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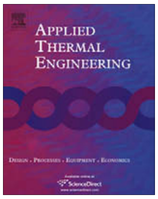

Assessing the effects of soil grading on the moisture content-dependent thermal conductivity of stabilised rammed earth materials

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ABSTRACT

New data for both the dry-state and the moisture content-dependent thermal conductivity of cement-stabilised rammed earth (SRE) materials is presented. For highly compacted SRE materials, no correlation was found between thermal conductivity and dry density or void ratio. The thermal conductivity of SRE materials increases linearly with the saturation ratio, S_r of the material and can be expressed as λ^*, the moisture content-dependent thermal conductivity. The sensitivity of λ^* to an increase in the saturation ratio of SRE materials varies according to soil grading. The influence of grading parameters on λ^* can cause material variations of approximately 0.8 m^2 K/W. The experimental data has been applied to standard SRE wall design configurations and the effect of wall moisture content on the total thermal resistance has been shown. The *R*-value of an SRE wall irrespective of cavity insulation can vary by as much as 0.13 m^2 K/W.

1. Introduction

Stabilised rammed earth (SRE) is a modern, commercialised practice of a traditional technique of wall building [1–3]. Its main advantages are that (i) it can provide temperature and relative humidity buffering reducing the enthalpy of indoor living spaces whilst saving operation energy costs and associated emissions, and (ii) it provides a low-carbon alternative to fired clay bricks using locally available raw materials [2,4,5]. The technique involves the dynamic compaction of carefully graded sub-soils that are moistened to optimum moisture content and placed inside removable formwork. The main difference between SRE and compressed earth blocks is that SRE requires the use of dynamic (as opposed to static, full-faced) compaction which usually yields a higher density and consequently requires a lower percentage of fine aggregate and clay content. In countries where SRE is more established and recognised by building codes (e.g. France, Australia, New Zealand, USA, and Canada) the use of Portland cement as a stabiliser is practised to reduce plastic behaviour, swelling/cracking, strength loss and durability issues under partially- or fully saturated conditions. The resultant material can therefore be classed as a weakly hydraulically-bound unfired earthen material typically containing hygroscopic clay minerals usually exhibiting a high density and a low void ratio.

2. Background

In previous research conducted by Hall it was found that the moisture ingress and drying characteristics of such materials can be manipulated and optimised through changing the pore structure using granular stabilisation techniques, i.e. altering certain grading characteristics [6–8]. The effect of altering pore structure on the thermal conductivity of SRE materials, in particular with regard to the effect of moisture content, is of interest and yet has never been studied previously. Adams and Jones [9] measured the thermal conductivity of stabilised earth blocks using a guarded hot box apparatus. The blocks were manufactured from a Sudanese soil using a mechanical press with full-face static compaction effort. Results were presented for solid and hollow blocks using two distinct soils and hydrated lime or cement stabilisation. Moisture content was not controlled at the time of measurement but was typically less than 0.5% and was factored in the final analysis. They found that thermal conductivity increased exponentially with dry density and that the lime stabilised blocks had a lower density than the cement stabilised blocks for the same soil. Walker et al. [10] found a similar relationship between dry density and thermal conductivity for rammed earth. The specimens were compacted to different densities using the same soil type and tested in a guarded hot box apparatus, however, moisture content was not featured. Goodhew and Griffiths [11] demonstrated that earth walls could meet the former (pre-2006) UK Building Regulations. They made measurements of unfired clay bricks and straw clay mixtures using an innovative thermal probe technique but appeared to ignore the moisture content of the materials. Houben and Guillaud [12] state

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that thermal conductivity is very sensitive to moisture content and that calculations must allow for variations due to hygro-thermal behaviour of the material. They also suggest that more data is required to understand these thermo-physical properties of rammed earth materials.

3. SRE sample production

When selecting a suitable soil for SRE the particle size distribution must normally fall within the upper and lower limits designated by the International Centre for Earthen Architecture, CRATerre [12]. Rather than using a selection of natural soils from different regions for this work, a discrete selection of quartzite sub-soil materials were used to manufacture the SRE test specimens which were obtained from a quarry pit in the Nene Valley region of the British Isles. They consisted of a 14–6.3 mm rounded pea gravel, a 5 mm-down medium grade grit sand, and a silty clay. These individual sub-soil components can then be proportioned and mixed together to form a range of sub-soils that all conform to the required particle grading for SRE materials. The advantage of this methodology is that the parameters of aggregate mineralogy, particle angularity and clay mineralogy are constant, whilst the only variable is particle-size distribution enabling very careful manipulation of grading parameters. The soils are oven dried and the silty clay is pulverised to dust before all three components are combined in a variety of mix recipes that produce SRE soils. The mix recipes are measured in mass units of ten and named according to the proportion of each component. The properties of the three SRE mix recipes are given by Table 1 and the particle-size distribution curves are shown in Fig. 1. The soils are all stabilised with the addition of 6% (by total dry mass) CEM IIa Portland cement before sufficient water was added to raise the material for optimum moisture content. The optimum moisture content was experimentally determined for each soil using the Proctor test; standard compaction. Further details of this methodology and associated test results have been published elsewhere by Hall [13].

Table 1
Properties of SRE mix designs

Mix type	Soil component proportions (kg/kg × 10)			
	14–6.3 mm rounded pea gravel	⩽5 mm medium grit sand	Silty clay	OMC (%)
433	4	3	3	8
613	6	1	3	8
703	7	0	3	8

One-litre test cylinders of the samples were prepared using an automated Proctor compaction machine and dynamic compaction input energy of 596 kJ/m^3 and cured in a 95% humidity chamber at 20°C ± 2° for 28 days. Test results for dry density and linear shrinkage were in close agreement with those obtained previously by the author (Hall) using these mix designs. The ISO-conforming thermal test apparatus (described in Section 4) required the manufacture of SRE slab specimens. Test slab dimensions require a square where the length of the sides is 150–300 mm and a maximum thickness of 65 mm. In order to reduce the scale effect of different aggregates as much as possible, an SRE slab mould of dimensions $300 \times 300 \times 50\ \mathrm{mm}^3(t)$ was used to prepare the specimens. The SRE materials were mixed to optimum moisture content and dynamically compacted using identical dynamic compaction input energy of 596 J/m^3. The slabs were also cured in a 95% humidity chamber at 20°C ± 2° for 28 days and the dry densities were in close agreement with those obtained for the test cylinders.

4. Testing thermal properties

Thermal conductivity testing was performed using computer-controlled P.A. Hilton B480 heat flow meter apparatus with

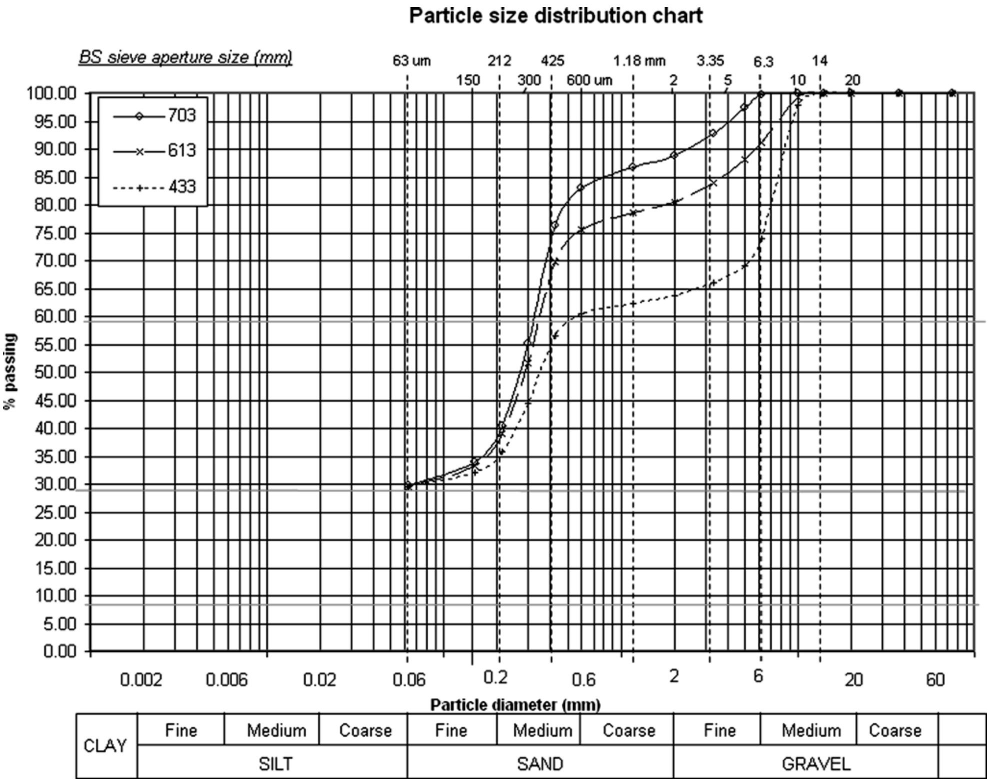

Fig. 1. Particle size-distribution curves for the SRE mix recipes.