

## Paper

# The performance of cob as a building material

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## Introduction

Earth has been used for several thousand years as a material in the construction of embankments, dams, walls and occasionally domed roofs. Examples of earth buildings include the Great Wall of China, which is faced only with stone, houses and granaries in many Third World countries, and some of the older dwellings in many other places. It is estimated that about a third of the world's population live in earth dwellings.

In some of the more developed countries, such as England, France and Germany, there is renewed interest in earth buildings - particularly with regard to the repair and preservation of existing buildings, and also the construction of new, environmentally friendly dwellings.

A great deal of information is available on the use of earth for buildings. However, there are only a limited amount of technical data relating to its properties and the effect of adding fibre. An investigation has started at the University of Plymouth to generate guidelines for some of the properties, site quality control, and testing the suitability of the earth (soil) being used as a building material. It is intended that this information will be beneficial to those parties concerned with the performance of earth buildings. To date only one type of soil has been used in the investigation. Straw has been added to simulate 'cob', the name of the material used in most West Country earth dwellings. Fig 1 shows a cob house built by Alf Howard in Down St. Mary, mid Devon, in 1990, at the moment it is unrendered.

## Methods of earth building construction

The way soil is used in building construction depends mainly on the traditions of the locality<sup>1</sup>. These will probably have developed as a result of the climate, the labour force, degree of mechanisation, and wall thickness. The methods include:

- Adobe - brickettes
- Wattle and daub
- Rammed earth
- Cob

In most cases, soil containing clay will be mixed with water until it becomes soft and sticky. It is then either placed *insitu* or made into blocks or brickettes. Subsequent drying increases the strength.

### Adobe

Soil with a high proportion of clay requires the addition of a lot of water to make it workable, and subsequent drying produces much shrinkage. Making brickettes allows this drying shrinkage to occur before use. Smaller brickettes dry faster because of an increase in surface area to volume ratio.

Fig 1. Cob house built in 1990, mid Devon



### Wattle and daub

Thin layers of clay are placed against a timber frame or screen, which provides the initial support for the weak clay and helps to prevent major drying shrinkage cracks

### Rammed earth

Rammed earth requires some form of formwork, similar to concrete. The soil used would be in a moist state, a lot stronger than soft clay, and would require significant pressure or compaction to force it into a dense state and make it adhere together. Immediately after compaction, the resulting mass should be strong enough to be self-supporting, require less drying/unit volume than brickettes and have less shrinkage problems.

### Cob

Clay that contains sufficient water to make it sticky will be in a weak soft state, and will require only a low pressure to make it adhere together. Higher pressures applied to it will have little additional benefit once the main air voids have been squeezed out. If the soil/water mix has little strength before drying, it is unlikely to be placed *insitu* without support. Support in the form of formwork could be used to provide the initial support. However, this would inhibit drying and the increase in strength necessary before the formwork can be removed.

In some parts of England, very moist clayey soil, in a soft state, is placed *insitu* in layers without any external support<sup>2</sup>. The soil is largely prevented from slumping and expanding laterally by the addition of tensile reinforcement. This reinforcement consists of natural fibres added to the softened soil during the mixing stage. In cob, the fibres are usually wheat or barley straw.

## Cob construction

There is a need for a greater understanding of the characteristics of cob, as the number of traditional craftsmen involved with its construction dwindles and the requirements for the building industry's need for knowledge increases.

Most cob buildings are between 100 and 400 years old. For these, local subsoil and straw would have been used, with the building work being carried out during the summer months using local labourers. The mixing, placing, trimming and rate of construction would have followed broad guidelines. Specifications, building inspections, quality controls, and details of the performance of the material, would not have applied. Common sense, experience, and a feel for the material, would have been the main guidelines. For any new cob construction, and some repair work, a more cautious approach is required.

### Suitable soil types

There is a very wide variety of soils throughout the country. They vary in the proportions of gravel, sand, silt and clay present, the shape and strength of the coarse particles, and the plasticity of the fine particles. If coarse particles are dominant, the strength depends mainly on how dense it is, and to a lesser extent its moisture content.

When the proportion of fine particles present, i.e. silt and clay, exceeds about 15%, there is sufficient to act as a binder between the coarse particles, and the strength will then be more dependent on the moisture content<sup>3</sup>. The strength of dry clayey soils can be very high depending on the amount and type of clay mineral present. The results of plasticity tests to measure the liquid limit (LL) and plastic limit (PL) can be used to give an indication of how clayey the fines in a soil are. These limits are in terms of moisture content, details of which can be obtained from most basic soils textbooks.

A typical soil for cob is likely to contain about 30% gravel, 35% sand, and 35% silt and clay. However, each of these could vary by  $\pm 10\%$  and still be acceptable. For material finer than 0.425mm, which includes all the silt and clay, an easy guideline for suitability is the plasticity index (PI). This is the moisture content range from the LL to the PL. If the PI value is less

than about 10%, the soil may not be sufficiently clayey to give adequate dry strength.

**Mixing**

A cob mix ready for placing requires the moisture and added straw to be evenly distributed throughout. The straw content is typically 1% to 2% by weight. The soil will be soft and adhering to the straw. If the soil is too dry, it is very difficult to mix the straw in and generate an adequate bond between the two. The best method of mixing involves some form of treading, forcing the straw and clay into contact.

Concrete mixers do not do this. If the soil is too clayey, i.e. a PI value for the fines greater than about 30%, the extra time and effort required to mix the water into the soil can become a limiting factor. Mixes are often turned several times and allowed to stand for 1 or 2 days in order to achieve an even distribution of moisture throughout.

Most of the cob used to date has been mixed in small batches with the aid of human treading, or in larger batches with the aid of cattle in yards; docile heavier breeds, such as South Devons, are ideal for this purpose. More recently, tractor wheels and back-acters have been used.

**Placing**

The base for a cob wall normally consists of a masonry wall, 450mm to 600mm wide. In some domestic buildings the height of the plinth could vary from 450mm above ground up to first-floor level<sup>3</sup>. It should be high enough to provide protection against rising damp and splashes. Cob is built up in horizontal layers, 50mm to 100mm thick, each layer being compacted by treading or using a wooden dolly. As the mix should be soft and workable, this form of compaction is adequate to achieve the density and bond required. A 'lift' is the result of consecutive layering. Lifts normally range from 300mm to 900mm high depending on soil type and wet strength. Subsequent lifts will be placed when the previous one has become sufficiently stable because of an increase in strength from drying. Some settlement and drying shrinkage will have taken place.

**Trimming**

When cob is placed, the sides will be irregular and wider than required. The surplus material is trimmed back by paring downwards when the material has gained sufficient strength not to deform because of the paring action. However, the material should not be so strong that the paring is difficult to carry out. The downward action helps to align the straw ends, so that rain water is more easily shed.

**Load support**

The highest vertical stresses in cob buildings are likely to be at the base of gable end walls, and under roof trusses, where wall plates help to distribute the load

**Laboratory investigation**

The items identified for the initial investigation include the effect of straw and moisture content on:

- the ease of mixing
- suitability for placing
- rate of drying
- shrinkage and cracking during drying
- the compressive strength, mode and deformation at failure
- deformation under a concentrated force
- weathering

From these an optimum straw content is suggested.

**Soil type**

The initial testing programme has used soil obtained from a site in Teignmouth, South Devon. It is a red, very clayey sand and gravel, derived from weathered breccia. Many satisfactory cob buildings in the area used similar material. Classification of the material indicated approximately 30% gravel, 35% sand, and 35% silt and clay. The LL was typically 40%, and the PI 20%.

**Specimen preparation**

Cylindrical specimens were formed in standard concrete moulds 300mm high and 150mm diameter. Smaller sized specimens were regarded as unrepresentative, and larger ones too heavy to handle conveniently. The cob mix was compacted into moulds in about eight equal layers, using a 2.5kg steel rammer.

The aim during compaction was to produce specimens that did not contain noticeable air voids. As the cob mix was generally in a soft state, overcompaction would have little additional effect on the density. The specimens were jacked vertically out of the moulds, placed upright in individual metal trays, measured and weighed.

The testing programme, to date, has been in 3 parts. The main variables for the sets of specimens have been the initial moisture content at which the specimens were prepared, and the straw content. All of the moisture and straw contents relate to the dry soil weights. Details of the 24 specimens for part 1 are given in Table 1.

TABLE 1 - Specimen details

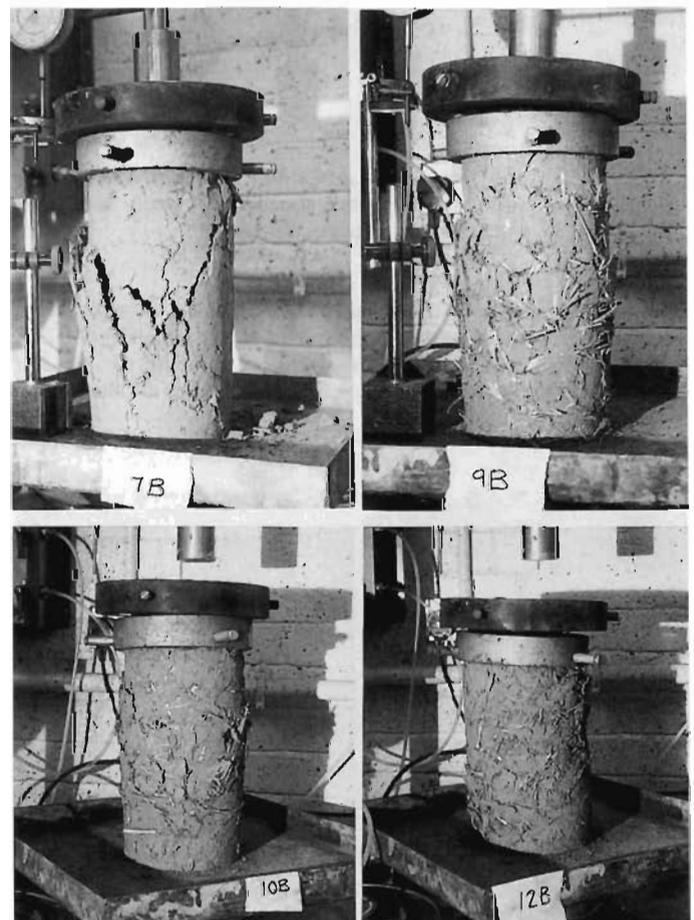
Straw content (% by weight)	Moisture content					
	Slightly dry		About right (Optimum)		Slightly wet	
0	1A	1B	7A	7B	6A	6B
0.2	2A	2B	8A	8B	3A	3B
0.6	4A	4B	9A	9B	5A	5B
1.2			10A	10B		
2			11A	11B		
3			12A	12B		

For part 2, 14 similar specimens were prepared with a straw content of 1.5%. Part 3 consisted of four pairs of specimens with straw contents of 0%, 0.6%, 2.0%, and 3.0%. All of the part 2 and 3 specimens were prepared at moisture contents judged to be close to the optimum for suitability of placing and strength.

**Testing**

For part 1, all of the A specimens were axially unconfined compression tested immediately after preparation, to give an indication of the initial wet strength. The B specimens were allowed to air dry in the laboratory for about 3 weeks. As they dried, their masses and heights were recorded at regular intervals, and observations made for shrinkage cracks. They were then unconfined compression tested, and often loaded to a strain well in excess

Fig 2. Failure modes for specimens with increasing straw content



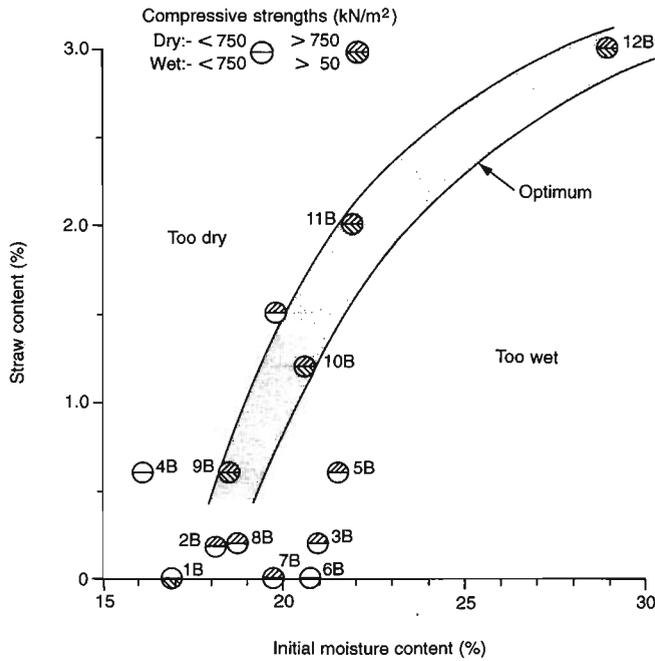


Fig 3. Optimum cob mixes based on initial wet strength and final air-dried strengths

of that at failure, to help clarify the failure mode, shown in Fig 2 for specimens 7B, 9B, 10B, and 12B.

The part 2 specimens were used to investigate the variation in compressive strength with moisture content. Several of these specimens were centrally loaded at one end via a 38mm diameter steel disc. Nominal loads were applied, and the disc penetration was recorded.

Strength tests on the part 3 specimens provided additional values at

Fig 4. Bonding and shrinkage of cob specimens

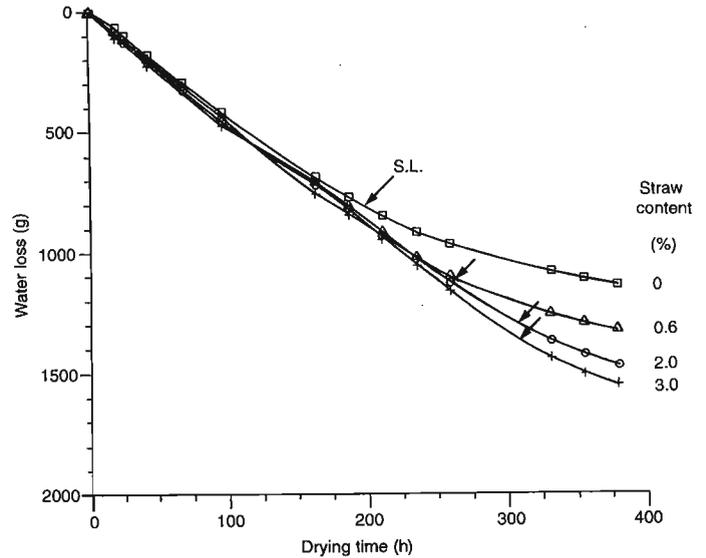
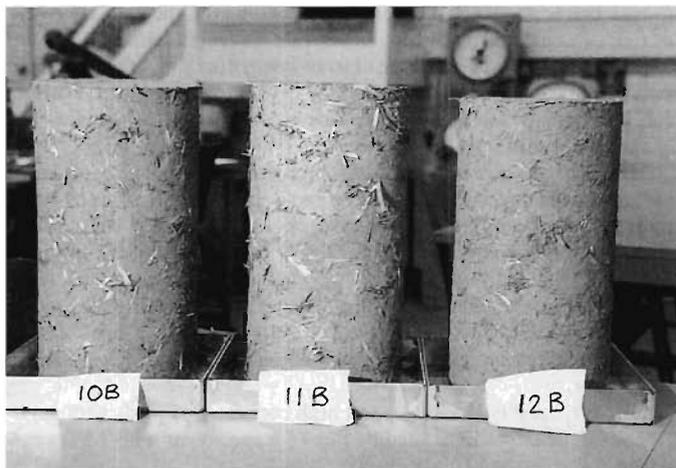
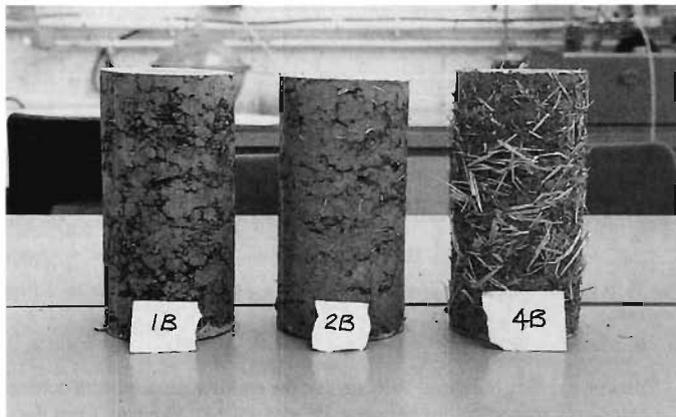


Fig 5. Drying rates for 300mm x 150mm diameter cob specimen

intermediate moisture contents. They were dried at a constant temperature of 25°C and a relative humidity of 75%, for either 10 or 17 days. Frequent weight and size measurements were taken.

**Test results and observations**

*Ease of mixing*

As a general rule, the higher the plasticity index and liquid limit, the more clayey the fine particles will be in a soil and the longer it will take for water to soak in to soften the soil to a state when the straw can easily adhere to it. These guidelines, together with the durability, strength, and shrinkage implications for a range of soil types, are under investigation. It is likely that clays with LL > 60% and PI > 30% will be unsuitable because of mixing time and shrinkage.

*Suitability for placing*

Cob that is in an optimum state is usually mixed so that the straw is coated with clay, and could be easily moulded by hand into an intact ball which feels sticky but not wet, the moisture content is judged to be 'about right'. It should then be suitable for placing to form a well-bonded mass.

Cob that is on the dry side will contain stronger lumps of soil and straw loosely adhering. This material will require much more compactive effort in order to form a dense mass with the soil and straw well bonded. Cob that is made too wet will either be relatively unstable during placing or require the addition of more straw to provide extra strength.

For the soil used, the effect of moisture and straw content on the suitability of the mix is illustrated in terms of wet and dry strengths in Fig 3. Optimum mixes have been regarded as cases where the initial wet strength is greater than 50kN/m<sup>2</sup> and the final air dried strength greater than 750kN/m<sup>2</sup>.

The specimens 1B, 2B, and 4B, which were prepared slightly dry, (Fig 4), show poor bonding and compaction, while specimens 10B, 11B, and 12B, with much higher moisture and straw contents, are intact. Poor bonding and compaction leads to lower strengths.

*Rate of drying, shrinkage, and cracking*

The drying rates for the part 3 specimens are shown on Fig 5. As the specimens were of similar initial dimensions, the actual water losses have been recorded to provide a comparison. The drying rates do not appear to be influenced by straw or moisture content for a particular soil, and are relatively uniform until linear shrinkage ceases. The points at which overall shrinkage ceased during drying are indicated, together with the corresponding moisture contents, the initial moisture contents, and the initial volume of water present. The moisture contents at which shrinkage ceased in relation to straw content, for the part 1 and 3 specimens, are recorded on Fig 6.

The overall linear drying shrinkage for these specimens, in relation to their initial moisture contents are recorded on Fig 7. The mixes that contained the most straw, and required the most water to provide a suitable mix, tended to shrink the most. Specimens 10B, 11B, and 12B, in Fig 4, are in the dried state. The larger height reduction for 12B is noticeable. Even

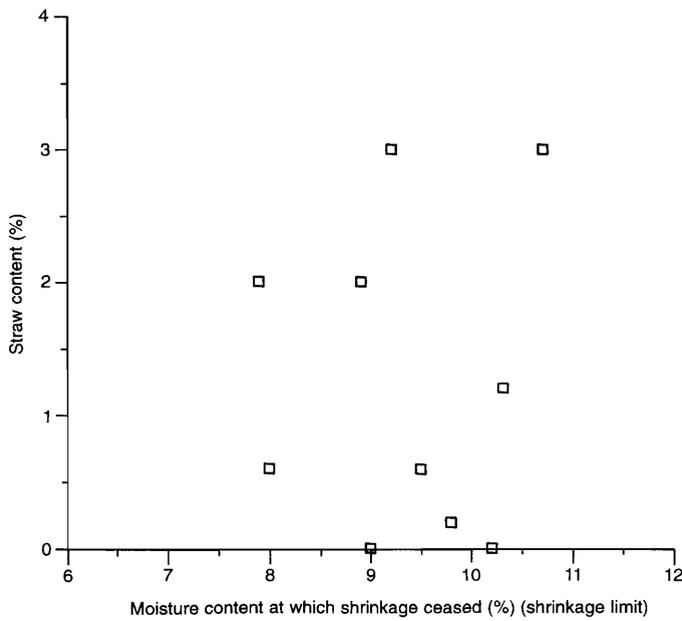


Fig 6. Drying shrinkage of cob specimens

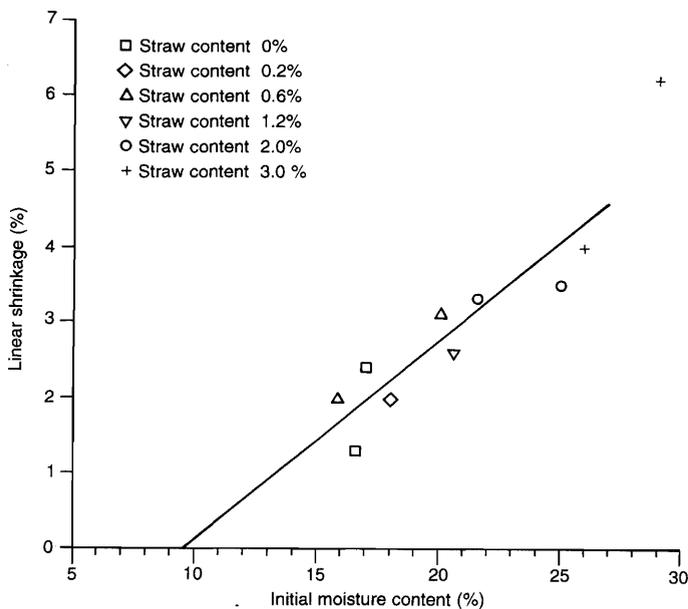


Fig 7. Drying shrinkage of cob specimens

though 12B shrunk most on drying, the higher straw content allowed the formation of only a few hairline cracks. The specimens with the lower straw content tended to contain the largest shrinkage cracks. The tensile strength and bonding of the straw clearly helped to reduce cracking, even though the overall volume changes were larger.

Extrapolation on Fig 7 indicates an initial moisture content of 9% to 10% for zero shrinkage, however, soil is not likely to be used at initial moisture contents as low as this, apart from rammed earth. This moisture content coincides with the average below which no more overall linear shrinkage occurred, however, some slight surface cracking continued.

*Variation in strength with moisture and straw content*

The variation in compressive strength of the specimens, Fig 8, has produced the inevitable scatter, partly due to no allowances for densities and the inclusion of weak specimens made too dry and lacking adequate bond. The general trend is an increase in strength due to a reduction in moisture content and an increase in straw content. Below a moisture content of about 10%, similar to the shrinkage limit, all strengths were greater than 600 kN/m<sup>2</sup>, irrespective of straw content. This strength is probably sufficient to provide an adequate margin of safety for structural loads within dwellings up to three storeys high.

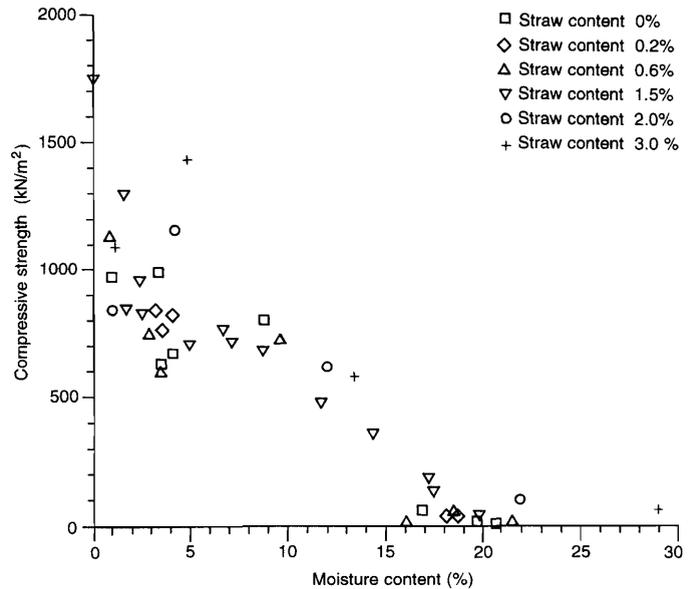


Fig 8. Variation in compressive strength with moisture and straw content

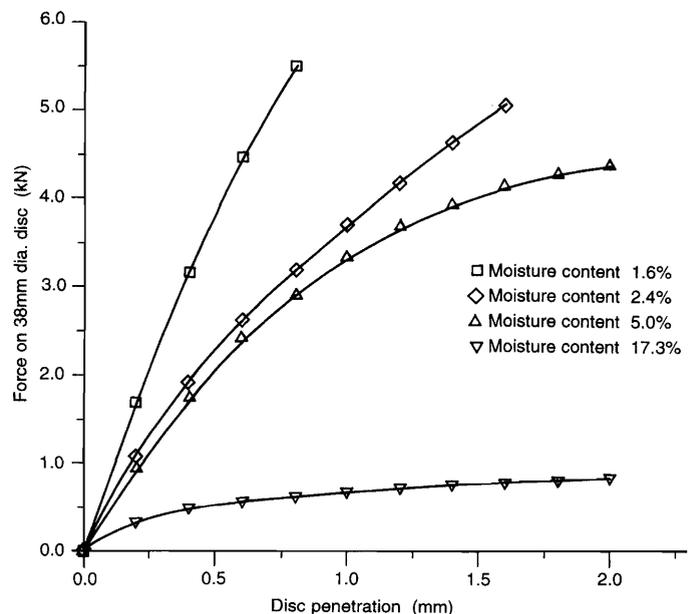


Fig 9. Indentation due to concentrated force on cob at various moisture contents

Tests on existing buildings indicate that the equilibrium moisture content for many cob properties lies between 3% and 4% (4). The part 1 test data, shown in Fig 8, indicate the possibility of a lower characteristic compressive strength below about 4% moisture content. However, the part 2 test data, for a straw content of 1.5%, do not indicate a strength reduction. Further studies to determine the influence of straw content on 'dry' cob strength are being undertaken. Evidence of the ability of 'dry' cob to support relatively high, concentrated loads without excessive deformation is shown in Fig 9 for specimens with 1.5% straw content.

The higher the straw content, the higher the strain at failure due to loading, as illustrated on Fig 2. The straw provides significant tensile strength. Specimen 7B contained no straw, and produced well-defined failure planes at an axial strain of 1.6%. The maximum stress in specimen 12B, with 3.0% straw, occurred at 11% strain, and also when there were virtually no visual signs of failure. Fig 1 shows the specimen at 30% strain. It is still holding together, and is failing by expanding along a series of shear planes. The failure strains for specimens 9B and 10B were 2.8% and 4.9%, respectively.

Intact 'dry' cob is able to support high concentrated loads with negligible deformation, as illustrated by Fig 9 for specimens with 1.5% straw content.

**Concluding remarks**

This paper concentrates mainly on the effect of straw and moisture on volume and strength changes for cob made with one soil type. Durability and thermal properties are also of major importance, and require investigation.

It is a well-known fact that, when the moisture content of clayey soils increases they become weaker. At higher moisture contents, the addition of straw has a beneficial effect on the strength, provided it is well bonded. If too much straw is added, the extra water also needed leads to increased volume changes during drying however the straw reduces the size of cracks. The straw content does not appear to effect the rate of drying, (Fig 5).

The main purpose of the straw is probably to enable soft clayey soil to be placed without the use of shuttering. The minimum wet strength adopted on Fig 3 of 50kN/m<sup>2</sup> would be sufficient for lifts of about 2 m to be constructed before being allowed to dry. A straw content of at least 0.5% appears to be required.

For the soil used, if the moisture content of the cob stays below about 9%, negligible volume changes should occur because of variations in moisture content, and the strength should be adequate, irrespective of straw content, for the range of straw contents considered.

If water were allowed to soak directly into cob, or if a gradual build-up were allowed to occur behind a cracked surface finish of low permeability, collapse could result. Collapse is likely to be less dramatic the more straw is present, provided the straw still has adequate strength. High moisture contents will also affect and eventually reduce the durability of straw, leading to a greater potential loss in strength for cob with higher straw contents.

A straw content of about 1.0% to 1.5% is probably optimal when all of the above factors are considered. This amount may vary for different soil types, and is a topic for future work.

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