtegeleidingskoëfficiënt, metselwerk droog: 0,7 W/(m·K); nat: 1,1 W/(m·K).
Warmteweerstand bij baksteenbuitenblad, 30 mm luchtspouw, 70 mm isolatiemateriaal en baksteen- of kalkzandsteenbinnenblad: 2,0 m^2·K/W.
Bestandheid Tegen vorst volgens eisen (ontwerp)-NEN 3872.

Optische eigenschappen (N)

Kleurechtheid Geen verkleuring onder invloed van UV-straling.

Akoestische eigenschappen (P)

Luchtgeluidsisolatie, geluidsabsorptie Afhankelijk van de samenstelling van de totale konstruktie.

Energie, overige faktoren (R)

Materiaalverbruik Halfsteensmuur: 74 stuks/m^2.

Toepasbaarheid, ontwerp (T)

Bruikbaarheid, funktioneel Metselbakstenen voor de woning- en utiliteitsbouw. Toepasbaar in buiten- en binnenmetselwerk, zowel voor dragende als niet-dragende konstrukties.
Ontwerpdetails Volgens KNB.
Mogelijke voegvormen: platvol, verdiept, gesneden of geknipt; voegafwerkingen: glad, afgestreken, ruw gekamd, geborsteld of geklopt.

Verwerkingskenmerken (V)

Transport Per vrachtauto in HULO stapeling of op éénmalige pallets verpakt in krimpfolie, aantal stenen per kleine pallet: ca. 330 stuks; per grote pallet: ca. 660 stuks.
Opslag Op vlakke, schone ondergrond; tassen afdekken.
Voorbereiding Metselprofielen en kozijnen stellen.
Verwerking Mortelsamenstelling volgens NEN 3835.
Meerdere pakketten tegelijk afnemen vanaf de zijkant (kops).
Stenen winddroog verwerken, zo nodig nog vooraf bevochtigen.
Vers metselwerk tegen uitdrogen beschermen.
Afwerking Schoonmetselwerk: voegen met aardvochtige specie; stootvoegen zo nodig eerst uithakken (zie ook Ontwerpdetails); vuilwerk berapen.
Metselwerk reinigen d.m.v. borstelen, eventueel met water. Afzuren vermijden.
Bewerkbaarheid Te hakken, knippen en zagen.

Ekonomische, kommerciële faktoren (Y)

Prijzen Franko, volgens opgave fabrikant.
Leveringsvoorwaarden Algemene voorwaarden vastgesteld door de vereniging "De Nederlandse Baksteenindustrie".
Levering Via de erkende steen- en bouwmaterialenhandel.
Levertijd In overleg of uit voorraad.
Leveringsgebied Nederland, België en Duitsland.
Garanties Levering onder vorstgarantie is mogelijk.
Technische service Technische en bouwfysische adviezen door de fabrikant of Koninklijk Verbond van Nederlandse Baksteenfabrikanten te De Steeg.

Referenties (Z)

Adressen Volgens opgave fabrikant.

STICHTING TECHNISCH CENTRUM VOOR DE KERAMISCHE INDUSTRIE
HOOFDSTRAAT 4 6994 AE POSTBUS 40 6994 ZG DE STEEG
TELEFOON 08309-59108 FAX 08309-53320 K.V.K. S 047499 ARNHEM

Hagens Steenfabrieken B.V.

Kruispunt 26

5441 PB OEFFELT

STEEKPROEFDATUM:	TYPE:	RAPPORTNUMMER:
09-06-1993	VORMBAK	705-930609

UIT DE SORTERING KHT ZIJN 40 PROEFSTUKKEN
ASELECT GETROKKEN DOOR HET TECHNISCH CENTRUM
EN ONDERZOCHT ZOALS BESCHREVEN IN NEN 2489

AFMETINGEN IN MM VAN 32/20 PROEFSTUKKEN	LENGTE	BREEDTE	DIKTE	#	HYGRISCHE EIGENSCHAPPEN VAN 10 PROEFSTUKKEN: SCHERF-GEWICHT KG/M³	SPEC. WATEROP-ZUIGING G/DM²/MIN	VRIJWILLIGE WATEROPNEMING % V/V	%M/M
GEM.	212	99	51	#	1750	54	23.6	13.6
HOOGSTE	215	101	52	#	1840	61	26.4	15.6
LAAGSTE	209	97	49	#	1690	46	19.7	10.7
SX	1.6	1.2	0.8	#	50	5	2.3	1.7
CONCLUSIE: WAALFORMAAT VLGS FABRIEKSOPGAVE				#		B3	B4	

==

MECHANISCHE EIGENSCHAPPEN
VAN 10 PROEFSTUKKEN IN N/MM²

	SPLIJTTREKSTERKTE	DRUKSTERKTE
GEM.	2.2	29 *
HOOGSTE	3.4	
LAAGSTE	1.5	
SX	0.6	
CONCLUSIE:	B5	B3

CHEMISCHE EIGENSCHAPPEN

	% M/M
SULFAAT ALS SO_4	0.07
Na_2O	0.003(
K_2O	0.002(
MgO	0.0015
LIPINSKI-GETAL	0.02

VOLDOET AAN DE STRENGSTE EISEN

==

TOEPASSINGSGEBIED B3
MAATKLASSE I

DE STEEG, 13-7-1993

mw A.G.A. Hekkelman

i.o. [signature]

* DE DRUKSTERKTE IS BEREKEND
UIT DE SPLIJTSTERKTE

APPENDIX C; Haller-number bricks.

Haller-number bricks after 7 sec. immersion NEN 2489						
Bricks	1	2	3	4	5	6
Seize (mm)	99*210	98*210	96*209	96*209	99*210	97*207
Weight of dry brick (gr)	2066	2001	2012	2003	2022	2014
Weight after 1 min in 5 mm water (gr)	2090	2023	2035	2028	2043	2039
Water absorption (gr)	24	22	23	25	21	25
Water /surface (dm^2)	12	11	11	12	10	12
Mean Haller number						11

Haller-number bricks after 7 sec. immersion NEN 2489						
Bricks	1	2	3	4	5	6
Seize (mm)	98*208	98*208	97*208	99*209	98*209	99*209
Weight of dry brick (gr)	1840	1841	1867	1868	1853	1893
Weight after 1 min in 5 mm water (gr)	1911	1918	1939	1947	1928	1972
Water absorption (gr)	71	78	72	78	75	79
Water /surface (dm^2)	39	42	39	42	40	42
Mean Haller number						41

APPENDIX D; Sieve-analysis of sand and code NEN 3835 concerning grading of aggregates.

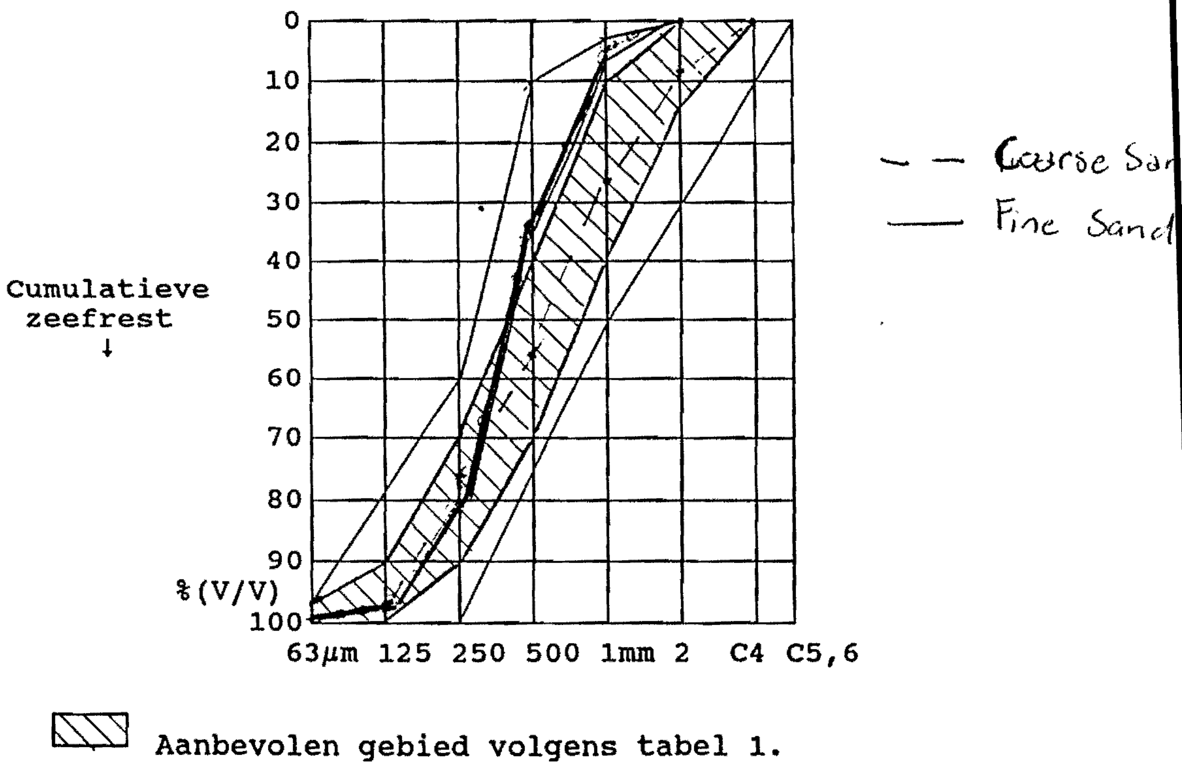
Sieve analysis of fine sand NEN 2560								
Fraction	< 63	125	250	500	1000	2000	4000	> 4000
Weight (gr)	5.8	24.1	277.7	709.8	448.0	34.6	-	-
Perc.	0.4	1.6	18.5	47.3	29.9	2.3	-	-
Cum. %	0.4	2.0	20.5	67.8	97.7	100	100	100

Sieve analysis of coarse sand NEN 2560								
Fraction	< 63	125	250	500	1000	2000	4000	> 4000
Weight (gr)	15.0	22.5	360.0	261.0	495.0	231.0	118.5	10.5
Perc.	0.1	1.5	24.0	17.4	33.0	15.4	7.9	0.7
Cum. %	0.1	1.6	25.6	43.0	76.0	91.4	99.3	100

Tabel 3.6 Korrelopbouw van zand voor metselmortels

Cumulatieve zeefrest op zeef volgens NEN 2560 [1]) % (V/V)								
	C 5,6	C 4	2 mm	1 mm	500 µm	250 µm	125 µm	63 µm
algemene eis	0	≤10	< 30	≥ 2 ≤ 50	≥10 ≤ 75	≥ 60	≥ 80	≥ 98
aanbevo-len	0	0	≤ 15	≥10 ≤ 40	≥ 40 ≤ 70	≥ 70 ≤ 90	≥ 90	≥ 98

[1]) De individuele zeefrest per aangegeven maaswijdte mag 60 % (V/V) niet overschrijden.



Grenslijnen voor de zeefkromme van zand van metselmortels.

APPENDIX E; Specifications of mortars.

Mortar	A
Date	07-12-93
Time	12.52
Temp. lab	± 20°
Perc. of moisture lab.	± 40
Sand	Fine
Quantity	10 litres

	lime	**tras**	**fly-ash**	**sand**
Mixture	1 volume			2 volumes
Volume	3.33 litres			6.67 litres
Specific gravity	0.7 kg/litre			1.6 kg/litre
Weight	2.33 kg			10.7 kg

Water content	2.9 litres	3.1 litres
Consistence (0 min)	142*140 mm	165*166 mm
Consistence (30 min)		140*145 mm

Samples		
	Prisms	**Walls**
Haller-number bricks		41
Number	6	3
Seize	160*40*40 mm	5 bricks 6 joints (15 mm)

Mortar	B
Date	07-12-93
Time	13.43
Temp. lab	± 20°
Perc. of moisture lab.	± 40
Sand	Fine
Quantity	10 litres

	lime	**tras**	**fly-ash**	**sand**
Mixture	1 volume			4 volumes
Volume	2.00 litres			8.00 litres
Specific gravity	0.7 kg/litre			1.6 kg/litre
Weight	1.40 kg			12.80 kg

Water content	2.2 litres	2.8 litres	3.1 litres
Consistence (0 min)	145*135 mm	155*160 mm	165*166 mm
Consistence (30 min)			150*145 mm

Samples		
	Prisms	**Walls**
Haller-number bricks		41
Number	6	3
Seize	160*40*40 mm	5 bricks 6 joints (15 mm)

Mortar	C
Date	16-12-93
Time	10.17
Temp. lab	± 20°
Perc. of moisture lab.	± 40
Sand	Fine
Quantity	10 litres

	lime	**tras**	**fly-ash**	**sand**
Mixture	1 volume	1 volume		3 volumes
Volume	2.00 litres	2.00 litres		6.00 litres
Specific gravity	0.7 kg/litre	0.9 kg/litre		1.6 kg/litre
Weight	1.40 kg	1.80 kg		9.60 kg

Water content	2.4 litres
Consistence (0 min)	170*170 mm
Consistence (30 min)	135*125 mm

Samples		
	Prisms	**Walls**
Haller-number bricks		11
Number	6	3
Seize	160*40*40 mm	5 bricks 6 joints (15 mm)

Mortar	D
Date	16-12-93
Time	10.25
Temp. lab	± 20°
Perc. of moisture lab.	± 40
Sand	Fine
Quantity	10 litres

	lime	**tras**	**fly-ash**	**sand**
Mixture	1 volume	4 volume		7.5 volumes
Volume	0.8 litres	3.2 litres		6.00 litres
Specific gravity	0.7 kg/litre	0.9 kg/litre		1.6 kg/litre
Weight	0.56 kg	2.88 kg		9.60 kg

Water content	3.2 litres
Consistence (0 min)	175*175 mm
Consistence (30 min)	155*155 mm

Samples		
	Prisms	**Walls**
Haller-number bricks		11
Number	6	3
Seize	160*40*40 mm	5 bricks 6 joints (15 mm)

Mortar	E
Date	16-12-93
Time	13.50
Temp. lab	± 20°
Perc. of moisture lab.	± 40
Sand	Fine
Quantity	10 litres

	lime	**tras**	**fly-ash**	**sand**
Mixture	1 volume		1 volume	4 volumes
Volume	1.67 litres		1.67 litres	6.67 litres
Specific gravity	0.7 kg/litre		1.2 kg/litre	1.6 kg/litre
Weight	1.17 kg		2.00 kg	10.67 kg

Water content	2.5 litres
Consistence (0 min)	175*170 mm
Consistence (30 min)	150*155 mm

Samples		
	Prisms	**Walls**
Haller-number bricks		11
Number	6	3
Seize	160*40*40 mm	5 bricks 6 joints (15 mm)

Mortar	F
Date	16-12-93
Time	14.00
Temp. lab	± 20°
Perc. of moisture lab.	± 40
Sand	Fine
Quantity	10 litres

	lime	**tras**	**fly-ash**	**sand**
Mixture	1 volume		3 volumes	8 volumes
Volume	0.83 litres		2.5 litres	6.67 litres
Specific gravity	0.7 kg/litre		1.2 kg/litre	1.6 kg/litre
Weight	0.58 kg		3.00 kg	10.67 kg

Water content	2.1 litres
Consistence (0 min)	180*180 mm
Consistence (30 min)	150*155 mm

Samples		
	Prisms	**Walls**
Haller-number bricks		11
Number	6	3
Seize	160*40*40 mm	5 bricks 6 joints (15 mm)

art 6.5: hallergetal steen

6.5 *Specifieke wateropzuiging (Hallergetal)*

Deze grootheid wordt gebruikt ter beoordeling van de verwerkbaarheid van een element.

6.5.1 *Definitie*

Onder de specifieke wateropzuiging (W_k) wordt verstaan het quotiënt van het oppervlak van één zijde van een element en de hoeveelheid water die door dit element wordt opgezogen, indien het gehele oppervlak van deze zijde gedurende 60 seconden, tot een diepte van 5 ± 5 mm in leidingwater van kamertemperatuur wordt gedompeld.

6.5.2 *Uitvoering van de proef*

Breng het element onder dezelfde vochtige omstandigheden waarin het zal worden verwerkt. Verwijder door borstelen de losse delen en bepaal daarna de massa van het element.
Breng vervolgens het element met het gehele oppervlak van een zijde, waarop na verwerking de grootste krachten worden uitgeoefend en waartegen zich dan de metselmortel bevindt, tot een diepte van 5 ± 5 mm in drinkwater van kamertemperatuur, waarbij er zorg voor moet worden gedragen dat aan deze voorwaarden wordt voldaan gedurende de totale duur van de indompeling.
Neem na 60 seconden het element uit het water en ontdoe het van het aan de oppervlakte hechtende water; bepaal vervolgens de massatoeneming (Δm) op 1 g nauwkeurig.
Bereken het oppervlak van het platte vlak, waarmede het element zich onder water bevond, in dm^2 uit de lengte en de breedte, bepaald volgens 5.2.4.1 en figuur 2.

De specifieke wateropzuiging W_k is dan:

$$W_k = \frac{\Delta m}{l \times b}$$ in $g/(dm^2 \cdot min)$, afgerond op het dichtstbijgelegen veelvoud van vijf.

Opmerkingen
l en b, bepaald volgens fig. 2, vertegenwoordigen het bruto oppervlak; eventuele aanwezige, bewust bij de fabricage aangebrachte openingen, gaten of perforaties worden niet afgetrokken.
De nauwkeurigheid van het beproevingsresultaat bedraagt ca. 3 $g/(dm^2.min)$.

5.4 Bepaling van de kleurechtheid van cementpasta (C4)

Bepaal de kleurstabiliteit van cementpasta's, waaraan de kleurmiddelen zijn toegevoegd volgens NBN T61-204.
De methode bestaat uit de bepaling van de trichromatische coördinaten van het proefstuk. De meting van de verstrooiende weerkaatsing moet geschieden met behulp van een bolfometer, beschreven in NBN 747.

6 Proeven op mortel (M, tabel 3 in NEN 3533)

Voor de uitvoering van de mechanische proeven op mortelspecies en mortel (resp. de proeven M1 t.m. M13 in tabel 3 van NEN 3533) gelden - voor zover het de proeven gemerkt met x betreft - de volgende bepalingen.
De mortelspecies moeten worden vervaardigd volgens NEN 3072. 1)
Tenzij de fabrikant van de hulpstof nadrukkelijk anders voorschrijft moet bij het bereiden van mortelspecie met vloeibare of oplosbare hulpstof, de hulpstof in een deel van het eerst toe te voegen water worden opgenomen.

In de ruimten waarin de proefstukken worden vervaardigd moet - tenzij bij de proefomschrijving anders is bepaald - een temperatuur van 20 ± 2 °C heersen, terwijl de relatieve vochtigheid ten minste 65 % moet zijn.
Ook de temperatuur van de materialen voor de mortelspecie, de gereedschappen en de apparatuur moet bij het begin van de proef 20 ± 2 °C zijn.
Er moet leidingwater worden gebruikt.
De proefstukken moeten, b.v. door middel van kunststoffolie, zodanig worden afgedekt dat verdamping wordt vermeden en tot aan het tijdstip waarop de mallen worden verwijderd in een ruimte geplaatst met een temperatuur van 20 ± 1 °C en een relatieve vochtigheid van ten minste 90 %.
De proefstukken moeten worden ontvormd nadat de mortelspecie voldoende is verhard. In het algemeen dient dit de dag na vervaardigen plaats te vinden.
De uit de vorm genomen proefstukken, die op een later tijdstip dan 24 uur worden beproefd, moeten - tot aan de dag van beproeven - rechtopstaand worden bewaard in met kalk verzadigd stilstaand water met een temeperatuur van 20 ± 0,5 °C.

6.1 Bepaling van de consistentie bij zelfde watergehalte (M1) 2)

6.1.1 Beginsel

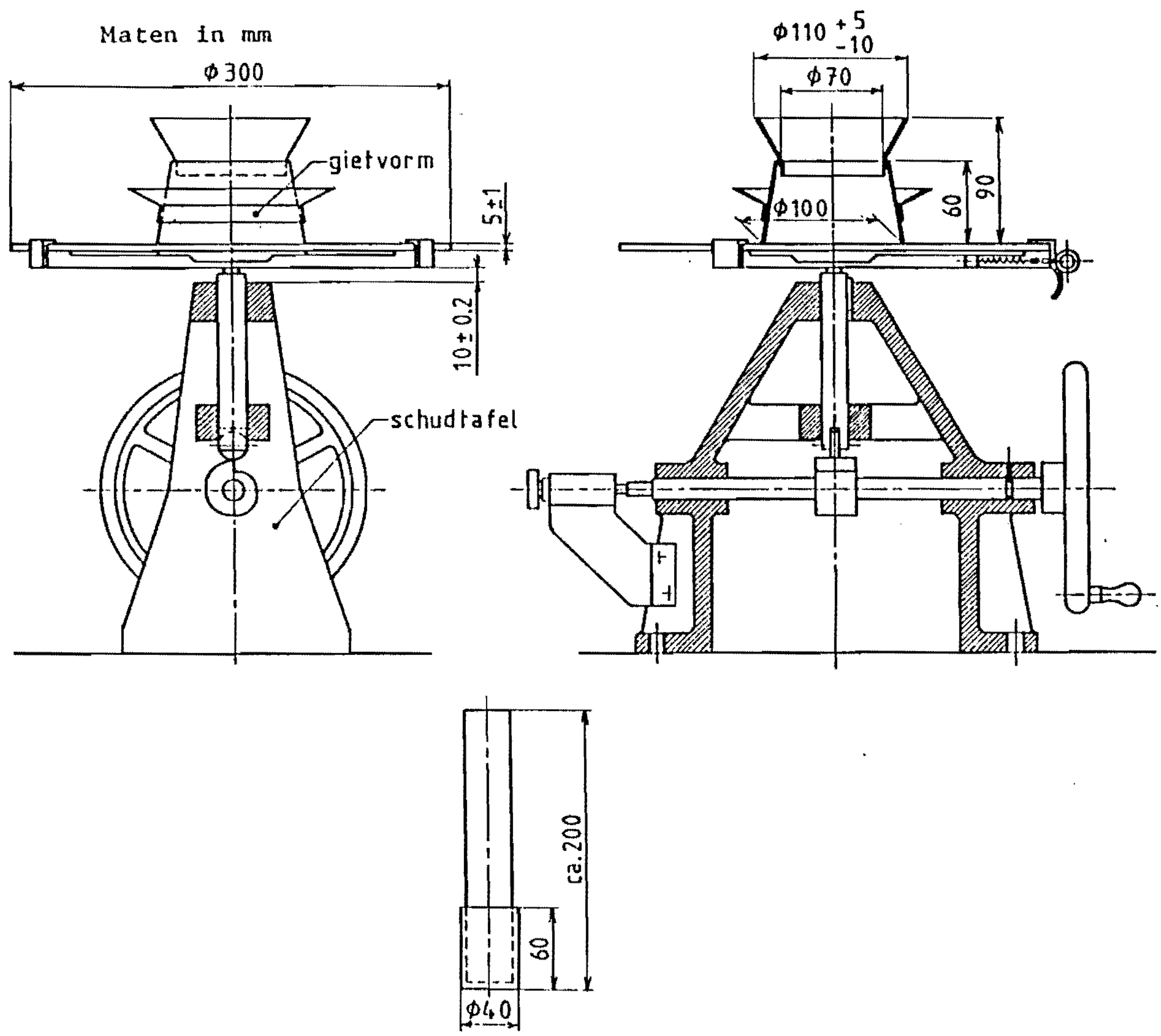
De consistentie wordt bepaald met behulp van een schudtafel.
Het watergehalte van de referentiemortelspecie wordt ook toegepast voor de mortelspecie met hulpstof.
De consistentie wordt zowel onmiddellijk na bereiding van de mortelspecie als 30 minuten hierna vastgesteld.

1) Zal t.z.t. worden vervangen door een Europese norm.
2) Gebaseerd op DIN 1060.

6.1.2 Toestellen en hulpmiddelen

6.1.2.1 Schudtafel

Een schudtafel, afgebeeld in figuur 1, bestaande uit een metalen gestel, geplaatst op een horizontaal vast vlak. Dit gestel draagt een tafel van staal of gietijzer. Deze tafel kan door middel van een door een kam bewogen verticale stift over een hoogte van 10 ± 1 mm worden opgetild; zij kan door het eigen gewicht daarna terugvallen. In het midden van de tafel is een cirkel gekrast met een middellijn van 100 mm.
De metalen tafel is afgedekt met een ronde dikke glazen plaat met een middellijn van 300 mm, die aan de zijkant met klemmen op de metalen tafel wordt vastgezet.
De massa van het beweegbare gedeelte van het toestel, waaronder wordt verstaan de metalen tafel en de glazen plaat, de verticale stift en de klemmen, bedraagt 3200 à 3350 g.



Figuur 1 - Schudtafel met stamper volgens DIN 1060

6.1.2.2 Gietvorm

Een metalen gietvorm (zie figuur 1), die de vorm heeft van een rechte afgeknotte kegel met een hoogte van 60 mm en met een cirkelvormig boven- en grondvlak, waarvan de binnenmiddellijnen respectievelijk 70 en 100 mm bedragen. De gietvorm moet voorzien zijn van een morsrand, die tevens dient voor het optillen.

6.1.2.3 Trechter

Een conische metalen trechter (zie figuur 1) met een hoogte van 30 mm en een bovenmiddellijn van 110 mm, die passend op de gietvorm kan worden geplaatst.

6.1.2.4 Stamper

Een houten stamper (zie figuur 1) van ca. 200 mm lengte met een cilindrisch ondereinde voorzien van een metalen schoen en die een totale massa heeft van ca. 250 g.

6.1.2.5 Liniaal

Een rechte scherpkantige stalen liniaal.

6.1.3 Werkwijze

Plaats de gietvorm met trechter midden op de glazen plaat.
Vul de gietvorm met de mortelspecie - zo spoedig mogelijk na de aanmaak hiervan - in drie lagen en stamp elke laag aan met 10 slagen.
Verwijder de trechter en strijk met de liniaal door een zagende beweging de bovenkant van de mortelspecie in de gietvorm vlak af.
Houd gedurende deze handeling de gietvorm met de hand vast, zodat hij niet kan bewegen.
Veeg na 10 à 15 s het water weg, dat eventueel onder uit de gietvorm is gelopen.
Licht de gietvorm daarna voorzichtig verticaal omhoog en laat de tafel 15 keer vallen met een frequentie van één val per s.
Meet daarna van de aldus verkregen koek de middellijn in mm in twee onderling loodrechte richtingen en noteer het gemiddelde hiervan, afgerond in mm.
Herhaal de bepaling met een andere charge mortelspecie.
Wanneer de genoteerde waarden van de verse mortelspecie meer dan 10 mm verschillen moet de bepaling worden herhaald totdat in twee opéénvolgende bepalingen minder dan 10 mm verschil wordt verkregen.

Als consistentie wordt beschouwd het gemiddelde resultaat van twee opéénvolgende bepalingen.

Rapporteer de consistentie (in mm) van zowel de referentiemortelspecie als de mortelspecie met hulpstof direct en 30 minuten na aanmaak. Druk de waarden na 30 minuten uit in percentage van die, welke direct na aanmaak werden verkregen.

stijfheid. Het verhardingsproces van de mortel wordt door de zuigende eigenschappen van de steen beïnvloed, zoals ook door C. Groot geconstateerd.

5 De mechanische eigenschappen van metselwerk.

Zoals gezegd spelen bij de sterkte van het metselwerk de sterkte van de componenten en de wijze waarop de componenten verwerkt zijn een grote rol. In de volgende paragrafen worden enige beschouwingen gegeven over de mechanische eigenschappen van metselwerk onder druk. Daarna worden resultaten van proeven, ook op trek en afschuiving, besproken.

5.1 Theorie van gedrukte composiet materialen

Zoals reeds eerder gesteld is metselwerk beter tegen druk dan tegen trek bestand. In de volgende paragraaf zullen twee modellen besproken worden waarmee het gedrag van op druk belast metselwerk verklaard kan worden. Hierbij speelt de dwarscontractie-coëfficiënt een grote rol. Bij metselwerk is deze verhouding afhankelijk van de eigenschappen van de gebruikte stenen en mortel.

5.1.1 Bollenmodel

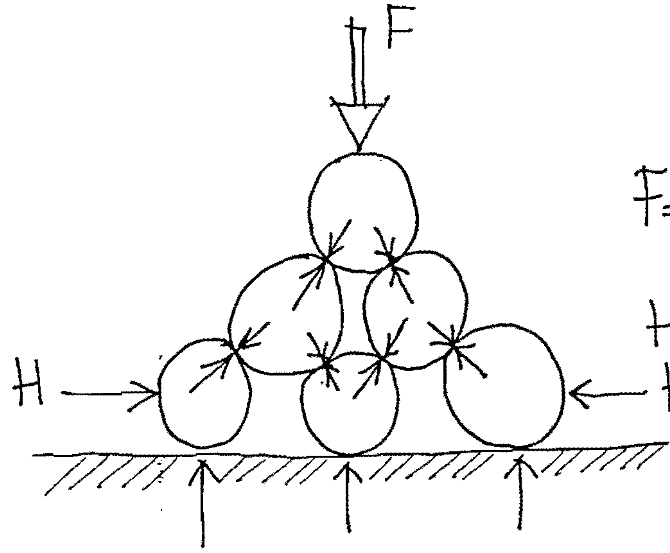
(Zie **figuur 5.5**) Het korrelskelet van de mortel tussen de stenen bestaat uit afgeronde zandkorrels, aan elkaar gehecht door de cement/kalk substantie. We gaan er even vanuit dat de stijfheid van de cement/kalk substantie gering is ten opzichte van die van de zandkorrels. Krachten die op het skelet worden uitgeoefend veroorzaken in de oplegvlakken horizontale reactiekrachten, die de steen op trek belasten. De optredende drukkrachten zijn goed opneembaar door de steen. De sterkte van gedrukt metselwerk wordt dus hoofdzakelijk bepaald door de treksterkte van de steen, die niet in alle richtingen gelijk is. Denk daarbij bijvoorbeeld aan de gelaagdheid loodrecht op het vlijvlak van een strengperssteen. De treksterkte in de lengterichting van dit type steen is lager dan die in de dikterichting.

5.1.2 Theorie van Haller

Om een indicatie te geven van de trekspanning in de steen, loodrecht op de drukspanning werd door Haller een formule opgesteld, welke nu besproken zal worden. Beschouwen we een centrisch op druk belast proefstuk dan zal dit in de lengte richting vervormen. Nemen we aan dat het materiaal homogeen is dan is er een verband tussen de verlenging van het proefstuk en de spanning in het proefstuk.

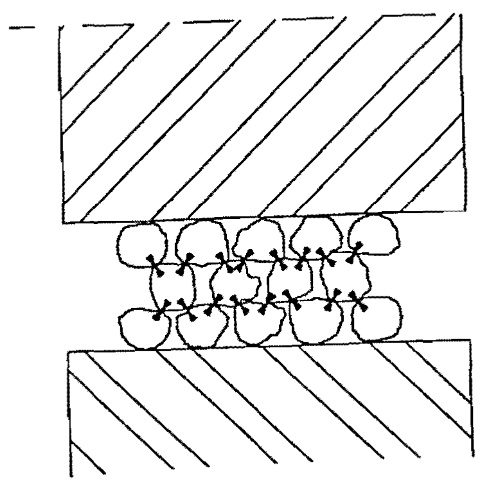
$$\epsilon=\frac{\Delta L}{L} \qquad \epsilon=\frac{\sigma}{E}$$

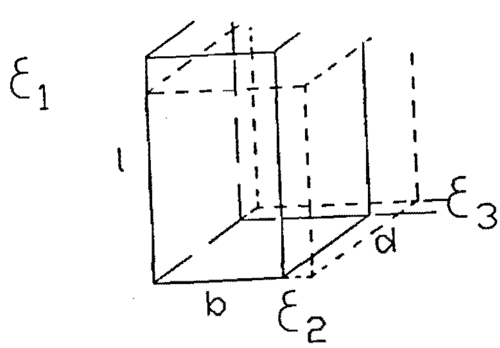
Wanneer een lichaam in de lengterichting verkort dan zal het in de dwarsrichting dikker worden. De dwarsuitzetting (ϵ_{dwars}) is afhankelijk van de modules van Poisson.



F = kracht op bollenstapel
H ⇒ horizontale reactie

fig 5.5.





$$\eta = \frac{\epsilon\ dwars}{\epsilon\ langs} \quad met \quad \frac{1}{\eta} = \nu \ (dwarscontractiecoef.)$$

Wanneer twee of meer materialen - op elkaar gestapeld - onder druk worden gebracht, zal er in het grensvlak een dwarsgerichte trekspanning ontstaan in één van de materialen, in het andere materiaal een drukkracht, afhankelijk van hun E. **(Zie figuur 5.6)**
Als $E_{mortel} < E_{steen}$ dan werken de spanningen zoals in **figuur** 5.6 is aangegeven. De richting van de spanningen is tegengesteld als $E_{steen} < E_{mortel}$. Op het grensvlak moet gelden: $\epsilon_{st} = \epsilon_m$. Met de uit het voorgaande afgeleide formule voor de verkorting van de steen:

$$\epsilon_{st} = \frac{1}{\epsilon_b} \left\{ \sigma_{st2} + \frac{1}{m_{st}} (\sigma_1 - \sigma_{st2}) \right\}$$

en die voor de verkorting van de mortel:

$$\epsilon_m = \frac{1}{\epsilon_m} \left\{ \sigma_{m2} + \frac{1}{m_m} (\sigma_1 - \sigma_{m2}) \right\}$$

en de relatie :

$$S_{st}\ \sigma_{st2} = \eta_m\ \sigma_{m2}$$

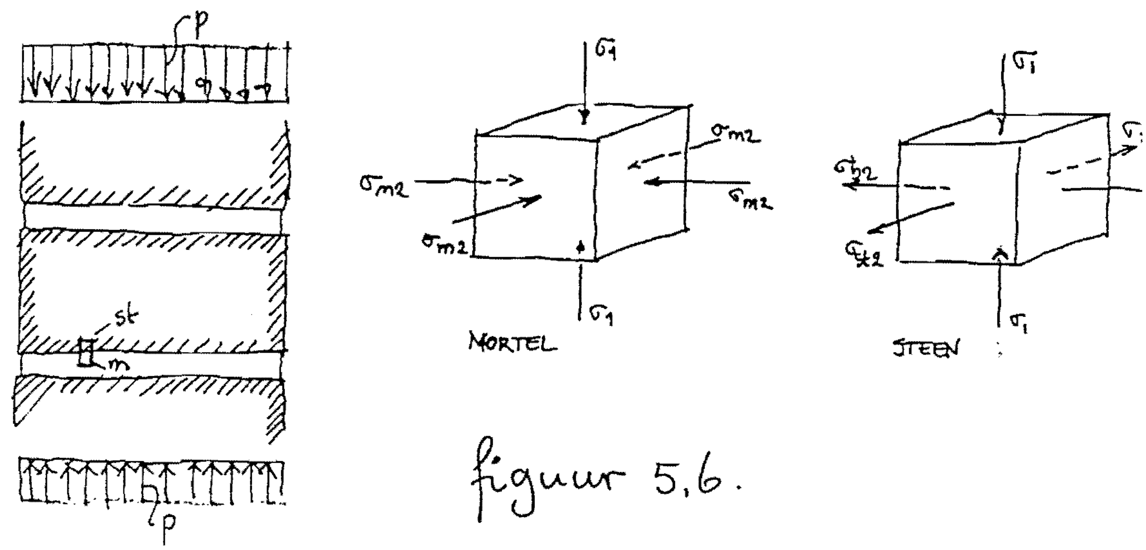
volgt na samenstellen het volgende verband tussen de spanning in dwarsrichting in de steen en de opgelegde drukspanning.

$$\sigma_{st2} = \frac{\sigma_1}{m_{st}} \frac{\frac{M_{st}}{M_m} \cdot \frac{E_{st}}{E_m} - 1}{\frac{E_{st}}{E_m} \cdot \frac{S_b}{S_m} (1 - \frac{1}{m_m}) + (1 - \frac{1}{m_{st}})}$$

Deze formule is theoretisch en benaderend, maar geeft een beeld van de optredende spanningen in de steen en/of de mortel. De dwars-spanning, σ_{st2}, in de steen is oorzaak van bezwijken op trekbelasting (verticale scheuren). Uit deze formule volgt:

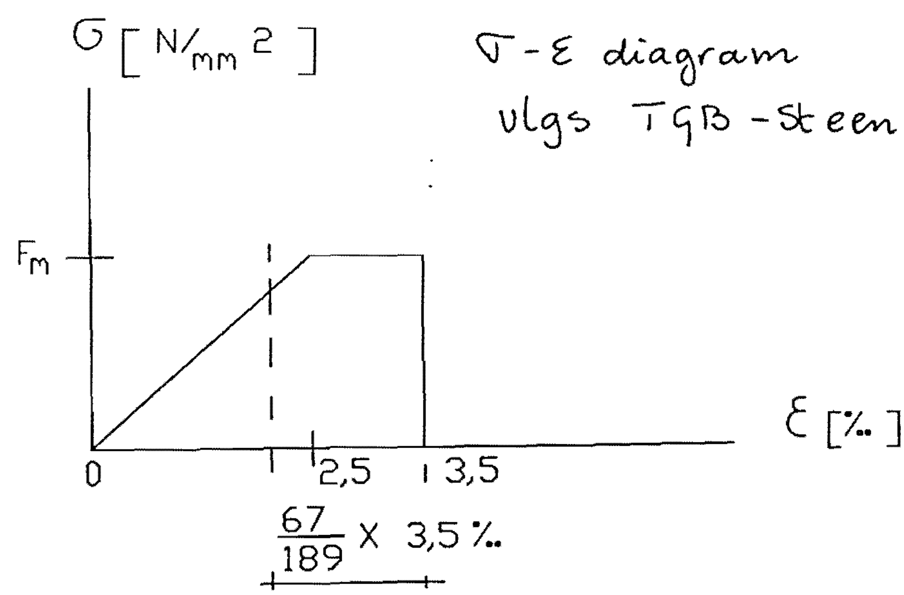
1. Wanneer het quotiënt van de vervormingsgrootheden $\nu_{st}E_{st} = \nu_m E_m$ gelijk is dan zijn er geen bijkomende spanningen loodrecht op de drukrichting.
2. De dwars-spanningen nemen toe met de verticale drukspanning en met de vervorming in dwarsrichting van de steen.
3. Bij dikkere stenen en dunnere voegen nemen de dwars-spanningen in de steen af (dus bij voegdikte = 0 zijn er geen dwars-spanningen).

Uit verticale scheuren in belast metselwerk blijkt dat spanningen volgens de theorie



figuur 5.6.

σ - ε diagram
vlgs TGB-steen.



van Haller optreden. De druksterkte van metselwerk hangt dus uiterst nauw samen met het gedrag van de steen en van de mortel. Steenachtige produkten die uit een (homogeen) materiaal bestaan scheuren ook loodrecht op de drukrichting. Dit dient toegeschreven te worden aan inhomogeniteiten in het materiaal, maar uiteraard ook aan het feit dat, zoals bij alle materialen, de druktrajectorie loodrecht staat op de trektrajectorie. Het proces van vervormen loodrecht op de drukrichting treedt altijd op, bij verschillende materialen echter in veel ernstiger mate.
Haller stelde verder dat:
- De belastingen op wanden zelden centrisch zijn.
- De steenstruktuur niet homogeen is (bij uitwendige druk treedt inwendig trek op)
- Er vraagtekens gezet moeten worden bij de wet van Hooke
- De Hypothese van Bernouilly (vlakke doorsneden blijven vlak) gehanteerd kan worden.

We komen hierop terug bij het bespreken van de berekening van constructie-elementen. Consequenties van de theorie van Haller zijn:

1. Metselwerk bezwijkt eerder op sterkte dan door instabiliteit.
2. Steen en mortel hebben meestal een inefficiënte samenwerking.
3. De stijfheid van de steen in relatie tot zijn treksterkte is zeer ongunstig voor de sterkte van metselwerk.

Samenvattend kan gesteld worden dat de treksterkte van de steen bepalend is voor het bezwijken van het metselwerk.

5.2 Druksterkte en E-modulus metselwerk volgens normen

Reeds eerder is gesteld dat de kwaliteit van metselwerk wordt bepaald door de stenen, de mortel, door de manier waarop deze verwerkt zijn, en door vele andere factoren. Het is de gewoonte de sterkte van metselwerk te relateren aan die van de twee gebruikte componenten. De steensterkte wordt daarbij bepaald met een enkele steen, de mortelsterkte wordt bepaald met drukproeven op prisma's. De invloed van de verwerking, de voegdikte en andere uitvoeringsfactoren worden daarbij niet in de beschouwingen betrokken. Ook wordt hierbij geen aandacht geschonken aan de invloed van de verwerkingscondities en de situatie op de bouw. Goede stenen en een goede mortel garanderen echter nog geen goed metselwerk, vandaar dat gewerkt wordt aan een proef waarmee de kwaliteit van het metselwerk gecontroleerd kan worden. Vergelijk dit met de betonkuben die op het werk gemaakt worden.
In de volgende paragrafen worden sterktecijfers gegeven volgens de TGB steen en de (ontwerp) Norm EC 6. Bij recent onderzoek is geen verband geconstateerd tussen de druksterkte van de steen, de druksterkte van de mortel en die van metselwerk.

5.2.1 Metselwerk-druksterkte, TGB tabel

De waarde van de druksterkte f'm is in de TGB-Steen afhankelijk gesteld van de steen- en morteldruksterkte. De steensterkten zijn weergegeven in NEN 2498 metselbaksteen en de mortelsamenstellingen en druksterkten in V1592 onder de

Hierbij moet de representatieve waarde van de morteldruksterkte volgens 9.1.4 zijn bepaald. Voor tussenliggende waarden mag rechtlijnig worden geïnterpoleerd.

Tabel 1 – Representatieve waarde van de druksterkte van metselwerk van baksteen in N/mm^2

gemiddelde druksterkte van de produkten volgens 8.3 van NEN 2489:1976	f'_{rep} N/mm^2		
	representatieve druksterkte van de mortel N/mm^2		
N/mm^2	2,5	7,5	≥ 12,5
5	1,0	1,5	2,0
10	2,0	3,0	3,5
15	3,0	4,5	5,0
20	4,0	5,5	6,5
25	4,5	6,5	8,0
30	5,0	7,5	9,0
35	5,5	8,5	10,0

Tabel 2 – Representatieve waarde van de druksterkte van metselwerk van kalkzandsteen in N/mm^2

gemiddelde druksterkte van de produkten volgens 9.3 van NEN 3837:1985	f'_{rep} N/mm^2		
	representatieve druksterkte van de mortel N/mm^2		
N/mm^2	2,5	7,5	≥ 12,5
15	4,0	5,0	6,0
25	6,5	7,5	8,5
30	7,5	8,5	9,5
35	8,0	9,0	10,0

Tabel 3 – Representatieve waarde van de druksterkte van metselwerk van betonsteen in N/mm^2

gemiddelde druksterkte van de produkten volgens 2.4 van NEN 7027:1973	f'_{rep} N/mm^2		
	representatieve druksterkte van de mortel N/mm^2		
N/mm^2	2,5	7,5	≥ 12,5
10	3,0	3,5	4,0
15	4,5	5,0	5,5
20	6,0	6,5	7,0
25	7,5	8,0	8,5
30	9,0	9,5	10,0

Tabel 4 – Representatieve waarde van de druksterkte van metselwerk van gasbeton in N/mm^2

gemiddelde druksterkte van de produkten volgens 6.4 van NEN 3838:1991	f'_{rep} N/mm^2	
	representatieve druksterkte van de mortel N/mm^2	
N/mm^2	mortel ≥ 7,5	lijmmortel ≥ 12,5
2,3	1,3	1,6
3,4	1,9	2,3
4,5	2,5	3,0
5,6	3,0	3,6
6,8	3,6	4,3

titel: mortels voor metsel- en voegwerk.

De gecombineerde waarden van baksteen en mortel zijn niet zonder meer te geven. Normaal gesproken zou de zwakste schakel in de keten de sterkte van het metselwerk bepalen doch op proefondervindelijke wijze is aangetoond dat dit niet het geval is.
De gecombineerde waarde die door proefnemingen is bepaald treft U aan in **tabel 1** van TGB-steen, NEN 6790.

Indien door proefnemingen wordt aangetoond dat afgeweken kan worden van de in **tabel 1** gegeven waarden voor metselwerkdruk-sterkten dan moet voldaan worden aan art. 9.1.2a van de TGB-Steen, waarin aangegeven is dat f'k bepaald mag worden met proeven zoals beschreven in bijlage A van de TGB-Steen.
De kalkzandsteen- en gasbetonproducenten hebben gebruik gemaakt van de mogelijkheid om hogere druksterkten toe te laten nadat dit door proefnemingen is aangetoond en hieruit zijn de resultaten van tabel 2, 3 en 4 van de TGB-steen voortgekomen.

5.2.2 Metselwerk-druksterkte Formule EC 6

In de EC 6 wordt in artikel 3.2.2.3 aangegeven hoe de breuksterkte van metselwerk bepaald kan worden. Hierbij wordt uitgegaan van de druksterkte van de stenen en de mortel. In formulevorm:

$$fk = K \,.\, fb^{\alpha} \,.\, fm^{\beta}$$

Voorgesteld wordt voor de factor K de waarde 0.4 te nemen.
Voor de exponenten α en ß wordt voorgesteld de waarden 0.75 en 0.25 te nemen. De parameters in de formule dienen nog op de situatie per land afgestemd te worden, vandaar dat de normcommissie vraagt om gegevens van elk betrokken land. Uit de formule blijkt dat de invloed van de mortel op de sterkte kleiner is dan die van de steen. Voor de steen- en morteldruksterkte moeten waarden ingevuld worden die volgens de EC-norm bepaald zijn. We hebben al gezien dat deze waarden alleen iets zeggen over de potentie van het materiaal en weinig over de sterkte van het metselwerk dat ermee gemaakt wordt.

5.2.3 Empirisch bepaalde metselwerk-druksterkte
De sterkte van de steen en van de mortel zijn reeds ter sprake gekomen, evenals het mechanische gedrag van de mortel tussen de stenen. Uit het reeds genoemde onderzoek naar de druksterkte van metselwerk blijkt dat er geen rekenkundig verband gegeven kan worden tussen de druksterkte van de mortel en de steen en het daarmee vervaardigde metselwerk. Door de leerstoel stapelbouw wordt gewerkt aan een beproevingsprocedure om de metselwerksterkte van een steen-mortel combinatie vooraf te bepalen (geschiktheidsproef), en om deze na het metselen te controleren (controle proef). De procedure moet ook gebruikt kunnen worden in geval van onenigheid tussen partijen (arbitrage proef).

Tabel 4. Druksterkte van gemetselde smalle proefstukken

mortel c:k:z	Steen	B50	BR&SM
1:½:4½	VE	10.2	8.7
1:½:4½	JG	19.2	16.3
1:½:4½	KZ		20.1
1:1:6	KZ		20.0
1:2:9	VE	10.8	
1:2:9	JG	20.6	
1:2:9	KZ	19.4	

VE = vormbaksteen   JG = strengperssteen
JB = harde strengperssteen
KZ = Kalkzandsteen
oud = gemiddelde ouderdom in dagen bij beproeven.

Tabel 5. Verhouding van de druksterkte van brede en smalle baksteen proefstukken

	1:½:1½	1:½:4½	1:½:9	gem.
VE	1.22	1.20	1.10	1.17
JG	1.18	0.98	0.96	1.04
JB	1.14	1.11		1.13
Gem.	1.18	1.25	1.11	

Gemiddelde van alle waarden: 1.11
Variatie-coëfficiënt: 8.80%

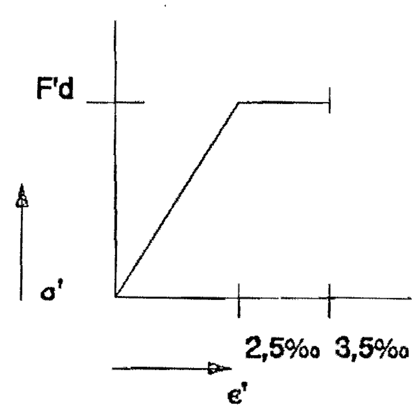


Fig. 5.7. σ-ε diagram NEN 6790, Druk

formule EC6:

$$f'_k = 0{,}4\,(f'_b)^{0{,}75} \cdot (f'_m)^{0{,}25}$$

↑ masonry ↑ brick ↑ mortar

$$f'_k = 0{,}45\sqrt[3]{(f'_b)^2 \cdot f'_m}$$

formule van Hermann:

$$f'_k = 0{,}1\,(2 f'_b + 3 f'_m - 7{,}5)$$

← waarden uit TGB steen tabel 1 voldoen hieraan.

5.2.3.1 Proeven B50
In de periode augustus 1990 tot april 1991 zijn in het van Musschenbroek laboratorium van de TUE voor CUR-commissie B50 drukproeven uitgevoerd op metselwerk proefstukken om de mechanische eigenschappen van de steen en de mortel in een zo realistisch mogelijke situatie te vinden. De gevonden eigenschappen worden gebruikt in computerprogramma's zoals DIANA en UDEC.

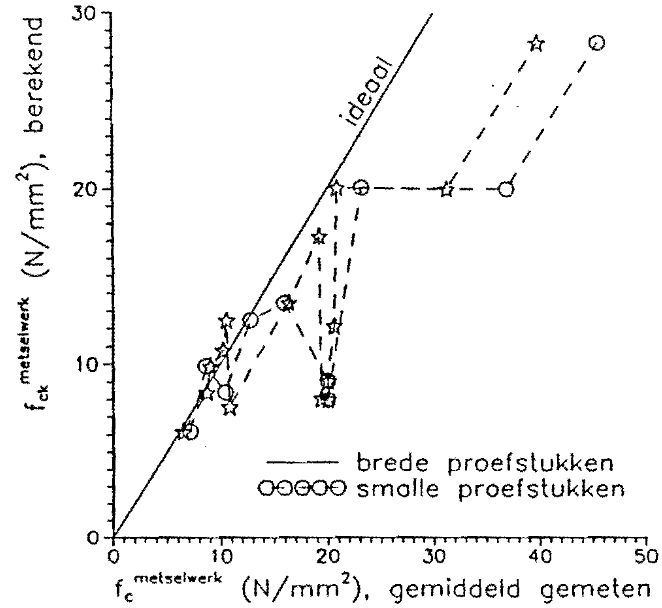
5.2.3.2 Proeven BR&SM
Als vervolg op de genoemde B50 proeven is onderzoek gedaan naar de invloed van de afmeting van de proefstukken op de druksterkte. Er zijn 36 brede en 36 smalle proefstukken beproefd. De resultaten worden in **tabel 4** gegeven.
De proefstukken zijn vervaardigd in overeenstemming met de regels die EC6 en RILEM geven. In **tabel 5** wordt de verhouding tussen de breuksterkte van de brede en de smalle proefstukken gegeven. Deze verhouding is gemiddeld 1,1. Bij het berekenen van de breukspanning is de bruto oppervlakte van de doorsnede genomen. In hoeverre de gevonden uitschieters toevallig zijn moet verder onderzoek uitwijzen.
De resultaten van **tabel 5** stemmen met de berekende waarde volgens Dutron overeen. De afmetingen van de proefstukken waren:
breed: 430 * 100 * 330 mm^3, en smal: 210 * 100 * 330 mm^3. Uit de formule van Dutron volgt voor de brede proefstukken een factor $\beta = 0.88$ en voor de smalle $\beta = 0.80$. De verhouding van de sterkte tussen brede en smalle proefstukken is dan: 0.88/0.80 = 1.10. De met proeven gevonden waarde is 1.11.
Uit het onderzoek van Page [4] is niet goed op te maken wat de invloed van de voegen op de aspect ratio is.

Scheurvorming en breuk
Het begin van scheurvorming is nauwelijks uit de kracht-vervormingsregistratie af te leiden. Bij ongeveer 80 á 85% van de breuklast begon de scheurvorming zich te manifesteren, vaak eerst alleen hoorbaar, en pas later zichtbaar. De scheuren zijn nagenoeg recht en lopen evenwijdig aan de werklijn van de belasting. Bij afnemen van de belasting komen schijven los met een dikte van 15 a 20mm. Bij verder vervormen valt het proefstuk uiteen en blijft enkel een diabolo-vormig deel over.

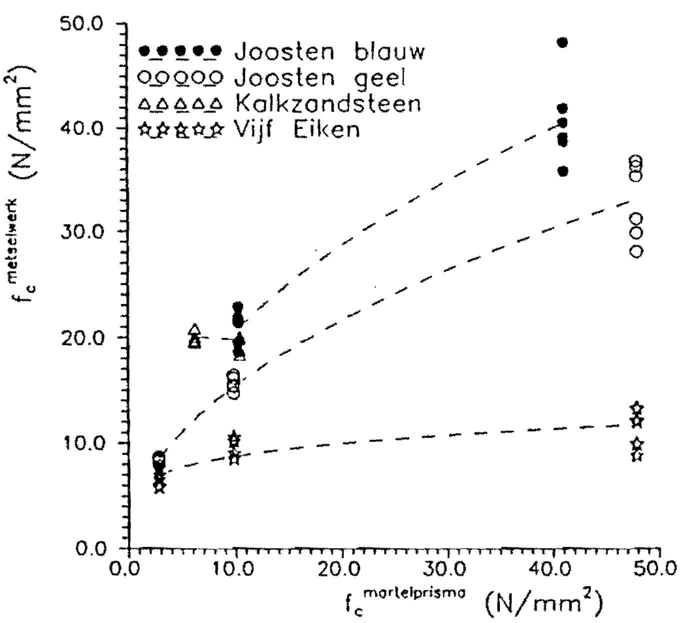
Praktijkproef
Uit de resultaten van het tot nu toe afgeronde deel van het onderzoek naar de sterkteverschillen van brede en smalle proefstukken kan geconcludeerd worden dat, met een proefstuk van 5 op elkaar gemetselde stenen de druksterkte van metselwerk bepaald kan worden. Voor verschillende constructietypen is wellicht een correctiefactor nodig. Verder onderzoek moet uitwijzen hoe groot en van welke parameters deze correctiefactor afhankelijk is.

5.2.4 E modulus metselwerk

(Zie figuur 5.7) Bij de berekening van metselwerk-constructies wordt hetzelfde bi-



Vergelijking tussen gemeten en volgens EC 6 berekende metselwerkdruksterkten



Metselwerkdruksterkte afhankelijk van de morteldruksterkte (NEN 3835)), gerangschikt naar steensoort

lineaire spannings-rek-diagram aangehouden als bij beton. (zie fig...)
Het "plastisch gedrag" kan optreden omdat in de metselwerk-constructie, nadat het materiaal gedeeltelijk is verbrijzeld, toch nog enige samenhang aanwezig is. In NEN 6790 worden de volgende E-moduli voor metselwerk in art. 9.4.1. gegeven:
Eloodrecht = 10^3 f'rep en
E// = 2 * 10^3 f'rep
Er wordt dus duidelijk onderscheid gemaakt tussen druk evenwijdig aan de lintvoegen en druk loodrecht op de lintvoegen. Voor de druksterkte is dit onderscheid er niet ! Bij het onderzoek aan brede en smalle proefstukken is gevonden dat de E-modulus afhankelijk is van de druksterkte volgens:

E_m = 525f'm - 560, doch dit is slechts een tendens.

Bij proeven met langeduurbelasting bleek, door kruip, de E-modulus terug te lopen tot Eloodrecht = 400 * f'm.

5.3 Hechtsterkte / Buigtreksterkte

(zie figuur 5.8) In het algemeen kan men niet rekenen op enige (buig-)treksterkte van het metselwerk. Toch kunnen wanden over het algemeen wel enige buiging opnemen. Het metselwerk heeft dus wel degelijk buigtreksterkte. Volgens art. 9.2.1. van de TGB-Steen mag de buigtreksterkte bepaald worden met proeven aan wandjes, of kan deze afgeleid worden van de hechttreksterkte die bepaald is met kruisproefstukken. De kruisporef wordt uitgevoerd op twee kruislings op elkaar gemetselde stenen, welke met hulpstukken van elkaar gedrukt worden. Het hechtvlak is ongeveer 10x10 cm^2. Deze proef is erg uitvoeringsgevoelig.
In de oude TGB-Steen werd een buigtreksterkte van 0.3 N/mm^2 toegestaan.
In recent onderzoek [2,3] is op verschillende manieren de hechttreksterkte en de buigtreksterkte bepaald.

In het Stevin lab. van de TUD zijn, onder begeleiding van van der Pluijm trekproeven op twee halve stenen met een voeg uitgevoerd. Kenmerk van deze proef was dat de boven en onderzijde van de proefstukken evenwijdig t.o.v. elkaar bewogen werden. Deze manier van belasten stemt het meest met de werkelijkheid overeen. Voor gebruik in numerieke modellen (DIANA en UDEC) zijn van belang: de hecht-treksterkte, de breukenergie en het post-piek gedrag. Deze grootheden konden met deze proeven bepaald worden.
(**Zie figuur 5.9**) Bij TNO, en ook in ons van Musschenbroek laboratorium, zijn eveneens (ex)centrische trekproeven uitgevoerd op dit type gemetselde proefstukken. Hierbij werden de proefstukken scharnierend aangesloten op de trekkoppen van de trekbank. Indien een voeg aan een zijde beter gehecht was dan aan de andere zijde viel de zwaartelijn van het proefstuk niet samen met de krachtlijn, dus dan werd er excentrisch getrokken. Deze proeven zijn uiteraard wel bruikbaar om een indicatie van de hechttreksterkte te verkrijgen.

Van der Pluijm is bezig (jan. 93) met de afronding van een onderzoek naar de buigtreksterkte van gemetselde wanden. Hierbij wordt tevens onderzocht wat de statistische kenmerken zijn.
Enkele resultaten van bovengenoemde proeven worden, ter indicatie, in **tabel 6**

1.5 Interactie steen en mortel

De baksteen zuigt uit de vers aangebrachte mortel water op waarbij de mortel "vaster" wordt. Bij een sterker zuigvermogen van de steen (hoog Haller getal) wordt veel water aan de mortel onttrokken, hierdoor neemt het verhardingsvermogen af en boet bovendien de verse mortel door de wateronttrekking aan vervormbaarheid in. **(Zie figuur 5.1)** Bij het opmetselen beweegt het bovenste gedeelte van de muur heen en weer, waarbij de mortelvoeg afgerond wordt. (wiebeleffect). De ruimten tussen mortel en steen verminderen het draagvermogen van het metselwerk bij centrische belasting slechts in geringe mate, bij excentrische belastingen daarentegen in hoge mate, doordat de ruimten het uitbuigen van het metselwerk onder belasting bevorderen. Deze werking van het zuigvermogen van de steen beïnvloedt dus de vervormbaarheid van de mortel tijdens het metselen nadelig. Vooral bij slanke kolommen en wanden heeft het wiebeleffect een grote invloed. **(Zie figuur 5.2)** Door Caspar Groot [1] van de TUD zijn proeven uitgevoerd waarbij met neutronen het vochttransport in de steen en de mortel is bepaald. Met name in de eerste minuten na het contact tussen steen en mortel vindt er een grote uitwisseling van vocht plaats, die erg afhankelijk is van de steen en mortelsoort. Bij baksteen vindt eerst vochttransport plaats van de mortel naar de steen en in een latere fase van de steen terug naar de mortel. Dit proces heeft grote invloed op de hechting tussen steen en mortel. Het contactvlak tussen de steen en de mortel is een "witte vlek", wat daar gebeurt wordt momenteel bestudeerd.

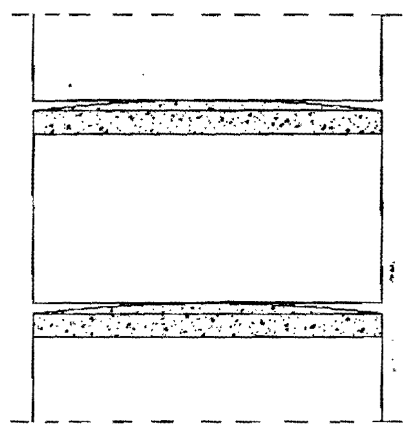


Fig. 5.1 Wiebeleffect

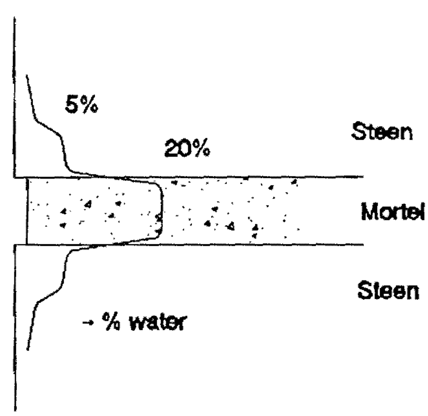


Fig. 5.2 Vochthuishouding in contactvlak mortel steen volgens Groot

APPENDIX J: Outcome of experiments.

Prisms Mortar A				
Strength of samples according to NEN 3835				
Flexural-tensile strength			Compressive strength	
Days	29			
Date	04-01-94			
	N/mm^2	Volume (N/mm^2)	N/mm^2	N/mm^2
A.1	-	-	0.63	0.66
A.2	0.04	158*40*40	0.30	0.63
A.3	-	-	0.57	0.55
A.4	0.04	159*40*40	0.33	0.38
A.5	0.07	157*40*40	0.33	0.34
A.6	0.06	160*40*40	0.38	0.33
Mean	**0.05**			**0.45**
Deviati on	**0.02**			**0.14**

Wall samples Mortar A		
Strength		
Days	29	
Date	04-01-94	
Days	Max. Force KN	Stress N/mm^2
A.1	92	4.4
A.2	77	3.6
A.3	82	3.9
Mean	**84**	**4.0**
Deviation	**7.6**	**0.4**

Prisms Mortar B				
Strength samples according to NEN 3835				
Flexural-tensile strength			Compressive strength	
Days	29			
Date	04-01-94			
	N/mm^2	Volume (N/mm^2)	N/mm^2	N/mm^2
B.1	0.06	No shrink	0.35	0.34
B.2	0.07	" "	0.37	0.34
B.3	0.02	" "	0.30	0.36
B.4	-	" "	0.35	0.37
B.5	0.05	" "	0.34	0.30
B.6	-	" "	0.29	0.38
Mean	**0.05**			**0.34**
Deviation	**0.02**			**0.03**

Wall samples Mortar B		
Strength		
Days	29	
Date	04-01-94	
Days	Max. Force KN	Stress N/mm^2
B.1	64	3.0
B.2	64	3.0
B.3	78 (30 days)	3.7 (30 days)
Mean	**69**	**3.3**
Deviation	**8.1**	**0.38**

Prisms Mortar C				
Strength samples according to NEN 3835				
Flexural-tensile strength			Compressive strength	
Days	27			
Date	12-10-94			
	N/mm^2	Volume (N/mm^2)	N/mm^2	N/mm^2
C.1	0.33	No shrink	2.46	2.33
C.2	0.33	" "	2.41	2.60
C.3	0.34	" "	2.54	2.72
C.4	0.34	" "	2.55	2.38
C.5	0.33	" "	2.51	2.35
C.6	0.32	" "	2.64	2.51
Mean	**0.33**			**2.50**
Deviation	**0.01**			**0.12**

Wall samples Mortar C		
Strength		
Days	27	
Date	12-01-94	
Days	Max. Force KN	Stress N/mm^2
C.1	155	7.3
C.2	162	7.7
C.3	152	7.2
Mean	**156**	**7.4**
Deviation	**5.1**	**0.2**

Prisms Mortar D				
Strength samples according to NEN 3835				
Flexural-tensile strength			Compressive strength	
Days	27			
Date	12-01-94			
	N/mm^2	Volume (N/mm^2)	N/mm^2	N/mm^2
D.1	0.39	No shrink	3.19	2.76
D.2	0.46	" "	3.12	2.94
D.3	0.42	" "	3.26	2.87
D.4	0.37	" "	3.31	3.51
D.5	0.36	" "	3.31	3.34
D.6	0.42	" "	3.43	3.68
Mean	**0.40**			**3.23**
Deviation	**0.04**			**0.27**

Wall samples Mortar D		
Strength		
Days	27	
Date	12-01-94	
Days	Max. Force KN	Stress N/mm^2
D.1	141	6.7
D.2	123	5.8
D.3	101	4.8
Mean	**122**	**5.8**
Deviation	**20**	**0.9**

Prisms Mortar E				
Strength samples according to NEN 3835				
Flexural-tensile strength			Compressive strength	
Days	29			
Date	14-01-94			
	N/mm^2	Volume (N/mm^2)	N/mm^2	N/mm^2
E.1	0.32	No shrink	1.12	1.26
E.2	0.34	" "	1.29	1.43
E.3	0.35	" "	1.34	1.33
E.4	0.29	" "	1.32	1.26
E.5	0.32	" "	1.29	1.38
E.6	0.30	" "	1.30	1.18
Mean	**0.32**			**1.29**
Deviation	**0.02**			**0.08**

Wall samples Mortar E		
Strength		
Days	29	
Date	14-01-94	
Days	Max. Force KN	Stress N/mm^2
E.1	149	5.7
E.2	138	6.5
E.3	143	6.8
Mean	**143**	**6.3**
Deviation	**5.5**	**0.6**

Prisms Mortar F				
Strength samples according to NEN 3835				
Flexural-tensile strength			Compressive strength	
Days	29			
Date	14-01-94			
	N/mm^2	Volume (N/mm^2)	N/mm^2	N/mm^2
F.1	0.35	No shrink	1.53	1.59
F.2	0.35	" "	1.42	1.25
F.3	0.36	" "	1.49	1.51
F.4	0.43	" "	1.59	1.62
F.5	0.39	" "	1.63	1.63
F.6	0.42	" "	1.51	1.67
Mean	**0.38**			**1.53**
Deviation	**0.03**			**0.12**

Wall samples Mortar F		
Strength		
Days	29	
Date	14-01-94	
Days	Max. Force KN	Stress N/mm^2
F.1	120	5.7
F.2	146	6.9
F.3	134	6.4
Mean	**133**	**6.3**
Deviation	**13**	**0.6**

APPENDIX K; **Compression-force/deformation-diagram of wall-sample, mortar F.**