Structural Performance of Composite Walls Made Out of Recycled Construction Waste and Stabilized Rammed Earth

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ABSTRACT: In developing countries accumulation of unmanaged industrial construction waste is becoming a major environmental concern since it ends up as piled up landfills. Innovation of sustainable construction materials through recycling of such waste appears to be a viable solution to this problem. Recycled construction materials will also be an economical option in designing green buildings. There has been no significant research carried out to utilize construction waste as a walling material. The aim of this research is to find a solution for the construction waste in the form of a walling material for building construction.

Waste materials such as concrete, plasters, pebbles and bricks with mortar are selected for the study and they were crushed and sieved through 10mm-15mm and 15mm-20mm sizes separately. A mix proposition was selected based on standard testing for grading of aggregate. The processed construction waste was mixed with laterite soil and cement. This mixture was used as dry ingredients rammed of stabilized rammed earth walls. The optimum proportion of construction waste, soil and cement was established using experiment results of cube testing. The recommended mix proportion was used to construct the wall panels for compressive testing. Durability of the proposed walling material was tested using accelerated spring erosion method. The strength and durability of the composite material has been found satisfactory, which paves the path for another green construction material.

Key words: *Construction Waste, Green walling material, Rammed earth wall, Building Construction, Strength and Durability*

1. Introduction

Masonry is one of the most popular building materials for construction of houses due to availability, cost effectiveness, durability, thermal comfort and adequate resistance to weathering. Sustainable development is emerging rapidly all over the world in the 21st century as global climate change becomes an increasingly serious concern for the future. The continuous use of natural resource based building materials has led to many environmental problems. Therefore, it is essential to develop alternative building materials that can give a comparable performance with respect to appearance, structural properties and durability.

One such material that has captured the interest of many researchers in the recent past is earth. Earth or soil can be used as a walling material by compacting between temporary forms. It is widely known as rammed earth walls. Rammed Earth buildings have many favorable qualities. It doesn't require a complicated construction process and it is economical to build. It needs low maintenance and is suitable for cold and hot climates. However, there are a few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability. These drawbacks can be significantly reduced by adding cement [1]. According to the study done by Jayasinghe and Kamaladasa (2006) on compressive strength characteristics of cement stabilized rammed earth walls, it was found that cement stabilized rammed earth can be used as a material for loadbearing walls of two storey houses[2]. Jayasinghe and Mallawaarachchi (2009) studied the flexural strength of compressed stabilized earth masonry walls. The research produced positive results which indicate that compressed stabilized earth walls have adequate flexural strength [3].

Construction industry generates a large amount of waste, in quantities that are fast increasing with economic and social development. Construction waste is defined as the "by product generated and removed from construction, renovation and demolition work places or sites of building and civil engineering structures"(Cheung 1993) [4]. Approximately 40% of waste generated globally originate from construction and demolition of buildings (Roach 2001, p24)[5]. The waste generated by construction and demolition is becoming a growing menace to the social as well as the natural environment in Sri Lanka. Even though sustainable and environmentally friendly designs are considered a norm at present, a sustainable and environmentally friendly solution for the recycling of waste generated by the construction industry is still being not looked upon.

This paper highlights the findings of a detailed research carried out to study the structural performance of a walling material made out of rammed earth and recycled construction waste.

2. Objectives

The research was carried out with the following objectives:

1. Determination of a suitable mix proportion for the composition of cement stabilized rammed earth and construction waste.

2. Determination of compressive strength of the composite wall panel

3. Determination of flexural strength of the composite wall panel

3. Methodology

The following methodology was adopted to achieve the above objectives:

1. Various soil types recommended in the literature were reviewed and a soil type commonly available in areas with tropical climatic conditions was selected.

2. Recycled construction waste was collected from COWAM (Construction Waste Management) center in Galle. Galle is a major city in Sri Lanka situated in the southern province. The selected recycled waste has particle sizes less than 12 mm.

3. Test cubes were cast for trial mix proportions to select the mix proportion that yields the highest strength.

4. Wall panels were constructed using the optimum mix proportion to test the compressive strength and the flexural strength.

5. The above parameters were used to assess the structural performance of the composite walling material made out of rammed earth and construction waste.

4. Soil Types for rammed earth constructions

The composition of soils differs based on its geographic location. Countries located close to the equator have laterite soil in abundance. Laterite soils are formed due to the weathering process of igneous or metamorphic rock over millions of years. These soils are rich in aluminium and ferrous oxides that give either yellowish or reddish colours. These soils are available in most parts of Sri Lanka except in some coastal areas and low lying areas. Literature suggests the use of laterite soil for stabilized rammed earth walls [2].

In a detailed study carried out in Sri Lanka for cement stabilized laterite soil blocks, it was found that the fines content consisting of clay and silt particles smaller than 0.06 mm should be less than 30% for obtaining better results. A drastic drop in strength was observed when the fines content increased above 40%. Therefore, a maximum fines content of 30% is generally recommended for loadbearing construction [6].

According to Bahar et al (2004) [6], the optimum water content to be used is about 9.5–11.0%. With these moisture contents, a dry density about 20 kN/m^3 was obtained. It is also reported that mechanical stabilization by dynamic compaction appears to give better results. Achieving a value as high as possible for dry density is considered important since density is related to strength and durability [7].

5. Recycling of construction waste

Recycling of construction waste is a huge issue prevailing in Sri Lanka. The Construction Waste Management Centre (COWAM) is a waste re cycling site situated in Galle, Sri Lanka. The main objective of this project was to optimize the sustainable use and management of construction waste in Sri Lanka. According to the COWAM newsletter No.02 - March 2007, the concrete waste collected will be crushed and sieve sorted at the COWAM centre [8].

Figure 1 COWAM center for recycling of construction waste in Galle

The concrete waste for the research was acquired from the COWAM centre in Galle. The recycling centre in Galle crushes the construction waste into three different particle sizes. They are 19mm-12mm, 12mm-2.36 mm and the dust(<2.36mm). Particle size distribution test was performed in accordance with ISO 17892 – 4 methods for determination of the particle size distribution of different particle size categories. The results are shown in Figures 2-4.

Table 1 Cube test results for different trial mixes

Condition	Tests	Mix Proportions				
		1:3:7	1:4:6	**1:5:5**	1:6:4	CSE (1:10)
	7 day compression test(N/mm2)	3.167	2.67	**4.83**	3.67	3
Dry	28 day compression test(N/mm2)	3.5	3	**6.33**	5.67	3.5
	7 day compression test(N/mm2)		2	**3.5**		
Wet	28 day compression test(N/mm2)	N/A	2.54	**6.5**	N/A	N/A

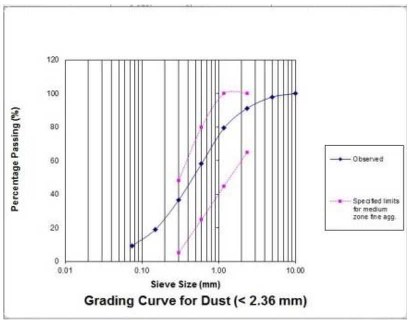

Figure 2 Particle grading curve for dust (<2.36mm)

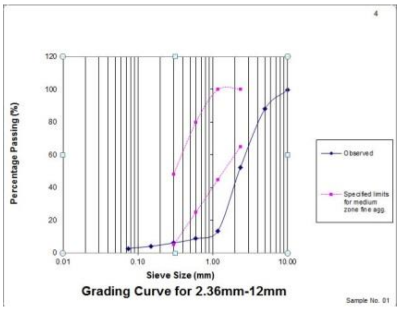

Figure 3 Particle grading curve for 2.36 mm- 12mm particles

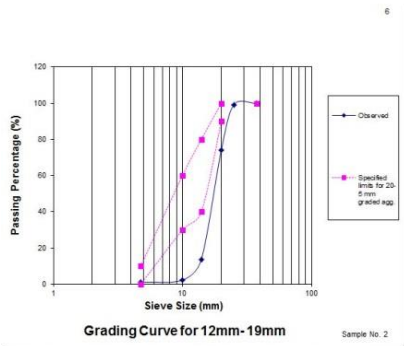

Figure 4 Particle grading curve for 12 mm- 19mm particles

A trial and error process was adopted to obtain a well graded recycled construction waste mixture from the three particle sizes mentioned above. The obtained proportion is presented in Table 2. A well graded mixture is required to get good compaction for wall panels. It will result in high compressive and lateral strength.

Table 2 Obtained mix proportion for a well graded recycled waste mix

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

The above mix proportion was used for all the test procedures in the research.

6. Experimental program and results

6.1 Selecting the optimum mix proportion

Five different trial mix proportions for cement, soil and construction waste were considered in the research. The compressive strength of cubes was considered the parameter to select the best mix proportion. Cube strength of 7 days and 28 days were tested. The compressive strength in wet condition was tested for two trial mix proportions to check the behaviour of the material in adverse conditions. The results are presented in Table 2.

According to the results in Table 1, the 1:5:5 mix proportion produces the highest compressive strength. It also has a comparatively high strength in wet condition. Therefore, 1:5:5 proportion was selected to construct wall panels to test the structural performance.

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Figure 5 Compressive strength testing of cubes

6.2 Construction of wall panels

Wall panels were cast using steel slip form moulds. The selected composition was then placed in layers of 150mm and compacted with a manually operated rammer. Figure 6 shows the arrangement of steel moulds and the supporting structures used in constructing the wall panels.

Figure 6 Arrangement of steel moulds and supporting structures

Test panels were constructed according to the BS 5628: Part 1: 1992 as shown in the Figure 6. According to BS 5628: part 1: 1992 the panels should be kept undisturbed for 28 days prior to testing. Appendix A of BS 5628: part1:1992, specifies the sizes of wall panels that should be used to test the compressive and flexural strength of wall panels. The dimensions of wall panels are specified in Table 3.

Table 3 Dimensions of wall panels constructed for structural testing

Test	Panel Dimensions(mm)			Number of Panels
	Length	Height		
Compression Test	1000	750	150	2
Flexure Perpendicular To Bed	550	1000	150	2
Flexure Parallel To Bed	1000	800	150	2

6.3 Compressive Strength of wall panels

The Figure 7 shows the test panel prepared for testing. Two dial gauges were fixed at the top of the panel and at the bottom to measure the vertical deflection. It is used to measure the vertical deflection and to identify the point failure of the wall panel.

Figure 7 A wall panel being tested for compressive strength

The results of the compressive strength testing are presented in Table 4.

Table 4 Results from the compressive strength testing

	Load at first crack (KN)	Load at failure (KN)	Compressive Strength (N/mm2)	Average Compressive Strength (N/mm2)
Panel 1	297.6	315.8	2.1	2.05
Panel 2	284.8	299.2	2	

The proposed material has high resistance for compression. According to the study done by Jayasinghe and Kamaladasa (2006) on Compressive strength characteristics of cement stabilized rammed earth; an average strength of 1.8 N/mm2 for 6% of cement was obtained [2]. According to the results obtained, the proposed walling material gives better results for the characteristic strength. The addition of recycled construction waste has increased the compressive strength.

6.4 Flexural Strength of Wall Panels

Flexural strength of a walling material is important to evaluate the performance when subjected to lateral loads due to wind, floods or any other load that can cause out-of-plane bending in a wall. The flexural strength of masonry can be determined by loading the wall panels laterally. The flexural strengths can be determined both parallel to bed joint and perpendicular to bed joint. Since the flexural strength parallel to bed joints is generally low, there is a tendency for the failure to occur at very low lateral loads. Konthesinghe (2008) showed that it is possible to obtain reliable results for flexural strength by testing them with low magnitudes of pre-compression [9]. This prevents failure due to any weakness caused during handling. In this test series, the pre-compression was limited to 0.06N/mm2.

Figure 8 Applying pre-compression for flexural testing

Figure 9 A wall panel being tested for f_{kx} Parallel to bed joints

Failure loads were determined when the direction of loading is parallel to bed joints and perpendicular to bed joints. The Table 5 presents the flexural strengths of wall panels considered in the experiment. During the flexural test parallel to bed joints, the panel failed in a plane parallel to bed joints close to the centre. The failure plane was perpendicular to the bed joints in the flexural test perpendicular to bed joints. The Figures 10, 11 show the wall panels after flexural testing.

Figure 10 Failure of wall panels tested for Flexural strength parallel to bed joints

Figure 11 Failure of wall panels tested for Flexural strength perpendicular to bed joints

Table 5 Test results from testing of flexural strength of wall panels

Test	Panel 1	Panel 2	Average Strength
Flexural Strength parallel to bed(N/mm2)	1.32 N/mm2	1.36 N/mm2	**1.34 N/mm2**
Flexural Strength perpendicular to bed(N/mm2)	1.60 N/mm2	1.75 N/mm2	**1.67 N/mm2**

The flexural strength values are comparatively high. According to a research done by Jayasinghe and Mallawaarachchi (2009) on Flexural strength of stabilized earth masonry material, a 240mm thick rammed earth wall section has a flexural strength of 0.463 N/mm^2 (parallel to bed joints) and 0.918 N/mm2 (perpendicular to bed joints) [3]. Rammed earth walls do not have any bed joints. This can be attributed to the relatively high value for flexural strength. The above values can be compared with the flexural strengths given in BS 5628: Part 1: 1992 for burnt clay bricks of water absorption ratio of above 12%. The flexural strength parallel to bed joint is 0.3 N/mm2 and perpendicular to bed joint is 0.9 N/mm2. Therefore, the proposed building material has high lateral strength.

7. Conclusion

The compressive strength and the flexural strength of wall panels made out of construction waste and rammed earth has been reviewed in the research. The cube test results showed that 1:5:5 cement: construction waste: soil mix proportion produces the highest strength. The wall panels made using the above proportion performed extremely well in compression testing and flexural testing.

When the wall panels were loaded in the vertical direction, the wall panel failed at one edge. This suggests that the vertical load was not uniform. Therefore, a uniform loading would have produced a much higher compressive strength. The compressive strength is also affected by the workmanship. If the wall panel is not vertical, the compressive strength is reduced. Therefore high workmanship levels should be maintained at construction.

The lateral load carrying capacity is important to prevent collapses of houses when subjected to lateral loads induced by cyclonic conditions or flooding. Since the pre compression can further increase the lateral load carrying capacity, it is suggested to introduce tie beams at few levels. The flexural strength of wall panels made of rammed earth and construction waste is high. It exceeds the values indicated in BS 5628 part 1: 1992 for masonry work. Since the flexural strength parallel to bed joints is low, the failure of a wall would be governed by it. Therefore, lateral resistance of 1.34 N/mm2 should be used for structural design calculations.

When a wall is lightly loaded in compression, the lateral carrying capacity is governed by the flexural strength. It is shown in the experimental program on wall panels made of rammed earth and construction waste that are subjected to low levels of pre compression have high flexural strengths in the region of 1.3 N/mm2. These values are comparable with the values given for wall panels constructed with masonry in BS 5628: part 1: 1992. The compressive strength of wall panels made of rammed earth and construction waste is adequate for single storey and two storey constructions. Therefore, it can be stated with confidence that the walling material made out of rammed earth and construction waste is a viable alternative for single leaf external and internal loadbearing walls of single and two storey houses.

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Appendix A

Calculation for compressive strength

$$Compressive\ Strength = \frac{Load\ at\ failure}{Cross\ sectional\ area}$$

For Panel 1:

Load at failure= 315.8 KN

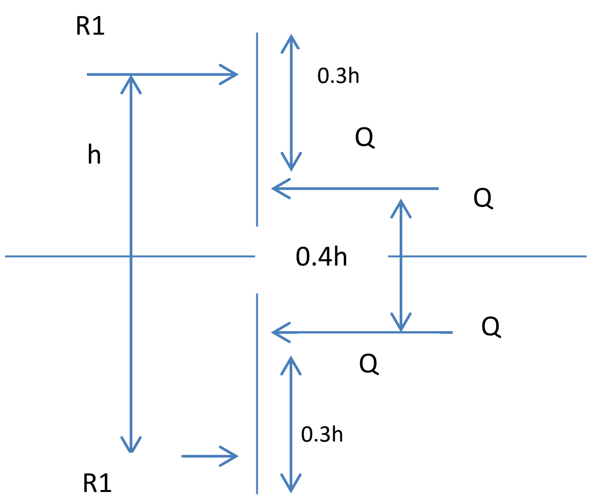
Cross sectional Area= 150mm x 1000mm

$$Compressive\ Strength\left(\frac{N}{mm^2}\right) = \frac{315.8 * 10^3}{150 * 1000}$$

$$Compressive\ Strength\ = 2.1\left(\frac{N}{mm^2}\right)$$

Appendix B

Calculation for Flexural strength



Where R: reactions at top and bottom (KN), Q: the applied load (KN), W: total applied load (KN): W=2Q, h: panel height-100 (mm): the span between the outer bearings, b: length of wall panel (mm), t: thickness of wall panel (mm),$\sigma c1$: stress due to applied pre compression, $\sigma c2$: Stress due to bending, Z: section modulus.

Considering horizontal equilibrium of the wall panel 1 parallel to bed joints;

$2R_1 = 2Q = W = 21.15$ KN

$$Bending\ Stress(N/mm2) = \frac{M}{Z} = \frac{\frac{W}{2} * 0.3h * 10^3}{\frac{1}{6} * b * t^2}$$

$$Bending\ Stress(N/mm2) = \frac{\frac{21.15}{2} * 0.3 * 900 * 10^3}{\frac{1}{6} * 550 * 150^2}$$

$$Bending\ Stress(\sigma_{c2}) = 1.384\ N/mm2$$

Therefore,

$$f_{kx} = \sigma_{c2} - \sigma_{c1}$$

$$f_{kx} = 1.384 - 0.06$$

$$f_{kx} = 1.324\ N/mm2$$

Similarly, the calculations can be performed for flexural strength perpendicular to bed joints.

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