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Composition, effective thermal conductivity and specific heat of cob earth-walling

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Abstract

Samples of cob earth-walling of the type used in vernacular buildings in the West Country region of the United Kingdom and thought to be of significance from both structural and historic points of view, have been assessed. The compositions of the samples were as expected. A transient thermal-probe technique was used to determine the thermal conductivities (~0.6W/mK) of the samples in their normally-moist state.Their specific heat capacity, for an average moisture content of 3%, was ~891 J/kgK.

Nomenclature

C	Specific heat capacity of the cob material (J/kgK).
k	Apparent thermal conductivity of the cob material, (W/mK).
PVC	Polyvinylcloride
Q	Rate of heat flow through the sample of cob material, (W).
T	Temperature, (°C).
t	time, (seconds).
1,2	Appropriate time intervals, (seconds).

The Problem

The widely-adopted practice, especially in the south-west of England, of constructing dwellings with un-baked earth-walling, lapsed at the start of the 20th century. However about 20,000 such buildings are still used within the counties of Devon and Cornwall (Building Research Board[1]). This is surprising in view of the fragility of the original walling material, and the length of time during which there has been a lack of available appropriate craft skills for the repair and maintenance of such walls. Many such surviving dwellings have now been listed by local authorities as buildings of special historic and architectural interest. There is therefore a requirement to conserve and protect such buildings, and for alterations to be restricted. The current building-regulations (Building Regulations[3]) require an assessment to be made of the heat flows through the external elements of a building, and this would apply when permitted alterations or extensions are to be undertaken to buildings of this type. It is therefore necessary to establish the thermal properties of the materials used in their construction. This information is unavailable, at the present time, for most historic un-baked earth materials.

The Material

Cob is a walling material comprising mainly of clay and straw, mixed with water and in some instances dung, to a consistency which is easily worked. The walls were usually built up in layers of approximately 50cm in height. Most agricultural cob buildings were left in this un-rendered state, whereas the cob walls of dwellings were often rendered with lime-based coverings to provide added protection from the elements and more uniform external and internal finishes. The moisture content of a rendered wall is determined by the hygroscopic salts contained within it and the local humidity. The cob walls of domestic dwellings tend to have a more stable moisture content than the less well-protected cob walls of agricultural buildings.

Grading Analysis

Samples of cob were obtained from Plymouth University. A sieve analysis was undertaken to verify whether the overall sample could be regarded as representative of West Country cob. The results were compared with historic data (Building Research Board[1])(Devon Historic Buildings Trust[2]).

To be representative implies satisfying:-

Criterion (i)

The sample's constituent parts closely resemble those of a typical piece of cob walling material from the West Country.

Criterion (ii)

The gradings of the sample satisfy the theoretical optimum with respect to ensuring the achievement of a stable walling-material.

The only two specific examples of itemised specifications (namely I and II) of the general composition of cob walling are those listed below. Thus to devise a standard that can be followed a 'middle ground' interpretation is taken between the two listings:-

Listing I

Ingredient	Percentage by Mass
Stones (residue on 7 x 7 mesh sieve)	24.40%
Sand, coarse (residue on 50 x 50 mesh)	19.70%
Sand, fine (through 50 x 50 mesh sieve	32.50%
Clay	20.60%
Straw	1.25%
Water	1.55%

Listing II

Ingredient	Percentage by Mass
Stones and gravel over 5mm diameter (about)	30-40%
Fine and coarse sands	25-30%
Silt	10-20%
Clay	10-25%

This 'middle ground' was found by linking the percentage associated with a particular size of particle with the sieve or group of sieves that most closely meet the range of gradings that described that particular particle.This can be seen in Tables 1 and 2.

TABLE 1: COMPARISON BETWEEN METRIC SIEVES AND GRADINGS

PASSING SIEVE SIZE	GRADING DESCRIPTION
10mm(retained upon a 5mm sieve)	Stones and gravel around 5mm in diameter, 30-40% by mass
5mm	
2.86mm	Fine and coarse sands, 25-30% by mass
1.18mm	
0.6mm	
0.3mm	silt, 10-20% by mass
0.15mm	
0.075mm	clay, 10-25% by mass
catchpan	

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TABLE 2: COMPARISON BETWEEN IMPERIAL SIEVES AND GRADINGS	
PASSING SIEVE SIZE	GRADING DESCRIPTION
1 1/2''	Stones, 20-30% by mass
3/4''	
1/2''	Coarse Sand, 15-25% by mass
3/8''	
1/30"	Fine Sand, 25-40% by mass
1/150"	Silt
Catch pan	Fine dust or clay particles

An appropriate sieve analysis was then carried out on the samples for both metric and imperial sieves. These results are shown in Tables 3 and 4, both with mass retained and mass passing each sieve.

TABLE 3: THE METRIC SIEVE TEST				
SIEVE SIZE	MASS RETAINED	PERCENTAGE MASS RETAINED	MASS PASSING	PERCENTAGE MASS PASSING
10mm	94.2g	24.6%	1903.6g	95.3%
5mm	398.2g		1505.4g	75.4%
2.86mm	275.6g	32.2%	1229.8g	61.6%
1.18mm	170.5g		1059.3g	53%
0.6mm	197.2g		862.1g	43.2%
0.3mm	165.1g	18.9%	697g	34.8%
0.15mm	213.8g		483.2g	24.1%
0.075mm	334.8g	24.1%	146.2g	7.3%
Catchpan	146.2g		—	— 310
TOTAL	1997.8g	99.8%	—	—

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TABLE 4: THE IMPERIAL SIEVE TEST

SIEVE SIZE	MASS RETAINED	PERCENTAGE MASS RETAINED	MASS PASSING	PERCENTAGE MASS PASSING
11/2''	—	15.5%	1986.7g	100%
3/4''	308.2g		1678.5	84.5%
1/2''	126.8g	14.9%	1551.7g	78.1%
3/8''	169.4g		1382.3g	69.6%
1/30"	704.2g	35.4%	678.1g	34.13%
1/150"	473.5g	23.8%	204.6g	10.3%
Catchpan	204.6g	10.3%	—	—
TOTAL	1986.7g	99.9%	—	—

After analysing the results shown in the above Tables, it can be seen that the results from both sets of sieve tests do match the proposed criteria laid out in tables 1 and 2. The Imperial-sieve test results appear to have a weaker correlation when compared with the good match given by the metric results. If the percentage mass retained column is compared with the grading descriptions, the Imperial-Sieves have an error of about 4.5% for 'stones' and a very slight discrepancy of 0.1% for 'coarse sand'. The value for fine sand is within the required measurement band and, as no real limits were put upon the amounts of either silt or clay/dust, it can be assumed that if the requirements laid down for the metric tests are met, then the sample would meet any that, in turn, might have been required for the Imperial tests.

The metric results shown in the 'mass-retained' column of Table 3 give a closer fit to the required banding stipulated in Table 1 than those of the Imperial sieve tests.

The two occasions that the readings diverge from the required limits is firstly for stones 'around 5mm' maximum dimension. This particular difference is 5.4%, which at first seems more important than the 4.5% error exhibited for the Imperial sieves, but the instance of a larger particle and therefore, larger mass being included or not included is more uncertain and has a considerably greater effect on the mass-retained figures than the more certain effect of a considerably larger quantity of smaller particles. For this reason, the Devon Historical Trust's figures were couched in very general terms for this particular grading (they state 'about' next to the requirement), the error can be 'down graded ' to a level that does not annul the validity of the sample and the possibility of the inclusion of particles of this size can be viewed as a matter of chance. Their existence within the walls of cob material is not detrimental but also not an essential ingredient. The rest of the results concur well with the grading descriptions, especially those of the silt and clay figures which in turn verify the missing figures from the Imperial grading descriptions.

These results fit the grading criterion (i) with a small enough margin of error to be viewed as being of a representative historical sample of cob. After criterion (i) has been satisfied, that the sample is historically representative then criterion item (ii), i.e. is the sample able to bear a reasonable load? needs to be addressed;

The strength of the material depends on the combination of many factors, including (i) the grading of the soil, (ii) the clay content, (iii) the presence of inert material e.g. stones, (iv) whether there is enough straw present to bridge any micro-cracking, which may occur, and (v) whether there is insufficient organic matter contained within the soil to decay and so cause significant numbers of voids.

A uniform grading is preferred, thus enabling as many particles to "interlock" or fill the voids between each other so reducing the quantity of air present and thus increasing the sample's overall density. The sample that was tested gave a very even spread of particles with no large concentrations of any single size, and only a moderate amount of particles below the 0.3mm dimension and so satisfies the requirement for a reasonable amount of clay. This will enhance the cohesion of the mix, but not lead to excessive cracking because of the larger quantity of greater than 1.18mm dimension material present .

Specific Heat Capacity

This was measured by heating two batches of samples (of 377g and 345g of cob respectively) wrapped in PVC film, and then placing them successively in an insulated calorimeter (of specific heat capacity 896J/kgK) containing 1100g and 1150g respectively of water at room temperature. The insulated lid was sealed and the temperature of the fluid was monitored every three minutes. The PVC film was stable up to 100°C, and had a mass of 4g per metre length, and a specific heat capacity of 540J/kgK.

Average Specific Heat Capacity Value for Cob C

$$= \frac{801.5+725.8+820.6+818.6}{4}$$

= 791.6J/kgK

The mass of the samples was measured for air-dry and oven-dry conditions , and the moisture content was found to be 3% by mass.The specific heat of soil-water mixtures may be calculated by proportioning according to the percentages of the weights of solid and water with their respective heat capacities; the specific heat of water[3] being 4186.8 J/kgK.

The specific heat capacity of moist cob was determined from:

$$\frac{(100\times\text{Specific Heat soil}) + (\text{Moisture Content}\times 4186.8)}{100 + \text{Moisture Content}}$$

If average moisture content = 3%

then Specific heat of soil mixture

$$= \frac{(100 \times 791.645) + (3 \times 4186.8)}{100 + 3}$$

= 890.53 J/kgK

Conductivity analysis

The transient thermal-probe technique (Batty et al[4,5]) was used because this enables the thermal conductivity of materials to be measured rapidly, i.e. without significant movement of the entrapped moisture occurring during the period of the test. The probes consisted of a stainless-steel cylinder of 2mm diameter containing a line-source double-constantan-wire heating-element. Separate leads were attached to the heating element for the delivery of electrical power and to measure the voltage drop across the heating element. A chromel-constantan thermojunction was attached to the sheath at the heater-wire's mid-point using a cyano-acrylate fast setting adhesive, which ensured a good thermal contact was achieved whilst preserving electrical insulation.

Two separate holes were drilled into the lump of cob and into these the probe was, successfully, fully inserted. Temperature measurements were recorded at 20-second intervals during two separate runs each of a little over 200 seconds duration for each hole. A typical result is shown in Fig 1. The thermal conductivity was calculated via filling the usual equation (Batty et al[4])(see below) to the approximately straight line section of the plot.

$$T_2 - T_1 = \frac{Q}{4\pi k} \ln\left(\frac{t_2}{t_1}\right)$$

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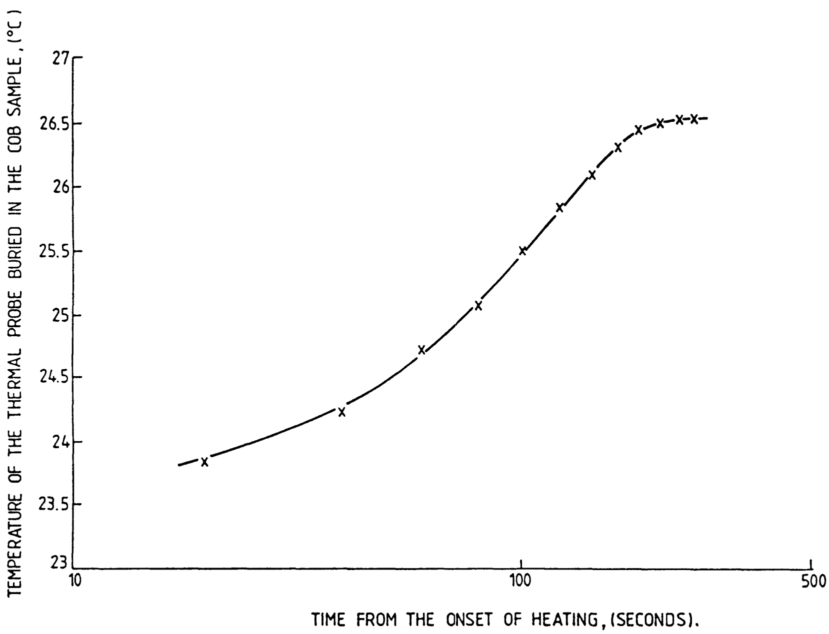

Figure 1: Typical change in Temperature with Time for the bottom of Cob Hole 1: Run 1

The average value of the effective thermal conductivity of cob earth walling so deduced was found to be 0.6 W/mK.

Conclusion

Because of the large numbers of different types of earth walling that have evolved in different parts of the British Isles, their different soil types and construction methods, many more assessments should be undertaken. Then, for instance, the variation of effective conduction with cob composition will be able to be deduced. Nevertheless the values of the properties evaluated in this investigation provide worthwhile indicators when typical behaviour needs to be predicted.

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