IOP Conference Series: Materials Science and Engineering

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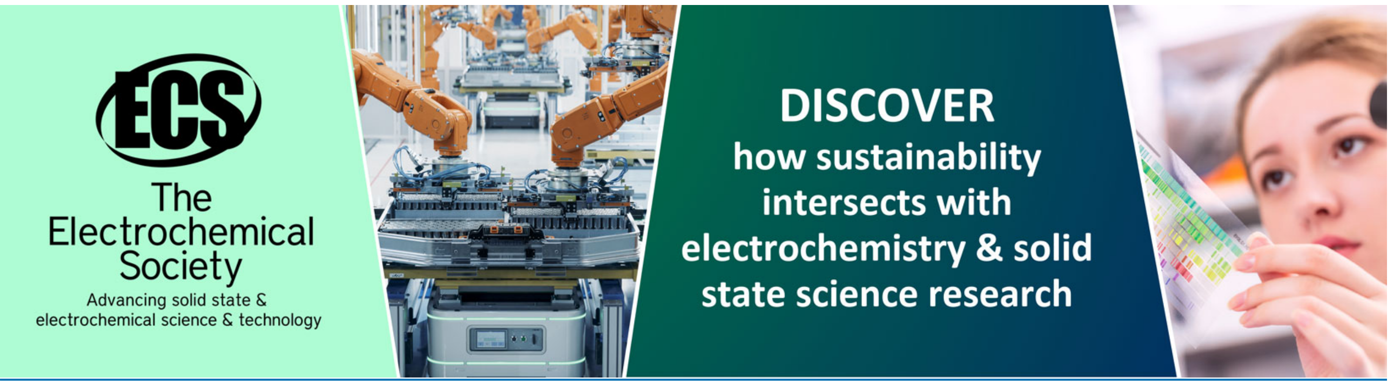

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Feasibility of Integrated Insulation in Rammed Earth

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Abstract. Building Codes in Europe stipulate strict thermal performance criteria which any traditional rammed earth recipe cannot meet. This does not infer that the material itself is inferior; it has many other face saving attributes such as low embodied energy, high workability, sound insulation, fire resistance, aesthetics, high diffusivity and thermal accumulation properties. Integrated insulation is experimented with, to try achieve a 0.22 [W/(m^2.K)] overall coefficient of heat transfer for walls required by 2015 Slovak standards, without using external insulation or using technologically complex interstitial insulation. This has the added aesthetic benefit of leaving the earth wall exposed to the external environment. Results evaluate the feasibility of this traditional approach.

1. Introduction

With the advent of thermal criteria for building codes, thermal comfort as a criterion is superseded by efficiency measured in kWh/m^2 p.a. which is a product of a buildings shape, size, airtightness and thermal resistance of the envelope and its parts. Contemporary stabilized rammed earth (SRE) is an evolutionary product of traditional rammed earth (RE) methods and materials, often incorporating steel reinforcing and rigid insulation, enhancing the structural and energy performance of the walls while satisfying building code parameters. Interstitial thermal insulation is known to be effective for many types of building envelopes made of sandwich or composite structures. The implementation of interstitial insulation in stabilized rammed earth (SRE) has received significant attention in Research and development as stringent thermal requirements for building codes continue to increase. Thermal conductivity tests, conducted by M.A. Hall, on composite SRE walls with extruded polystyrene (XPS) insulation demonstrated that the combination of a high mass wall with the low conductivity of foam

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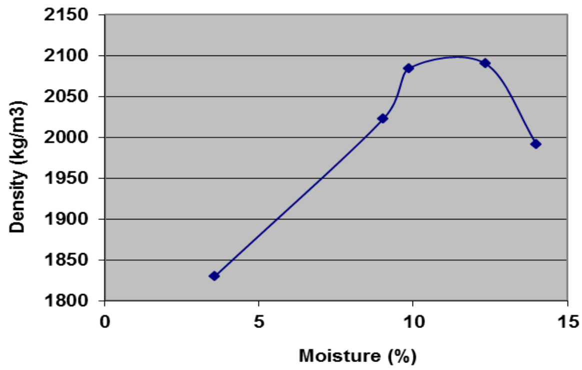
insulation resulted in a wall that had a lower thermal conductivity than a solid earth wall or an earthen wall with insulation located at only the internal or external face, while improving the mass performance of the wall as a whole [1, 2]. However, due to the complexity and technological limitations of implementing (SRE) interstitial sandwiches in situ, the authors were inspired to analyse if it is holistically feasible to integrate bulk insulation in rammed earth.

2. Sample production

All tested soil components were obtained locally and oven-dried to a constant mass at a temperature of 60 °C as opposed to 110 °C to prevent potential changes in the material structure. The Portland cement (type III) content was 10 % by weight. The clay and silt (30 % content) was pulverized into a coarse powder, passing through an 8 mm sieve, and then mixed with sand and gravel using a variable speed mixer to ensure uniformity between batches.

Table. 1 Determination of OMC for 8 [%] cement content.

CS0108 Sample: 8%



		1	**2**	**3**	**4**	**5**
Volume of material in cylinder	[m^3]	0.000947	0.000947	0.000947	0.000947	0.000947
Mass of cylinder with material	[kg]	6.46	6.754	6.834	6.889	6.815
Empty mass of cylinder	[kg]	4.665	4.665	4.665	4.665	4.665
Mass of moist material	[kg]	1.795	2.089	2.169	2.224	2.15
Bulk density of material	[kg/m^3]	1895.459	2205.913	2290.39	2348.469	2270.337
Mass of receptacle + moist sample	[g]	0.0620	0.0797	0.0570	0.0420	0.0736
Mass of receptacle + dry sample	[g]	0.0612	0.0765	0.0555	0.0401	0.0694
Mass of receptacle	[g]	0.0388	0.0411	0.0403	0.0247	0.0394
Mass of dry material	[g]	0.2240	0.0354	0.0152	0.0154	0.0300
Mass of moisture in the material	[g]	0.0080	0.0320	0.0150	0.019	0.0420
Moisture content	[%]	3.571429	9.039548	9.86842	12.33766	14.000
Dry bulk density of material	[kg/m^3]	1830.099	2023.04	2084.67	2090.545	1991.515

Eleven kilograms of soil were used to make one test specimen that measured 32.5 x 32.5 x 5.5 cm. A controlled amount of water was added to raise the soil to optimum moisture content (OMC) which is the moisture content at which a material reaches its maximum dry density (MDD) for a given compactive effort. This is said to influence the strength and durability of the material. Table 1 shows the MDD and OMC of the reference sample. Columns one through five represent the five test points on the line curve and represent increased moisture content for the same recipe [3]. The material for all test samples was compacted using a pneumatic tamper with a 55 mm head.
Component soils were blended in ratios and then graded to obtain their particle-size distribution parameters plotted logarithmically with respect to percentage (by dry mass) of the total specimen on a linear scale, see figure 1. STN EN 1015-1/A1 (72 2441) and STN EN 933-2 (72 1186) were used to classify the granular materials and sedimentation into different physical dimensions using a number of meshes and sieves [4; 5; 6].

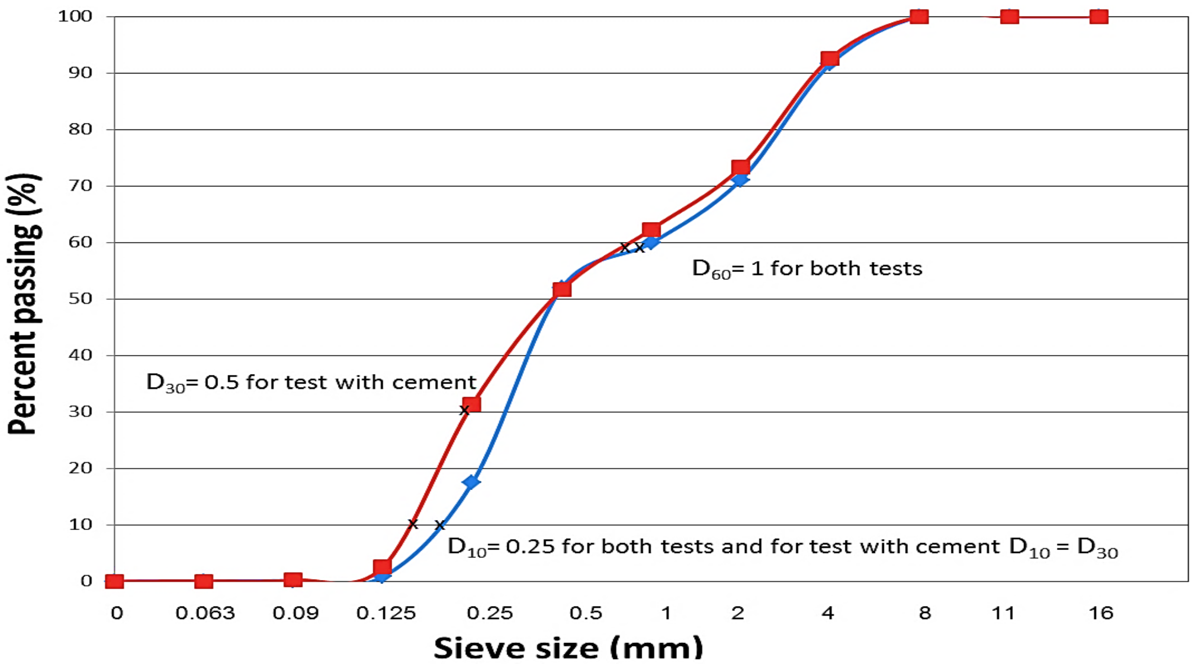
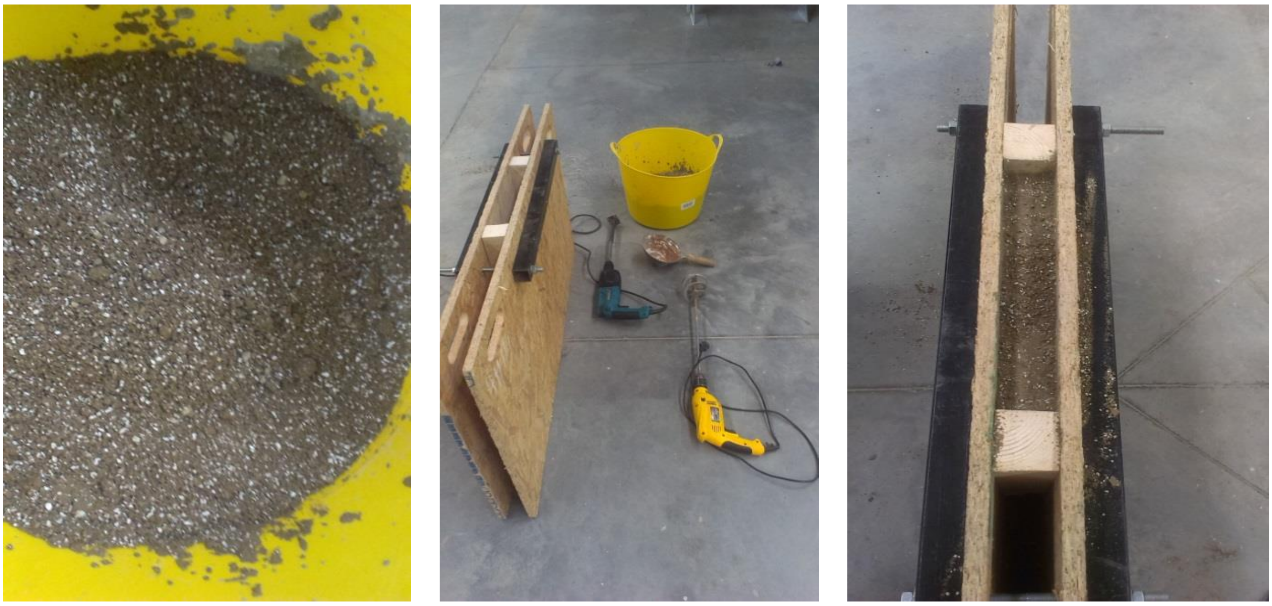


Figure 1. Cumulative particle-size distribution curve (Red line: cement included; blue line: cement omitted).

2.1. Selection of thermal insulation
Insulation had to fulfill several criteria. These included that the material be ecological; natural based; inherently hydrophobic, but not a vapour barrier; be relatively incompressible and withstand the impact of ramming. Foam glass, clay pellets and cork were amongst those considered, but hydrophobic expanded perlite seemed the most promising. Batches were defined by the percentage of bulk volume of thermal insulation that was put in the form. Reference batches had no insulation, while each subsequent batch had an increase of 20 % bulk insulation while the maximum feasible case had a 100 % volume of bulk insulation relative to the volume of the form. Figure 2 illustrates a freshly

removed sample left and a dried sample right ready for testing. Figure 3 overleaf shows the preparation of the test specimens, equipment used and formwork for the test specimen.

Figure 2. Left: A freshly removed sample, Right: A sample after curing until reaching a constant mass.



(a) (b) (c)

Figure 3. (a) soil and expanded perlite mixture; (b) mixing and compacting equipment; (c) braced formwork with test specimen.

3. Determination of the coefficient of thermal conductivity

Thermal conductivity was measured using a calibrated Stirolab heat flow meter with compliant Lm 305 software. Accuracy was set to 99 % with only a 1 % permissible deviation. Each test lasted 3600 seconds and every specimen was tested twice. The first test stabilized the high mass material while the second test produced the final measurement results.

3.1. Test Procedure

The Stirolab lambda meter works by placing a test sample between a warm and cold plate. The standard setting is 0 ºC for the bottom plate and 20ºC for the top plate producing a 20 K temperature difference. The temperatures of the plates are kept constant while the amount of energy required to maintain constant temperatures depends on the conductivity of the material. The conductivity of the material is therefore directly proportional to the amount of energy required to maintain a constant temperature between the plates. Thus thermal conductivity is calculated as:

$$\lambda = \frac{j.d}{\Delta T} \qquad (W/m.K) \qquad (1)$$

Where

j	- is the heat flow	(W/m^2)
d	- is the thickness of the test specimen	(m)
ΔT	- is the temperature difference	(K)

Figure 4 shows the simultaneous thermal stabilization curve of the reference specimen for the warm and cold plates.

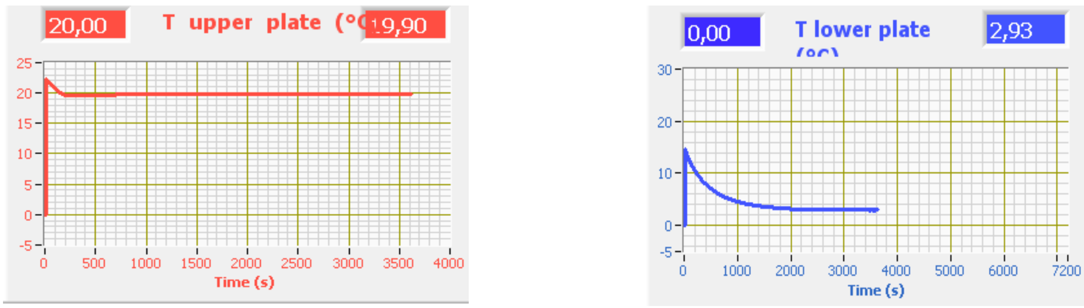
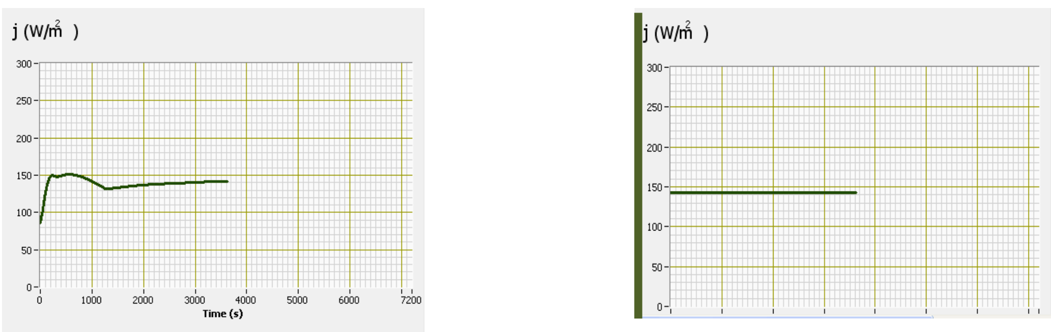


Figure 4. Heat flow meter approaching steady-state: Left, warm plate; Right, cold plate.



(a) (b)

Figure 5. (a) stabilizing the heat flow; (b) energy required to maintain steady-state measurement.

Figure 5 below depicts the heat flow needed by the warm and cold plates to maintain a constant temperature.

4. Results and discussion

Table 2 was drawn to define the dry mass, density, quantity of insulation expressed as a percentage of total volume and statistical thermal conductivity of each test specimen. These are statistical values averaged over multiple samples. The volume of each sample was approximately 0.0058 m^3.

Table 2. Determination of OMC for 8 [%] cement content.

Percentage bulk insulation [%]	Weight [kg]	Density of samples [kg/m^3]	Coeff. Thermal conductivity [W/(m.K)]
0	12.304	2037.4	0.510
20	12.099	2022.4	0.499
40	11.224	1823.5	0.462
60	10.694	1656.7	0.413
80	9.187	1530.5	0.412
100	8.784	1500.8	0.410

Conditions of the feasibility study were that the walls should have a coefficient of thermal conductivity that is low enough to meet thermal transmittance targets without sacrificing load bearing ability. Therefore, multiple Schmidt hammer tests were performed as an indicator of strength for each corresponding test sample. The Schmidt hammer was used because the shape of the specimens did not conform to compression tests via crushing. The tests were performed in the direction of the ramming and showed that each 20 % increase in perlite dramatically reduced the strength. The reference sample had a characteristic strength of almost 4.94 MPa, the 20 % had strength of 2.45 MPa and all subsequent samples had strengths lower than the minimum required for identification. Ignoring this fact and focusing only thermal conductivity and Thermal Admittance related values [7], the results were still disappointing. Figure 6 shows the heat flows due to unit swing in the internal environmental temperature that would occur over a 24 h period.

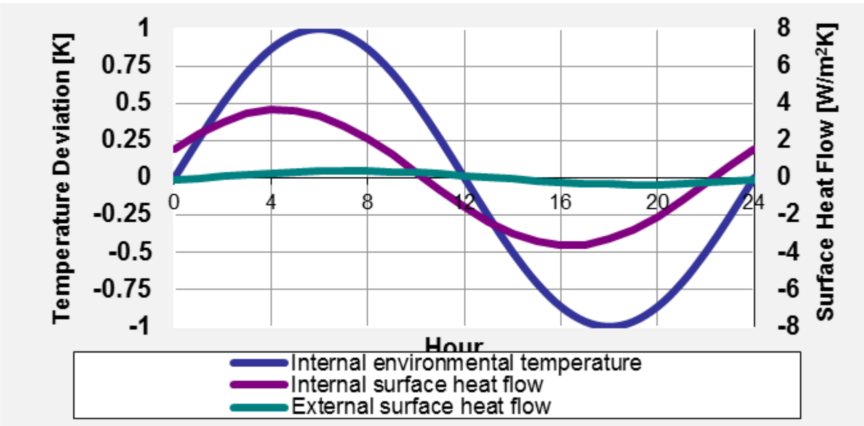


Figure 6. Heat flow of the 100% bulk volume specimen for a 1 K temperature variation over a 24 hour period.

5. Conclusions

The paper experimented with the feasibility of integrating expanded perlite into SRE to reasonably attain a 0.22 [(W/(m^2.K)] overall coefficient of heat transfer for walls required by 2015 Slovak standards while maintaining minimum strength requirements. The experiment failed on two accounts. The first failure was that rammed gains its strength from its density. Intermolecular forces weaken if the perlite is compressed. Rammed earth technology is impact based and most bulk forms of insulation are either too brittle or compressible to make this a viable alternative. Secondly, although a dramatic increase in thermal insulation produced a rapid reduction in strength, it only produced a marginal improvement in thermal resistance. This can be explained by using the 40 % volume and 100 % volume specimens as examples. The 40 % perlite per volume specimen produced the greatest improvement in thermal performance as it is assumed there was enough rammed covering the perlite to prevent significant compression of individual perlite particles. However, the 100% volume of perlite mixed with rammed earth was easily compressed producing only a marginal improvement over the previous layer. A wall thickness in excess of 1.7 meters would be required to attain a thermal transmittance of 0.22 [W/(m^2.K)] making the use of perlite in this way unfeasible. In addition, the authors doubt whether any other form of integrated particle insulation could be used to attain 0.22 [W/(m^2.K)] overall coefficient of heat transfer, but does not rule out that low density cob with large thicknesses might achieve these values.

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