Thermal Performance of Composite Walls Made Out Of Recycled Building Waste and Stabilized Rammed Earth

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ABSTRACT: Several building materials with lower life cycle cost have been developed with the aim of promoting sustainable construction. This in turn would limit the over exploitation of natural resources used to produce conventional building material such as bricks and cement sand blocks. Building demolition waste has added to the environmental impacts created by the building industry. This paper covers a research carried out to investigate the possibility of using recycled building demolition waste (BDW) in constructing some building elements with a comprehensive experimental programme. BDW has been combined with stabilized rammed earth (SRE) which is another greener material, to construct a composite walling material. The optimum mix proportion of BDW and SRE was established together with other important material properties to assess the proposed material for acceptable building performance. Based on the results, the proposed composite walling system made out of BDW and SRE can be confidently used as a load bearing walling material.

Key words: - Building demolition waste (BDW), Stabilized rammed earth (SRE), Material properties, and Thermal performance.

1. INTRODUCTION

Rapid urbanization prevails in developing countries together with reconstruction programmes after several natural disasters (eg - Tsunami, landslides in the years 2010, 2012, and 2013) has caused a generation of building demolition waste (BDW) in excessive quantities. The research covered in this paper has been focused on reuse of construction waste in wall construction. Reusing construction waste is given recognition in the Green rating systems as well (LEED of US Green Building Council). In order to develop a sound walling material, construction waste was combined with stabilized rammed earth and insitu casting of the wall was carried out as composite panels using the slip form technique.

Currently BDW is primarily being used as a land filling material without proper management, causing some environmental problems with over supply. This has been coupled with another environmental concern generated with over exploitation of finite natural resources in the production of building materials such as bricks and cement blocks. Since stabilized rammed earth (SRE) has been identified as an alternative material for wall construction. [1] [2] The research covered in this paper was aimed at developing a composite walling material with SRE and BDW. Reusing BDW is given recognition in the Green rating systems such as LEED (Leadership in Energy & Environmental Design) of US Green Building Council.

The composite walling system covered in this paper includes SRE and BDW mixed to a desirable proportion based on the strength parameters. In order to be comparable with the other walling materials, the composite walling system was tested for strength, durability and thermal properties. The optimum mix proportion was first established after selecting a suitable mix of aggregate from the recycled BDW. The strength and thermal properties of the composite wall were established with a detail testing programme backed by computer simulations for the thermal modeling.

There is a high demand for building materials due to rapid urbanization in most of the countries all over the world. This causes significant amount of environmental degradation due to over exploitation

of natural resources such as sand mining, coral mining, extraction of clay and depleting forest cover. These problems have tempted us to explore the possibility of using alternative materials. One such alternative is earth wall construction which has been given a lot of thought in the recent past. Earth alone would not fulfill the structural requirements of a building material. Therefore, stabilization techniques have been introduced to improve the strength and durability of earth as a building material. Stabilized rammed earth (SRE) is one such material which consists of compacted soil stabilized with cement [6] or lime [7] and moulded as a wall using the slip form technique.

Thermal properties of a walling material have a significant impact on operational energy consumed by the building. Based on the thermal conductance and specific heat of the material, indoor temperature can vary which will have a major impact on building performance and occupant comfort levels. When introducing a new material it is very important to evaluate the life cycle cost since it can assess comparable performance with the other walling materials. The walling system developed with cement stabilized rammed earth (CSRE) and Building Demolition waste (BDW) is termed as "composite wall" in the rest of the sections of the paper.

2. Objectives

The study covered in this paper was aimed at following objectives:

a. Determination of a suitable mix proportion for the composite mix of CSRE and BDW.
b. Determination of compressive strength of the composite mix of SRE and BDW.
c. Establishing thermal properties of the composite material.
d. Assessing thermal performance of the proposed composite material.
e. Assessing durability of the composite material of CSRE and recycled BDW.

3. Methodology

The following methodology was adopted to achieve the above objectives:

Initially Feasibility of different Soil types available in the study area were assessed with laboratory testing based on the literature review. Next BDW was collected from Construction Waste Management Center (COWAM Center) in Galle which is the Southern capital of Sri Lanka. This Center was selected due to the presence of recycling equipment at the yard itself. Testing was carried out for the cube strength of various mix proportions of BDW and CSRE. Compressive and flexural strength of the walls constructed out of composite material was determined experimentally and the details are presented in another publication. Thermal properties of the composite material were established with laboratory testing. In order to assess the material for the thermal performance, physical models were constructed and the temperature variation was monitored. Verification of thermal modeling was carried out with the thermal properties as inputs to the computer simulations and compared with experimental results. Durability testing was carried out on specimens of composite wall panels.

4.0 Determination of a suitable mix proportion

The recycling center in Galle (COWAM center) crushes the construction waste into 3 different particle sizes. They are 19 mm-12 mm, 12 mm-2.36 mm and the dust(<2.36 mm). Particle size distribution test was performed in accordance with ISO 17892 – 4 [13]. A mix design was performed to obtain a well graded recycled BDW mixture for the study. The mix proportion achieved for the well graded curve is presented in Table 1.

Table 1: Mix proportion for a well graded curve

Particle size	Proportion	Mix proportion of aggregates
< 2.36 mm	1	2:4:1
2.36 mm- 12 mm	2	
12 mm – 19 mm	0.5	

The grading of aggregates indicated in Table 1 has been used in the entire experimental programme of the research covered in the paper.

In order to optimize the mix proportion of CSRE further by adding recycled BDW, several trials were conducted. Test cubes were made for assessment of compressive strength with trial mixes and the results are shown in Table 2.

Table 2: Compressive strength of trial mixes

Mix proportion	Compressive strength (7 days) N/mm^2	Dry Compressive strength (28 days) N/mm^2	Wet Compressive Strength (28 days) N/mm^2	Density (kg/m^3)
1:4:6	2.67	3.0	2.0	1763
1:3:7	3.17	3.5	-	1812
1:6:4	3.67	5.67	-	1961
1:5:5	4.80	6.33	6.0	2064
1:10 (Rammed earth)	3.00	3.5	-	1828

Figure 1 presents the variation of compressive strength of the composite mixes with the mix proportion. Two curves represent the compressive strength at the ages of 7 days and 28 days. The maximum compressive strength can be seen for the mixture 1cement:5 Soil: 5 BDW.

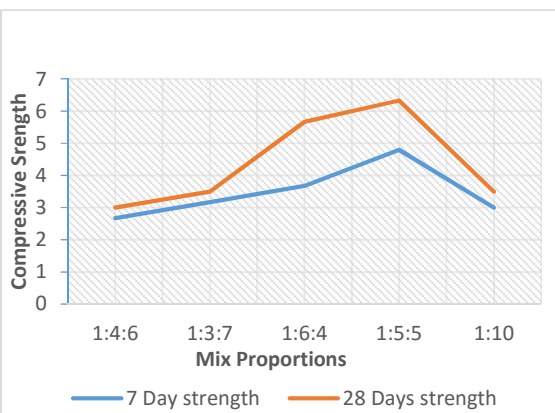

Figure 1 - Variation of compressive strength over mix proportions

5.0 Properties of the composite material with BDW and CSRE

Compressive strength of test cubes made out of BDW and CSRE have indicated the maximum value for the mixture with the proportions 1 cement: 5 BDW: 5 soil. In order to assess the performance of the composite material, a detailed experimental programme was carried out on the density, thermal conductivity, specific heat and thermal performance with physical models. Durability of the material was assessed experimentally with accelerated spray erosion testing.

5.1 Density of the Composite Material

Density of the composite material was determined by using the cubes cast for the testing programme. A sample of ten cubes of 150 mm× 150mm × 150 mm was used to measure the dimensions and the weight to determine the density of the material. The oven dried weight was obtained together with the dimensions of all the cubes. The average value for the density was worked out to 2234 kg/m^3 for the bulk density and the 2021 kg/m^3 as the dry density. The density of the composite material is comparable with the conventional masonry materials.

5.2 Specific Heat Capacity of the composite material (S)

Specific heat is the amount of energy needed to raise the temperature of 1 kg of a material by 1 unit of temperature. This property is needed to assess the thermal performance of the material. An experimental programme was conducted to determine the specific heat of the composite material. Test specimens were prepared as per the ASTM D4611 [14] and the testing was carried out in lees disk method.

Figure 2: Test Specimen

Figure 3: Specific Heat Testing

Heat loss of the specimen = Heat gain by the water in jar

$$m\,S\theta = MS(\Delta\theta)$$

$$S\times0.107\times(100-33.08) = 0.325\times4179\,(33.08-27.77)$$

$$S = 1007.19\ {}^{J}/_{K\,.\,Kg}$$

$$S = 0.28\ {}^{Wh}/_{K\,.\,Kg}$$

Weight of the specimen 0.107 kg
Weight of water 0.325 kg
Specific Heat of water = 4179 J/k.Kg
Conversion = 3600 J/k.Kg = 1 Wh/k.kg

Specific heat of the composite of BDW and CSRE has been found to be 0.28 Wh/kg.k which is comparable with similar conventional materials such as burnt clay brick 0.25 – 0.27 Wh/kg.k, cement block 0.25 Wh/kg.k, CSRE 0.28 Wh/kg.k [18]

5.3 *Thermal Conductivity of the composite material*

Thermal conductivity is the property of a material that indicates its ability to conduct heat. Conduction will take place when there is a temperature gradient in a solid medium. Where steady state heat transfer is given by equation 2.

$$H = \frac{KA\,(T_2 - T_1)}{X} \qquad (2)$$

Where, H- Steady state rate of heat transfer
K- Thermal Conductivity
A- Cross Sectional area
T_2-T_1 = Temperature difference across the sample thickness 'X'

Heat loss from the side of the sample through glass wool is negligible. Lee's disk method was used to determine the conductivity of BDW and CSRE sample. The experimental specimen in the form of a disc was made with a smaller thickness and a large cross sectional area, as shown in Figure 4.

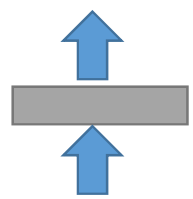

Figure 4 – Heat flow through the specimen

In the apparatus used, there were two circular copper plates. The specimen has been made to suit the diameter of these copper plates. Thermo couples were attached to both two copper plates to read the temperature variation. Once the specimen is placed between the copper plates, it was insulated using glass wool. The copper plate at the bottom recorded the temperature of 101.6 ^{0}C at the steady state. The heating was carried out by an electric heater. At the steady state the upper copper plate recorded 48.7^0 C. The heat flow through the specimen H, is given by KA dT/dt. Then the temperature variation of the upper copper plate while cooling down in air, was plotted with time. The gradient of the graph presents the rate of cooling which is dT/dt.

Figure 5 - Thermal Conductivity Testing

Using the above experimental data and equation (3), thermal conductivity can be calculated.

$$K \times A \times \left(\frac{dT}{X} \right) = M \times C \left(\frac{dT}{dt} \right) \ldots (3)$$

K= Thermal Conductivity of the composite material
A= Area of the specimen

$$\frac{dT = \text{Temperature difference between two plates at the steady state}}{X = \text{Thickness of the specimen}}$$

M= Mass of the copper plate
C= thermal conductivity of copper
$\frac{dT}{dt}$ Factored gradient of the heat dissemination curve at 48.7 ^{0}C

Cross sectional area of the specimen A = 2.248 $\times 10^{-3}$ m^2
Temperature variation dT= 101.6-48.7 = 52.9^o
Thickness of the specimen X= 0.022 m
Thermal conductivity of copper C= 3900 $J/_{C\,.\,Kg}$
Thermal Conductivity of the composite material (K) = 1 $\frac{W}{m.K}$

Thermal conductivity of the composite of BDW and CSRE has been found to be 1 W/mk which is comparable with similar conventional materials such as burnt clay brick 0.6 – 1.0 W/mk., cement block 1.0 W/mk., CSRE 0.80 W/mk. [18]

6.0 Building performance of composite BDW & CSRE walls

The strength parameters of the proposed composite wall have been found comparable with that of conventional walling materials (covered in another publication). The building performance of the proposed material would be the other concern in the assessment of the feasibility of this material. When considering the building performance, durability and thermal performance are the predominant factors. In order to assess the thermal performance, physical models were constructed out of proposed composite material and another set of models were constructed with conventional materials for comparative purposes. Thermal performance of above materials was assessed in both actual condition and with computer simulation.

6.1 Experimental program with physical models

Walling materials significantly contribute towards indoor thermal comfort. When a new walling material is introduced, thermal modeling has to be carried out to assess the performance and indoor comfort levels. Therefore a comprehensive experimental program was conducted with physical models built out of the proposed walling material and two other conventional materials for comparison purposes. The internal dimensions of the models were 820mm (length) × 800mm (width) × 1000mm (height) with 150mm wall thickness. Roof is covered by corrugated asbestos sheets and the rear of the models covered by 9mm thick 1000mm (height) ×800mm (width) plywood sheets. The front face of all models were facing the Eastern direction. The composite walls were constructed using plywood framework and the wall thickness of 150 mm was used to construct the models and walls were compacted manually with the compaction ratio of 2, for CSRE and BDW.

In order to get the thermal measurements of the physical models, thermocouples were used for 8 consecutive days and the data logger was programmed to take the temperature measurements at every ten minute interval to identify the heating and cooling patterns of temperature variation. Ambient temperature, external and internal surface temperature measurements were taken in southern and eastern walls. Figure 7 presents the variation of the indoor surface temperature in different walling materials.

Figure 6 – Physical models

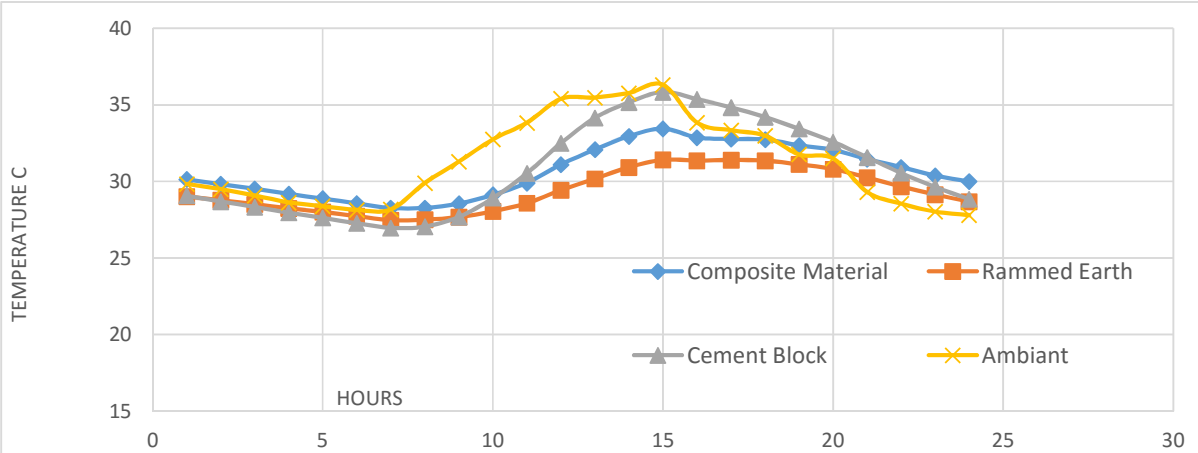

Figure 7 – Indoor surface temperature comparison of different materials

6.2 Computer Simulation

The results obtained from the experimental program was backed by the computer simulation so that it can be used in evaluating the walling material for thermal comfort in green rating system.

Computer simulation was carried out by using a software package called DEROB-LTH (Dynamic Energy Response of Buildings-LTH). This is capable of simulating the condition on hourly basis considering the heat gains, losses and ambient condition. The thermal properties established by the research were used as input parameters of the program. In order to validate the outputs of the experiments, computer simulation has been carried out. By conducting a computer simulation using DEROB-LTH, it is possible to compare the actual temperature measurements and the hourly temperature values that is given by the software.

The output of the computer simulation was compared with the results obtained from the experimental study with physical models. If the two sets of results are significantly close the

computer simulation can be used to establish the comfort with this material under any other circumstances such as different time of the year with different finishing materials etc. Table 4 shows the experimental values of the proposed building material and Table 5 shows the parameters of other conventional building materials.

Table 4- Properties of composite building material

Material Property	Value
Density	2200 kg/m^3
Thermal Conductivity	1W/mk
Specific Heat Capacity	0.28 Wh/kg.k

For simulation, an average climatic data file for April was used since the exact variation in solar radiation intensities that took place during the actual measurements are difficult to simulate with an interval of one hour. However computer simulation provides a reasonable comparison with the results of actual temperature measurements and the isolated, ideal condition surface temperature variation of the models. Three models were created in DEROB by inserting the parameters of building materials. Experiments were conducted without any surface finishes. Thus the comparisons were also carried out with absorption of similar colours where there was a coefficient of absorption of 60% and emittance of 80%.

Table 5- Properties of conventional building materials [4]

Material	Conductivity (W/mk)	Specific Heat (Wh/kg.k)	Density (kg/m^3)
Cement Blocks	1.00	0.25	1200
Soil Blocks	0.85	0.24	1800
Rammed Earth	0.80	0.28	2000
Asbestos	0.40	0.25	1600
Plywood	0.135	0.75	550

7.0 Analysis of Results

Thermal comfort is defined in British Standard BS EN ISO 7730 [16] as: 'that condition of mind which expresses satisfaction with the thermal environment. 'So the term 'thermal comfort' describes a person's psychological state of mind and is usually referred in terms of whether someone is feeling too hot or too cold. Thermal comfort is very difficult to define because you need to take into account a range of environmental and personal factors when deciding what will make people feel comfortable. These factors make up what is known as the 'human thermal environment'.

For the analysis of thermal performance, the surface temperature is the best for comparison. Both indoor and outdoor surface temperature could indicate the idea about thermal mass and time lag. Hence, indoor temperatures are used for comparison purpose. It can be seen that the DEROB-LTH simulations also has given a similar trend of variation and approximately equal values. This is an important step since DEROB-LTH could be used for comparison based on actual hours and also with different surface finishes and materials.

The results shows that the inside surface temperature of the block wall has the highest values at the day time with respect to other materials. Next to the cement block wall temperature, the wall that has been constructed using the composite material gives slightly low surface temperature in the day time. At the day time rammed earth wall gives the minimum tamperature values. The thermal performance of the proposed composite wall can be considered as comparable to there of conventional alternatives.

8.0 Conclusion

When introducing an alternative building material its performance should be assed on on structural aspects and thermal comfort. Walling materils are usally monitered for thermal performance since indoor comfort largly depends on walls of a building. Which in turn would contribute towards lower operational energy.

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