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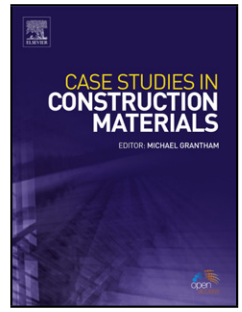

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Mud concrete Paving Block for Pedestrian Pavements

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Population growth and rapid urbanization have led to mass infrastructure development in many sectors such as buildings, roads, urban public areas, etc. However, little attention has been given to human comfort and environmental sustainability of paving blocks.

This is an attempt to search for alternative eco-friendly earth paving material for public walkways with both the strength and durable properties of concrete while ensuring pedestrian comfort. Approaches were made to change the fine particle percentage while keeping the sand and gravel constant, once the optimum most practical mixture was known, the standard tests were done. The results obtained revealed that the proposed self-compacting block can be produced by using soil with less than 5% fine particles, 55% of 65% sand particles and 18% of 22% cement by weight together with the moisture content between 14% and 15%The tested mud concrete paving blocks were already used in practical application in Sri Lankan urban context.

I. Introduction

“Natural surfaces are composed of vegetation and moisture-trapping soils that absorb solar energy to assist evapotranspiration, which releases water vapor making the surrounding air cooler, whereas built surfaces are composed of high percentages of non-reflective, water-resistant materials, absorbing a significant amount of solar energy, which is reflected to the microclimate as heat.” Built Environment (Architectural Science) is more or less growing artificial environments by replacing the natural environment. Nevertheless, the danger is that modern concrete technologies are unable to decrease the impact to the natural environment, such as weather rain evaporation, etc. Therefore, the world should look for eco-friendlier materials, which may be much more suitable for replacing the natural setting [1].

Earth is a building material that closely follows the natural setting [2]. For instance, earth materials can absorb heat more than concrete and act as thermal mass. As well as earth materials assist evapotranspiration of water better than concrete[3]. In additional following advantages are there to use earth as construction materials;

- Reduction of initial cost and energy costs related to transportation.
- Reduction of construction waste generation.
- Support of local businesses and resource bases.

Most studies have suggested that the reduction of the cost, as well as the energy cost of the building materials, can be reduced by using earth as the main building material [4][5][6][7]. Earth as construction materials do not produce waste; because the earth (soil) can be, degrade back to the earth in its similar form. In addition, the manufacturing process of earth materials can be done in local context and which help to produce local materials industry.

This study and the experiments focused on producing earth-paving materials to replace the heat producing concrete pavements. Not only the heat island effect but also there are health concerns in designing pavements that indicated the walkways should be designed to provide safe, attractive, interesting and comfortable space for pedestrians. The qualitative level of pedestrian comfort might be promoted under six broad aspects: safety, security, convenience and comfort, continuity of the walkway, system coherence and attractiveness[8]. They provide motivation for people to use the walkways resulting in an environmental benefit by minimizing motorized transportation [9]. More than 95% of road users wish to have roadside walkways with visual identification from the traffic path [10]. The albedo value of construction material is another important factor to be considered when selecting material for outdoor development, especially in countries with hot climatic conditions [11][12].

In order to achieve this user comfort and environment-friendly outdoor urban development, a new construction material should be invented. Use of earth itself is an interesting solution. Thus, earthen walkways become drenched during rainy seasons and dusty during dry seasons. In addition, there are a major health and environment hazards [13]. However, many artificial paving materials available in the construction industry such as brick, asphalt, granite, concrete, etc. They have their own advantages as well as disadvantages relating to economic, technical and environmental aspects. The clay bricks are the most preferred artificial construction material to cover outdoor surfaces, among the general public and it is recommended that further development of new paving materials could either be based on clay burnt bricks or on its beneficial characteristics [10].

Asphalt concrete and cement concrete play an important role in pavement construction. They are usually used for the construction of most outdoor facilities such as road parking lots, walkways, etc. [14]. Cement concrete paving blocks have lately become an attractive & economical engineering material in outdoor construction. Because they are considered to be consistent and durable [15][16].Although several research studies have been done to improve the engineering properties of cement concrete blocks while managing solid waste issues [17], little attention has been paid to the user discomfort caused by using these artificial materials[18][19]. In order to develop energy-efficient construction methods and promoting sustainable material minimizes the negative environmental impact produced by artificial outdoor surfaces[20][21].

The idea of developing clay bricks as paving materials merely because of cost concern. The economic value of construction materials is one factor to consider in sustainable development [22]. Consequently, with rising construction costs, there is a need to develop low-cost materials and technology for the construction industry. Clay burnt brick is one of the most popular materials in many countries for construction because of its valuable properties such as durability, relatively low cost, availability, sound and heat insulation, acceptable fire resistance, adequate resistance to weathering and attractive appearance [23]. Though clay burnt brick is one of the most popular construction materials, the energy consumption and environmental pollution during the manufacturing process are the main disadvantages in respect of sustainability [22]. An alternative type of brick identified as mud concrete block, which has received attention due to low energy content and carbon emission[7][19]. The mud concrete block is an advanced development of soil cement block.

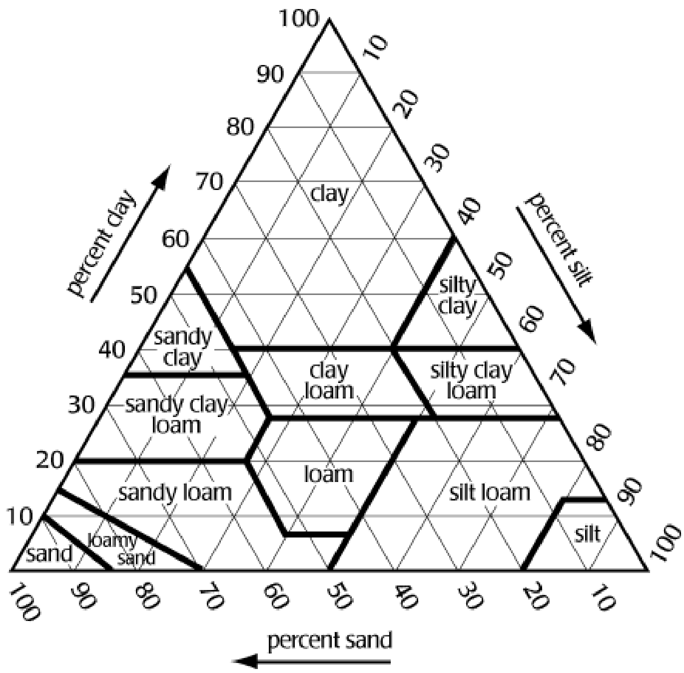

Figure 1: Physical and mechanical properties of soil[24]

Source:http://hydrology1.nmsu.edu/teaching/soil350/Physical%20Properties%20of%20Soil.htm

The soil is the principal ingredient of mud concrete block. Therefore, the properties of the soil greatly affect the strength and durability of the block. The major components of soil are gravel, sand, silt, and clay, which influence the soil properties. The properties of the soil in generally shown in Figure 1. This research investigates the possibility of producing an environmentally and user-friendly paving block using the mud concrete technology[25].

1 Experimental program

The initial mixtures were developed by doing extensive trial mixes. These trial mixes were done according to the previous materials development experiment [26]. When the study was conducted to identify the best mix design for a pedestrian paving block to get the optimum strength. The final Experimental program was based on a series of standard test methods to develop the paving block. Moreover, the paving material was developed by considering the basic engineering properties of construction materials. After the standard tests, certain quality improvements were done in order to optimize this novel pedestrian paving block.

1.1 Materials

1.1.1 Soil

Soil samples were obtained from the university premises from homogeneous layers 600 mm below the top of the soil to make sure that organic matter is not included in the sample. The oversize soil particles were removed by using a 20mm sieve. The composition of the soil used in this experimental series confirmed to the sieve analysis[27]. The results of the sieve analysis are shown in Figure 8.

Table 1: Physical and mechanical properties of soil

Properties	Value
Physical properties	
Natural water content	26.00%
Liquid limit	36.77%
Plastic limit	22.95%
Plasticity index	13.82%
Linear shrinkage	6.71%
Specific gravity	**2.37**
Particles	
Gravel	46.00%
Sand	44.00%
Silt & Clay	10.00%
Chemicals	
Silica (SiO_2)	71.16%
Alumina (Al_2O_3)	16.15%
Iron oxide (Fe_2O_3)	4.98%
Potash (K_2O)	1.46%
Magnesia (MgO)	0.25%
Loss on ignition	5.61%

The soil was selected after an evaluation of the typical soil condition in Sri Lanka. The Sri Lankan soil 74% water absorption value and its density at saturated surface dry (SSD) condition were 2.65 g/cm$^{3.}$ The natural water content was 26%, the liquid limit was 36.77%. The plastic limit was 22.95 and the plasticity index is 13.82%. Sri Lankan typical soil (below 600mm) content is 46% of gravel, 44% of sand and 10% of silt & clay (see the Table 1).

1.1.2 Stabilizer

Table 2: Physical and mechanical properties of the cement.

	CEM 42.5N
Initial setting time (min)	200
Final setting time (min)	280
Volume expansion (mm)	1
Specific gravity (g/cm3)	3.15
Blaine fineness (cm2/g)	3.54 103
Compressive strength (MPa)	
2 days	25.3
7 days	40.5
28 days	51.7

The key stabilizer was cement for this experiment: industrially available Portland cement was used of strength class 42.5N. The physical and mechanical properties of cement are presented in Table 2. For the experiment purpose, one-line production of cement was used and stored in the required lab condition before using it for the mix development.

Figure 2: Test block preparation

II. Methodology

The mud concrete paving block is a combination of cement and soil mixed together with the addition of water. A series of test cubes were cast and tested with different ratios of soil & cement by controlling the water content. In addition, different vibration patterns were applied to identify the best method to achieve the required compressive strength of blocks for pedestrian pavements. The blocks tested for four variables in order to identify their effect on the strength. The selected variables were cement content, soil compositions, water content and compaction pattern. This was done in the first and second stage of this study (see Figure 3).

In the third stage, mud concrete paving blocks cast in the actual size with a selected mix proportion and tested for standard tests named in Table 3. The experimental work in selecting the mix proportion was done in the structural testing laboratory at the University of Moratuwa, Sri Lanka, and a skid resistance test was done in the Road Development Authority (RDA) laboratory.

Cement Content: The cement used in this research was Portland cement. Portland cement is one of the common stabilizers for earth blocks. Soil cement blocks have the wet compressive strength of 1.32 N/mm^2, and 1.97 N/mm^2 for 3.5% and 7% cement respectively[22]. Based on the literature data, in order to have the minimum required wet compressive strength (i.e., 15 N/mm^2) for paving blocks and to be economical, 18% cement was taken as the cement content at the initial stage.

Water content: For the soil cement blocks, the optimum moisture content was 14% [22]. Based on this water content value, samples were cast for three different moisture contents.

Compaction pattern: The compaction effect used in this experiment series was the application of vibration. Three different vibration patterns were applied for each mix proportion as no vibration (i.e. zero vibration), vibration for 15 seconds and vibration for 30-second duration. The vibration was applied by using an electrically operated vibration table.

Soil composition: The suitability of a soil as construction material depends on its constituents (i.e. gravel, sand, and silt &clay proportions of the soil). Therefore, it is essential to explore the constituents of the available soil. Therefore, a sieve analysis was conducted to determine the constituents of the soil. This test was expected to present a preliminary picture of the properties and constituents of the soil to be used in producing mud concrete paving blocks. Accordingly, 10 % and 05% fine particles (i.e., particle size in 0.002 to 0.06 mm) contained soil was selected to develop mud concrete block [28][29]. Because, the optimum strength can be gained by the composition of 35% gravel, 60% sand, and 5% clay &silt[29].

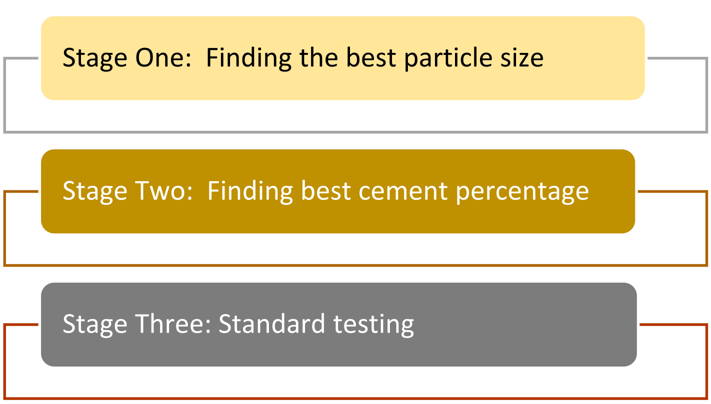

Figure 3: Testing procedure of mud concrete paving block

Stage One: Test cubes were prepared in two series in Stage 1. In the first series, the cement percentage selected for the casting test cubes was 18% and was kept constant. Blocks were cast by systematically varying the other three variables mentioned above in the methodology section.

The first series of test cubes were cast with sand content by varying it in 10% increments in a range of 40% to 70% as the first variable for the fixed fine particle content of 10%. Then soil was modified by adding or deducting sand and gravel to achieve the required composition ratios of fine particles, sand, and gravel. Dry soil weighing 10 kg was measured to cast 12 test cubes of size 70mm x 70mm x 70mm for each trial mix. The prepared dry soil mix was thoroughly mixed manually. Then 18% cement (by weight) from the total dry soil mix was spread on the surface and mixed again.

Next, a measured volume of water to produce the required moisture content was added little by a little while mixing thoroughly to ensure a uniform wet soil mix (see figure 2). The prepared wet soil mix was poured into the well-prepared moulds by applying mould oil, in two layers. The test cubes were then compacted under the three different compaction methods described above using the vibration table (four numbers of cubes for each compaction method). Samples from the prepared wet soil mix were kept for 24 hours in the oven to calculate the moisture content. After 24 hours from the time of casting, the cubes were remoulded and the test cubes were kept for 28 days under proper curing.

The second series of test cubes cast with a 5% fine particle content. The results obtained in the first series helped to determine the sample mix proportions for casting the second series of test cubes. Test cubes of the same size used for this casting according to a similar procedure for mixing, molding and demoulding.

Stage Two: In this stage, the cubes were tested for cement optimization. The cement content was increased by 2% in a range of 18% to 22%. Soil and water content proportions were selected according to the results obtained in stage one. Test cubes of the same size were used for this casting according to a similar procedure followed for mixing, moulding, and demolding.

Stage Three: In this stage, blocks were cast in the actual size, for paving block size 200 x 100 x 80 mm and rectangular in shape, for the selected mix proportion according to the results obtained in stages one and two. The blocks were tested for standard quality checking tests. In addition to standard tests, another set of cubes were cast for the wet compressive strength with the same procedure in above two stages for mixing, moulding, demoulding of test cubes.

Table 3: Important performance measures specified in codes of practice

Requirement	BS EN 1338:2003[30]	ASTM C936 [31]	Sri Lanka[32]
Compressive strength (MPa)	-	≥ 55.2	Class A – 50N/mm2 Class B – 40N/mm2 Class C – 30N/mm2 Foot path–15N/mm2
Tensile splitting strength (MPa)	≥ 3.6	-	-
Skid resistance(BPN)	≥ 45	-	≥ 45
Cold-water absorption (%)	-	≤ 5	≤ 6
Durability test	BS EN 1338	ASTM C 1262	
(Freeze Thaw test)	Mass loss after freeze thaw test ≤ 1.0Kg/m^2 as a mean with no individual value ≥ 1.5		

1. **Compressive strength test**

A compressive strength test was done according to BS EN 1338:2003, SLS 1425 (2011) at 28 days. The dimensions of each test cubes were measured before soaking them in water and calculated the plan area. The test cubes were then soaked in water for 24 hours and tested for the compressive strength-testing machine for wet compressive strength. The wet compressive strength was calculated by dividing the maximum load by the plan area and multiplying the result by the appropriate factor given in BS EN 1338:2003, SLS 1425 (2011). The minimum strength requirement for strength class 4 for use of pedestrian walkways is 15 N/ mm^2.

2. **Tensile splitting strength**

The splitting tensile strength testing was done according to BS EN 1338:2003. The tensile strength of mud concrete paving blocks was determined at 28 days. The thicknesses of the specimens were determined from two points before the application of load. The load was applied with a universal testing machine from the middle of the specimen with the apparatus shown in Figure 4.

Figure 4: Measuring tensile splitting strength of mud concrete paving block

3. **Skid resistance test**

Skid resistance is important for the safety of pedestrians' walkways, both roadside and in recreational areas. Surface characteristics are very important among many variables that influence skid resistance. A skid resistance test was conducted according to the standard testing BS EN 1338:2003 [30].

The skid resistant test was used to determine the qualities of the mud concrete paving blocks and to determine whether the particular surface finish was appropriate for the application. There are two approaches to measuring skid resistance; static and dynamic [33]. The common device used for static measurement is the British Pendulum Skid Resistance Tester. Four mud concrete paving blocks of size 200 mm x 100 mm x 80 mm were tested. To perform a test, the test surface is wetted, the pendulum is pulled back and the shoe rubbed across the surface. Friction resistance is read on a scale on the machine as the British Pendulum Number (BPN).

4. Cold water absorption

Figure 5: Measuring cold-water absorption

The cold water absorption test is for evaluating the density quality standard of paving blocks. The testing was carried out by using ten whole paving blocks from similar condition samples developed by the study. The specimens were dried in a ventilated oven at a temperature of 105°C to 115°C until they attained a substantially constant mass. All the specimens were cooled to room temperature and then their weights of specimens as (M1) were measured. Then, the dried specimens were immersed completely in clean water at a temperature of 27+2°C for 24 hours (see Figure 5). The specimens were removed and any traces of water wiped off with a damp cloth and the specimens were weighed to obtain (M2).

The cold-water absorption, percentage by mass, after 24 hours' immersion in cold water was measured and calculated using the following formula shown in Equation 1.

$$W = \frac{M_2 - M_1}{M_1} X100 \qquad (1)$$

5. Durability measurement study

Durability measurement study is to understand the long-term use of this material, because, the use of this paving as a green alternative material has no use if the durability is poor. Therefore, the study was extended to understand the durability of selected optimum mix proportioned paving blocks. The standard method of measuring durability is by conducting a freeze thaw cycle test [30]. Therefore, in order to measure the durability of paving blocks, freeze thaw cycle testing was conducted according to BS EN 1338.

The specimens were preconditioned and then subjected to 28 freeze thaw cycles. The material that had scaled off was collected and weighed. And the results are expressing kilograms per square meter. Three samples, 28 days old, were cured for 24 hours in the climate chamber with a temperature of (20 ± 2), relative humidity of (65 ± 10) %. Before testing, freeze thaw samples were cleaned to remove all flashing and loose materials on the surfaces of the test specimens. The rubber sheet was glued to all surfaces of the specimen except the top surface and remained glued during the test. All chamfers around the perimeter of the specimen were filled with sealant (silicon glue) to provide a seal around the test surface and to prevent water penetration between the specimens while the surface was covered with a 3 % NaCl (common salt) solution.

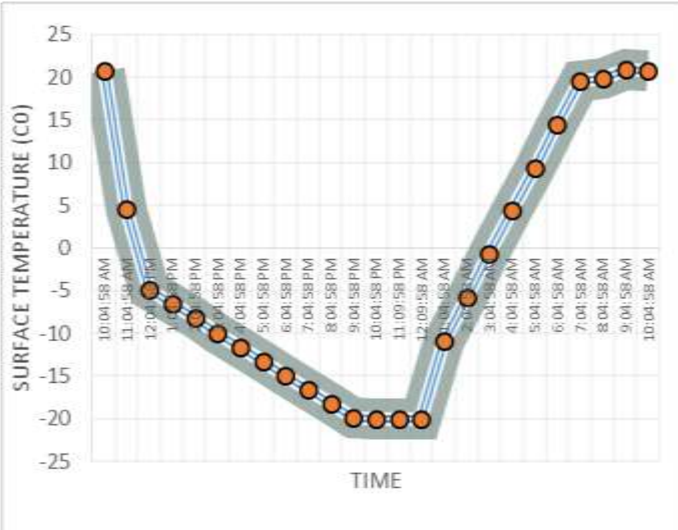

Figure 6: Time- temperature cycle for freeze thaw test

The edge of the rubber sheet was kept 20 mm above the test surface.0.5 mm rubber sheet and 20mm polystyrene sheet was used as thermal insulation. Freezing chamber with temperature controlled according to the standard shown in Figure 7. Refrigerating and heating system with a capacity and air circulation that the time-temperature curve presented in Figure 6. The data logger was used to temperature measuring device for measuring the temperature of the freezing medium on the test surface with an accuracy within ± 0,5 °C and logged temperature during the testing period.

Figure 7: Freeze thaw cycle testing in climate chamber

The scaled material from the test surface was collected by rinsing into the vessel. Washing off scaled material and washing the salt out of scaled material was done by using a spray bottle. Potable water was sprayed on to scaled materials surface by using a 30mm wide paintbrush. Liquid and scaled material were poured into the vessel through the filter paper. The filter paper was dried for 24 hours in the oven at a temperature of 110 °C. Then the weight loss after freeze thaw cycles was measured by using following equation 2.

$$Weight\ loss\ freew\ thaw\ cycle\ (L) = \frac{Scaled\ off\ mass\ (M)}{Area\ of\ the\ test\ surface\ (A)}\ (2)$$

III. Results and Discussion

A. Sieve analysis

A sieve analysis was done for two samples collected arbitrarily from the soil heap used for the casting process. Figure 8 shows the results obtained from sieve analysis.

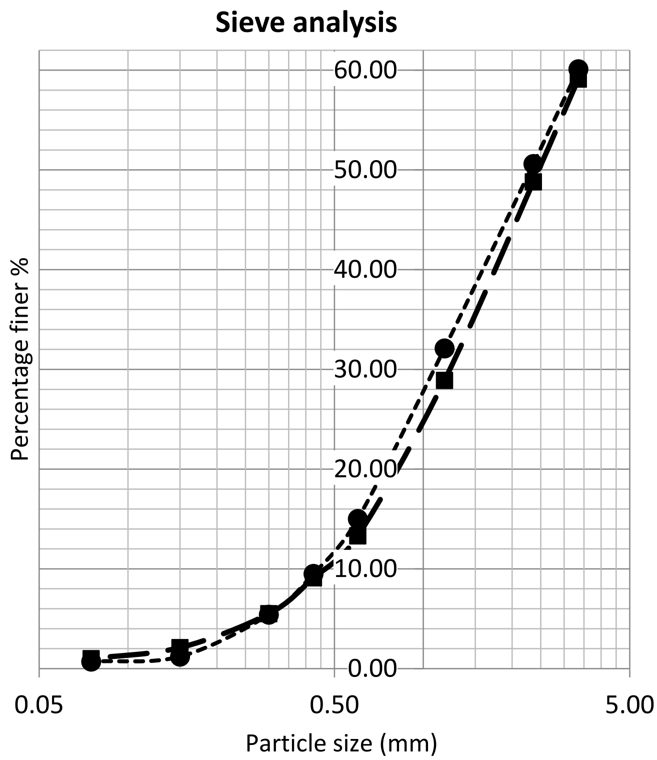

Figure 8: Particle size distribution of soil used for Mud concrete Paving Blocks

B. Mix development

After the sieve analysis and particle distribution study, the next step was to find out the most suitable mix proportions and the manufacturing method for mud concrete paving block. The study was conducted as described in section II. A per the results indicated in stage I, the best wet compressive strength was shown when the moisture content was between 14% to 15%. The results obtained are shown in table 4 and figure 9-11. After the confirmation of water content, it was found that the best sand content is between 50% and 60%. It was also found that changing the vibration time did not produce a significant effect on the strength of the blocks. The maximum wet compressive strength obtained in this series was 14.3N/mm^2 and 15.1 N/mm^2 for the soil composition of 60% sand with 30% gravel without applying any vibration and sand 50% with gravel 40% together with the application of 15-second vibration respectively.

According to these results and to minimize the use of energy, it was decided to select 60% sand content for the mix proportion in the second series of test cubes with a content of 5% fine particles. The results obtained in this series of tests and the variations of wet compressive strength with moisture content are shown in Table 5 and the accompanying Figures 12:

Table 4: Average wet compressive strength for test cubes in stage one: series one.

Sand	Gravel	Moisture %	Average wet compressive strength (N/mm^2)		
			No vibration	15s vibration	30s vibration
70	20	12.0	6.3	3.0	6.1
		14.1	8.7	7.9	12.5
		15.6	6.6	8.0	7.7
60	30	10.3	3.1	1.6	2.1
		13.9	12.5	12.1	12.5
		14.8	14.3	11.9	14.0
50	40	12.7	5.1	2.9	9.0
		13.5	10.8	10.9	12.2
		14.2	13.2	15.1	12.6
40	50	14.2	6.1	5.4	6.0
		16.1	8.3	9.6	10.7
		18.4	6.9	7.3	5.9

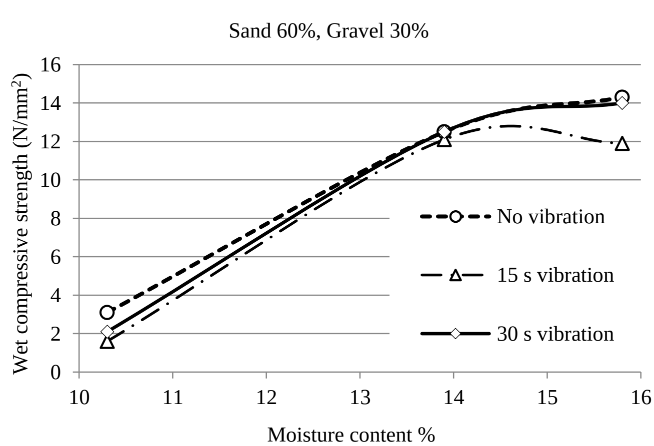

Figure 9: Variation of wet com. strength with sand 60% and gravel 30%

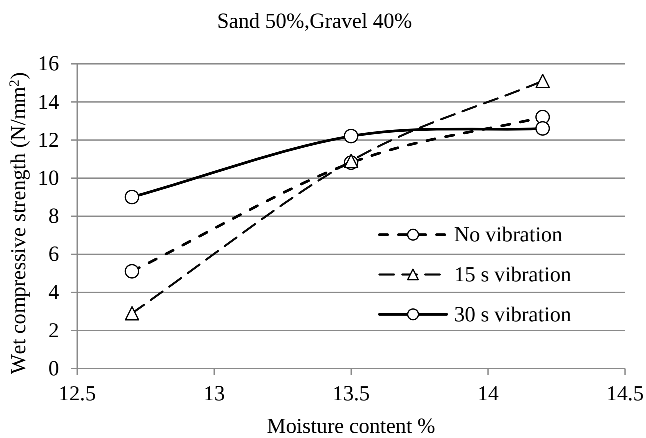

Figure 10: Variation of wet com. strength with sand 50% and gravel 40%

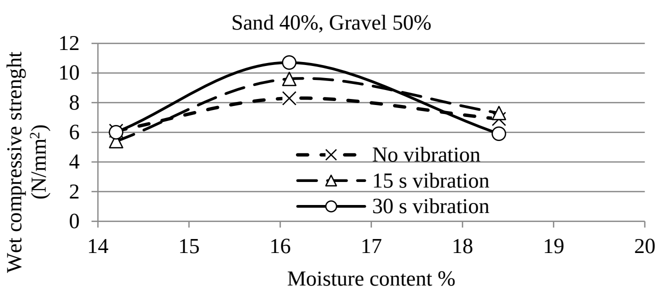

Figure 11: Variation of wet com. strength with sand 40% and gravel 50%

Table 5: Wet compressive strength for test cubes of stage one: series two

Moisture %	Average wet compressive strength (N/mm2)		
	No vibration	15s vibration	30s vibration
13.5	12	9.2	10.3
14.2	15.4	12.5	13.8
15.1	14.6	7.8	8.1

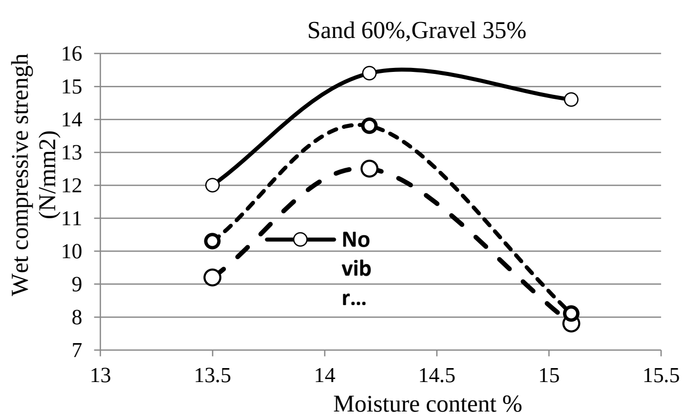

Figure 12: Variation of wet compressive strength with moisture content.

The results show that mud concrete paving blocks with 5% clay content showed better strength than those with 10 % clay content. Furthermore, a maximum strength of 15.4 N/mm^2 was achieved when the sand content was 60% together with 14.2% moisture content and without applying vibration.

The results obtained in the stage one with the sand content of 60% were plotted in support of a better conclusion for the behavior of mud concrete paving block strength with the vibration pattern. Table 6 summarizes the wet compressive strength values and shows the variation of wet strength with the vibration pattern.

Table 6: Summary of wet compressive strength for sand content of 60%

Moisture Content	Wet Compressive Strength (N/mm^2)	Wet Compressive Strength (N/mm^2)	Wet Compressive Strength (N/mm^2)
	No vibrations.	15s vibration	30s vibrations.
Fine particles - 5%			
14.2	15.4	12.5	13.8
13.5	12.0	9.2	10.3
Fine particles - 10%			
13.90	12.5	12.1	12.5
14.80	14.3	11.9	14.0

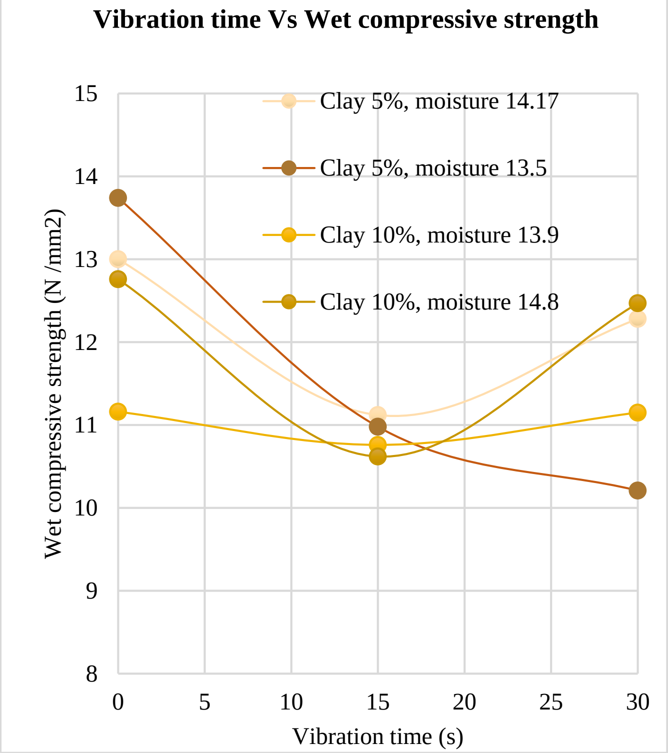

Figure 13: Variation of wet compressive strength with vibration time.

C. Finding best cement proportion

The conclusions on the best mix proportions for the newly invented mud concrete paving block were arrived by testing another set of test cubes. In these test cubes, the cement content was increased in order to establish the strength variation with cement content. The cement percentage was increased to 20% and 22% and the soil proportion was selected as fine particle content of 5% and sand content varying from 55% to 65% in 5% increments. Average wet compressive strength values obtained from these tests are shown in Table 7, while Figure 14 shows the variation of wet compressive strength with sand content.

Table 7: Average wet compressive strength

Sand %	CEM 18%	CEM 20%	CEM 22%
55	11.2	13.8	14.8
60	15.4	15.5	15.7
65	13.4	14.4	15.8

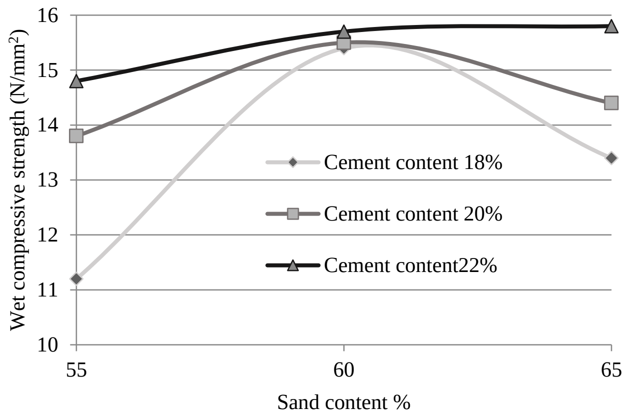

Figure 14: The behavior of wet compressive strength with cement content.

The results indicated that the use of sand content in the range of 55% to 65% can achieve the required strength. They also indicated that the best mix proportion was the sand content of 60% with a cement content of 18% for economic blocks. Furthermore, it was concluded that the mix proportions of 5% fine particle content, 60% sand content and 22% cement content were the best for the proposed mud concrete paving block.

D. Standard testing

A set of paving blocks with a selected mix of actual size (i.e., 200mm x 100mm x 80mm) were tested for wet compressive strength, tensile splitting strength, skid resistance, cold water absorption, and durability. A sample block and paving area with newly invented mud concrete paving blocks are shown in Figure 7.

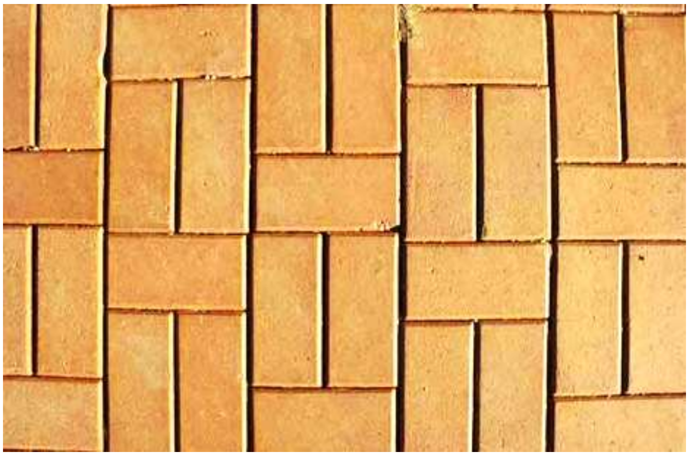

Figure 15: Mud concrete paved area.

Dry unit weight

The density values of the produced mud concrete pavement blocks in comparison with concrete paving blocks are presented in Table 8. The density and specific heat were measured and given after measuring three samples under similar conditions. However, mud concrete paving blocks are less dense than the concrete blocks and yet provide the equal strength required for pavements.

Table 8: Measuring coefficient of thermal conductivity &and specific heat

	Concrete paving block	**Mud Concrete Paving Block**
Density		
	2138 Kg/m^3	1960 Kg/m^3
Coefficient of thermal conductivity		
DRY-	2.325 m^2 K W^{-1}	2.012 m^2 K W^{-1}
WET-	2.909 m^2 K W^{-1}	2.618 m^2 K W^{-1}
Specific Heat		

Specific heat	680 Kj/kg*k	850 Kj/kg*k

Nonetheless, the specific heat is comparatively higher than typical concrete pavements. If the specific heat higher, the materials should absorb more heat to increase the surface temperature[34]. This is a good for pedestrian pavement, because the high capacity of heat absorption will create much cooler surfaces than concrete paving blocks.

1. Compressive strength

Compressive strength is an important parameter in the evaluation of paving block quality up to the required standard. Compressive strength values were taken from the best particle proportion and the best cement proportion. The average strength was measured as 17.2 N/mm^2 and the average cement concrete paving block was measured as reference data to compare the strength of the mud concrete block shown in Figure 16 and Table 9.

Table 9 : compressive strength comparison

Sample	MCB Wet compressive strength (N/mm^2)	Cement Concrete Wet compressive strength (N/mm^2)	MCB Dry compressive strength (N/mm^2)	Cement Concrete Dry compressive strength (N/mm^2)
1	16.82	14.19	29.7	25.12
2	17.39	13.95	31.25	24.76
3	17.67	13.25	28.8	21.63
4	16.93	16.12	29.8	28.38
5	17.35	15.02	31	26.8
6	16.72	12.52	33.5	25.06
Av. Strength	17.147	14.175	30.675	25.292

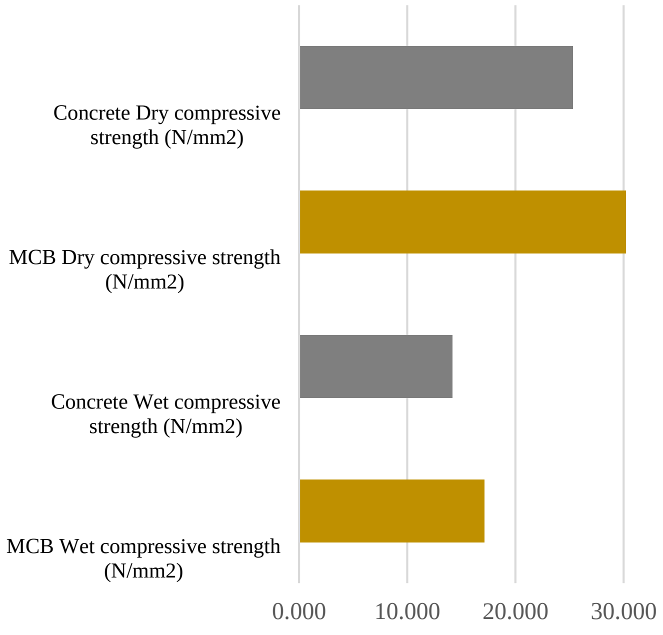

Figure 16: Relationship between 28-day compressive strength

2. Splitting tensile strength

Table 10: Splitting tensile strength comparison

Samples	Dimensions	Mud concrete Splitting Tensile Strength (N/mm^2)	Cement Concrete paving Splitting Tensile Strength (N/mm^2)
Sample 1	220X110X80	2.1	2.5
Sample 2	220X110X80	1.9	2.2
Sample 3	220X110X80	1.6	2.6
Average		1.9	2.4

Table 10 shows the splitting tensile strength of mud concrete paving blocks and a comparison with standard cement concrete paving blocks in Sri Lanka. The average tensile strength of mud concrete paving blocks is 1.9 N/mm^2 and this is not suitable for vehicular paving and up to the standards of BS EN 1338:2003. [See Table 3]. Nevertheless, for the pedestrian walkways, the strength is adequate.

3. Skid resistance

The skid resistance of the surface of blocks was measured using the Pendulum Skid Resistance Tester(*Figure 17*). The skid resistance values are the mean value of three readings. SLS 1425(2011) mentions that the mean pendulum value shall not be less than 45. The measured values shown below indicate that all the values achieved were higher than the SLS 1425 (2011) requirements. Thus, it can be concluded that the newly invented mud concrete paving block fulfilled the skid resistance requirements and is therefore suitable for use in the construction of pedestrian pavements.

Figure 17: Skid resistance testing process

Table 11: The measured values of four blocks

Block No.	Mean pendulum value
1	65
2	65
3	70
4	70
Average	67.5

According to BS EN 1338:2003 and to the SL standards for paving blocks, mud concrete paving blocks are adequate for pedestrian use. The skid resistance values are the mean value of three readings. BS EN 1338:2003 and SLS 1425(2011) mention that the mean pendulum value shall not be less than 45. Thus the average for mud concrete blocks is 67.5 see the Table 11.

4. Cold Water absorption

Coldwater absorption test is very important for understanding pedestrian paving materials performance when exposed to rain. Water absorption of paving materials is naturally related to a number of the pore spaces within the material. To understand the pore spaces within the mud concrete pavement blocks, series of microscopic images were taken. And it was found that there are considerably high pore spaces inside the blocks (see the Figure 18).

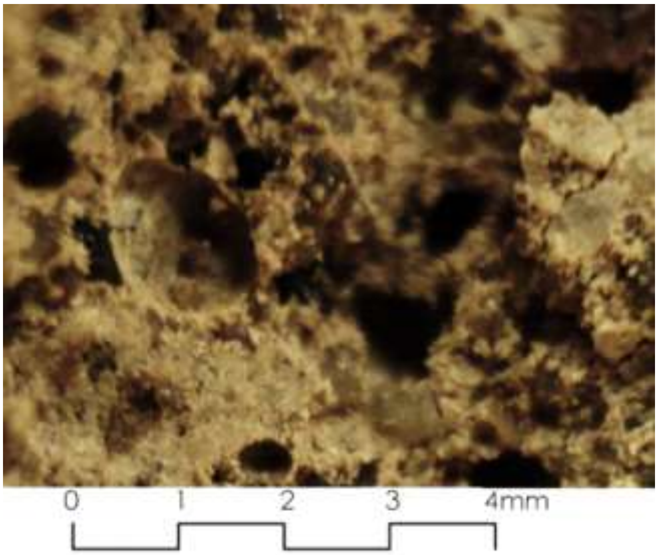

Figure 18: Microscopic image of pores structure of mud paving block.

Thus, a cold-water absorption test was carried out and results obtained was calculated using equation 1.According to Sri Lankan standards, the required cold-water absorption rate is 6% and ASTM C936 water absorption is 5%. shows that most of the test samples pass the Sri Lankan standards but not the ASTM.

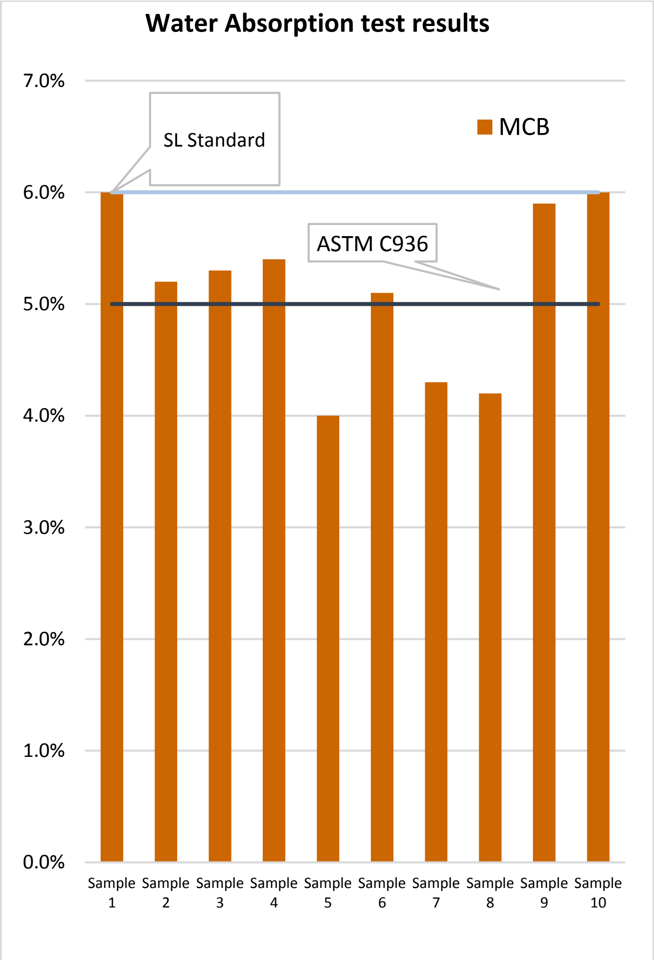

Figure 19: Cold-water absorption test results.

5. Durability test (Freeze thaw cycle test)

Three samples from the selected mixture were tested for twenty-eight freeze thaw cycles in order to understand the durability of the selected paving block. And the results are shown in Table 12.

Table 12: Freeze-thaw cycle test results

sample name	mass	surface area	weight loss per square meter
sample one	21.18g	0.022m^2	0.984Kg/m^2
sample two	18.81g	0.022m^2	0.845Kg/m^2
sample three	16.61g	0.023m^2	0.732Kg/m^2

According to the standard EN 1338: 2003, the required freeze-thaw cycle weight loss should not be more than 1kg/m^2. However, all the results were lower than the required standard. The Sri Lankan climate never experiences freezing temperatures in any case. In addition, the 1kg/m^2 standard is for vehicular paving blocks , but this is not for vehicular pavements. In addition, the surface was studied to understand the possible surface changes due to the freeze-thaw cycle test shown in Figure 20.

Figure 20: surface of the test specimen after the freeze-thaw cycle test

IV. Conclusion

This research study was undertaken to develop a new paving material 'Mud Concrete Paving Blocks' for outdoor pedestrian constructions. The preliminary study was carried out to understand the possibility of manufacturing soil-based paving blocks. Next, the prior study was conducted to optimize the idea of building mud concrete paving blocks. The initial test was carried out to optimize the best particle proportion for the mud concrete pavement block. And then the study was focused on understanding the best cement proportion to build paving blocks. According to the results obtained in the laboratory tests series for mix design, it can be concluded that the new block can be produced using soil with 5% of fine particles, 55% of 65% sand particles, 18% of 22% cement by weight together with a moisture content of 14% to 15%.

Furthermore, this type of mud concrete block doesn't need any compaction. The typical paving blocks such as concrete paving blocks needed heavy machinery like compaction to produce the paving block. But this novel mud concrete block production does not need any compaction or vibration. This is because the mixture of mud concrete is already malleable with water. To obtain better results it was concluded that mix proportions of soil with the sand content of 60% fine particle content of 5% and stabilized with 22% cement together with 14% to 15% moisture content were more appropriate.

After the initial discovery of mud concrete paving blocks, a series of standard tests were carried out to check the quality of mud concrete paving blocks and to improve their quality. Since the ultimate experiment was to improve the compressive strength of mud concrete paving blocks, the compressive strength of MCB was already up to the standard for a pedestrian paving block. And the specific heat tests were carried out to understand the material properties of mud concrete blocks. The skid resistance test results showed that all the British Pendulum Number (BPN) values achieved exceeded the requirements of SLS 1425(2011). Thus, it can also be concluded that the newly invented mud concrete paving block fulfilled the skid resistance requirements and is therefore suitable for use in the construction of pedestrian pavements. A cold-water absorption test was carried out according to Sri Lankan Standards and ASTM C936. Thus in this soil material, the water absorption level is comparatively high and the standard test for water absorption of ASTM C936 was not successful. The durability of this block was tested by freeze-thaw cycle test method according to EN 1338: 2003.And the study shows that Mud concrete paving block was suitable according to the standard.

Further, the production process of the new blocks is manual and does not use any kind of energy except for the production of cement. Hence, the embodied energy is much less compared to the other materials, especially cement concrete blocks, which are the most commonly used material. Even more important is that the mud concrete paving block can be produced without much-skilled labor while the materials are readily available. So material transportation and labor costs are less compared to other materials.

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