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Investigation of rain surface erosion and bonding strength of different wall care putty materials along with different walling materials

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ABSTRACT

In tropical countries such as Sri Lanka, wall care putties are applied as primers in building constructions providing a smooth shield for the wall. This research study was conducted to investigate the durability performance in terms of rain surface erosion and the bonding strength by shear testing of different wall care putty materials along with walling materials. Four types of walling materials and ten types of wall care putty mixtures were selected. Accelerated erosion test and lap shear strength test were conducted and bond breaking patterns were examined. X-ray diffraction analysis was conducted to investigate the chemical compositions of putty mixtures. Results demonstrate that cement block walling material and putty C+10% cement wall care putty mixture have the highest bonding strength. Similarly, cement added putty mixtures showed higher durability and bonding strength than putties in their pure form.

1. Introduction

In building design, walls are the core structural elements which separate indoor and outdoor environment. Outdoor environmental conditions such as rainfall, solar radiation and wind have more critical effect on the wall of a building. In tropical countries such as Sri Lanka, people have the habit of selecting solid walling materials due to high solar radiation and heavy monsoon rain [1,2]. At present Sri Lanka's most available walling materials are cement blocks (CB), cement stabilized earth blocks (CSEB), fired clay bricks (B) and cabook blocks. Mud concrete blocks (MCB) and geo polymerized earth blocks have been recently developed and possess sustainable characteristics [1,3]. Similarly, coatings are applied on the wall in order to protect it from extreme climatic conditions [4]. Coatings can be categorized as sealers, primers and top coats according to their functionality [5]. In Sri Lanka, masonry coatings such as cement plaster and rough cement plaster are used as a sealer in building constructions. Wall care putty materials are used as the primer and paints are used as the top coat in the building sector.

Wall care putty materials provide a protective base for the sealer and a smooth surface which bring out a finished appearance suitable for paint application. The minerals such as calcium carbonate, quartz and talcum are the main constituents of most wall care putty materials [6]. In the past, lime putty was the traditional material with a wide application in the construction [7]. At present, white cement wall putty, acrylic wall putty and plaster of paris (POP) are some of the well-known commercially available putty types. White cement wall putty which is a mineral, is the trendy putty type. It is constituted by white cement and polymer based putty of solid base formulated to give white coating, bright, smooth and superior finishes on wall surface. Acrylic wall putty is an acrylic and water based ready to use putty type of liquid base. POP is basically gypsum, a white powder of solid type which sets and gets hard when mixed with water and is used as a base.

Wall care putties are bonded to both masonry and paints where, bonding strength is a crucial factor. Bond strength can be explained as the amount of stress required to rupture an adhesive bond between two surfaces [8]. It can be quantified by bond energy and bond dissociation energy where the nature of the coating affects the bonding strength [9]. Bonding strength between a coating and a substrate can be described as adhesion where several mechanical, physical and chemical forces come into play. These forces have effects on each other [10]. Wall care putty materials play an important role in guaranteeing the quality in engineering projects where it should depict an appropriate durability, high bonding strength and good crack resistance [11]. The durability performance of the walls increase with the durability of the wall care putties

Abbreviations: B, Brick; CB, Cement Block; CSEB, Cement Stabilized Earth Block; MCB, Mud Concrete Block; RCP, Rough Cement Plaster.

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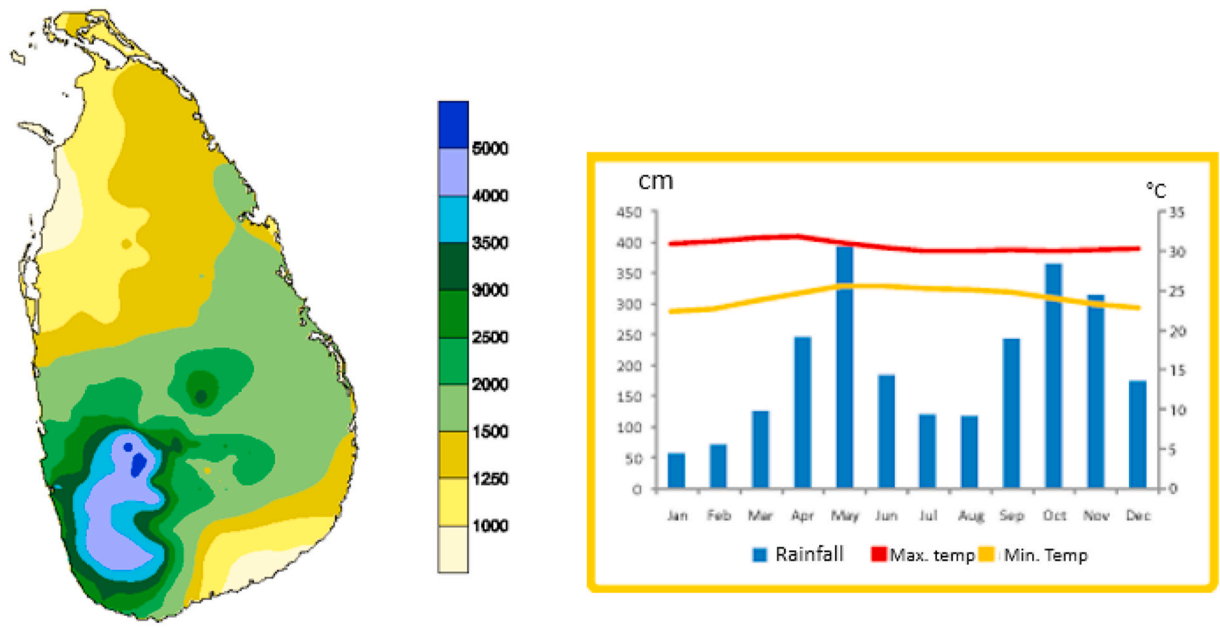

(a) (b)

Fig. 1. (a) Rainfall variation across the country in mm, (b) Rainfall and temperature variation in Colombo region.

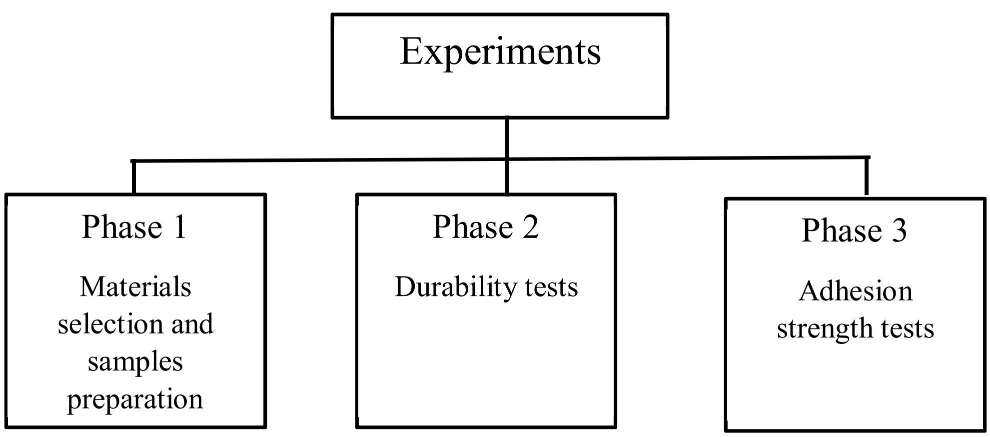

Fig. 2. Phases of the study.

Table 1
Selected walling materials.

Selected walling materials	Abbreviation
1.Burnt brick (BB)/Brick (B)	W1
2.Cement block (CB)	W2
3.Rough cement plaster (RCP)	W3
4.Cement stabilized earth block (CSEB)	W4
5.Mud concrete block (MCB)	W5

Table 2
Selected wall care putty mixtures.

Selected wall putty mixture	Composition	Abbreviation
Lime putty	(LP)	P1
Putty A (pure)	(PA)	P2
Putty A+5% cement	(PA+5%C)	P3
Putty A+10% cement	(PA+10%C)	P4
Putty B (pure)	(PB)	P5
Putty B+5% cement	(PB+5%C)	P6
Putty B+10% cement	(PB+10%C)	P7
Putty C (pure)	(PC)	P8
Putty C+5% cement	(PC+5%C)	P9
Putty C+10% cement	(PC+10%C)	P10

[6].

Durability is one of the properties that usually provide measures of the performance and functions of the materials under the expected conditions [1213]. According to the ASTM standard E 241 durability can be defined as the safe performance of a structure or a portion of a structure for its expected design life [14]. Hence it is essential to select durable material components to perform their functions over their expected lives [15,16]. Stress factors such as mechanical, thermal, environmental or biological factors can cause a material to degrade over time and to produce poor durability performance. Solar radiation, wetting due to monsoonal rainfall, wind erosion are the typical stress factors which affect the durability in a tropical climate [17]. Out of the above mentioned stress factors, rainfall has the most impact on durability performance under Sri Lankan condition [18]. Being a tropical

Table 3
Dimensions of walling materials.

Walling materials	Dimensions (length × breadth × height)
B	24 × 18 × 5 cm^3
CB	19 × 14 × 39 cm^3
RCP	15 × 15 × 15 cm^3
CSEB	18 × 15 × 8 cm^3
MCB	15 × 15 × 15 cm^3

(B= Brick, CB= Cement Block, RCP = Rough Cement Plaster CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block).

country, Sri Lanka has a humid warm climate constant throughout the year. As it is an equatorial country it receives intensive sunlight creating relatively high temperature [19]. The temperature fluctuates between 26.5 °C and 28.5 °C with a mean annual temperature of 27.5 °C [2]. Monsoonal, convectional and depression rains account for a foremost portion of rainfall with annual values varying between 900 mm in driest parts and 5000 mm in wettest parts (Fig. 1) [20]. Surface decaying is the most common phenomenon occurring due to rainfall which affects the durability performance. Bouncing rain and wind driven rain are the most significant rain types that contribute to surface decaying [1,17]. When the durability performance of the wall care putties is high, it ensures the durability performance of the wall as well as the top coat.

In this research study, the first objective is to identify and compare the durability performance of different wall care putty materials along with walling materials in terms of surface decaying caused by spray erosion testing. The second objective is to determine the bonding strength of different wall care putty materials regarding walling materials by shear testing and characterizing bond breaking patterns. According to the literature, durability performance and bonding strength of different walling materials have been investigated [21]. However, durability performance and bonding strength of wall care putties with different walling materials have not been assessed so far.

Spray erosion test or accelerated erosion test is the ideal testing method used for quantifying the surface decaying caused by rainfall. In other terms it measures the resistance to weather under extreme conditions [22]. The surfaces of a wall should represent its first line of defense against deterioration, because once the surface is eroded, it can rapidly lead to the exposure of less dense, less compacted, and more vulnerable inner core. This exposures can lead to irreversible and accelerated damage to the whole block [13]. Density of the surface material and surface roughness are two of the prime factors which affect surface decay. Similarly, water absorption is affected by the density of the surface material. Wall putty is applied to an average thickness of 3–5 mm in Sri Lanka [23]. In exterior environments, wall putty acts as a protective covering to the wall. It reduces the surface roughness and increases the density of the material surface [21,24]. By spray erosion testing we can quantify the depth to which surface decaying is caused in wall putties.

There are different types of bond strength test methods where shear, tensile, peel testing with torsional and pull-off tests are the most commonly performed. These bond tests allow determining the adhesive bond strength in a given direction or under a given type of stress. Lap shear strength test determines the shear strength of adhesives for bonding materials when testing on a single-lap-joint specimen [25]. Wall putties are scaled off through shear forces. Therefore lap shear strength test can be used to identify the bonding strength of wall care putty materials. Adhesive strength, surface preparation parameters and adhesive environmental durability can be determined by this test. An adhesive is applied between the two substrates and its bond strength and the ability to hold the two substrates together while under stress is determined [26]. A force is applied, steadily increased and the bond fails until the materials separate; the highest possible joint strength is identified. By characterizing the bond breaking patterns, strength of the

(a) (b) (c)

Fig. 3. Application of wall care putty mixtures; (a) test specimens after application of putties, (b) smoothing the surface by sanding, (c) applying filler.

Table 4
Samples prepared for testing.

Walling materials	Putties									
	Lime	Putty A			Putty B			Putty C		
		0% cement	5% cement	10% cement	0% cement	5% cement	10% cement	0% cement	5% cement	10% cement
B	W1P1	W1P2	W1P3	W1P4	W1P5	W1P6	W1P7	W1P8	W1P9	W1P10
CB	W2P1	W2P2	W2P3	W2P4	W2P5	W2P6	W2P7	W2P8	W2P9	W2P10
RCP	W3P1	W3P2	W3P3	W3P4	W3P5	W3P6	W3P7	W3P8	W3P9	W3P10
CSEB	W4P1	W4P2	W4P3	W4P4	W4P5	W4P6	W4P7	W4P8	W4P9	W4P10
MCB	W5P1	W5P2	W5P3	W5P4	W5P5	W5P6	W5P7	W5P8	W5P9	W5P10

(B=Brick, CB= Cement Block, RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block).

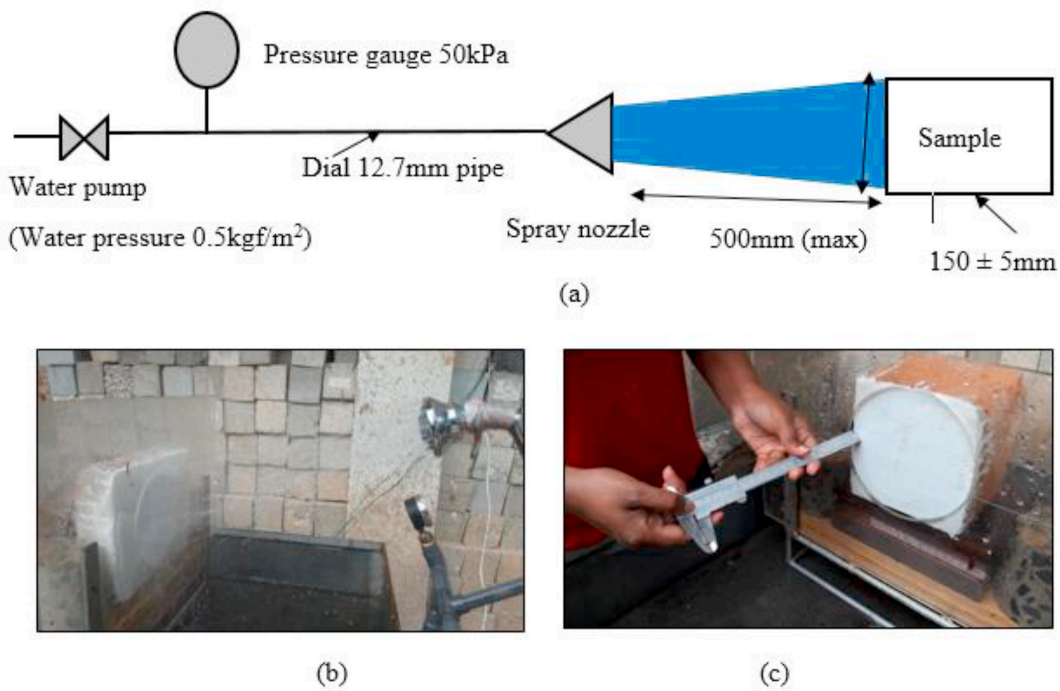

Fig. 4. Spray erosion test; (a) Schematic diagram of apparatus, (b) water spraying, (c) pit depth measurements.

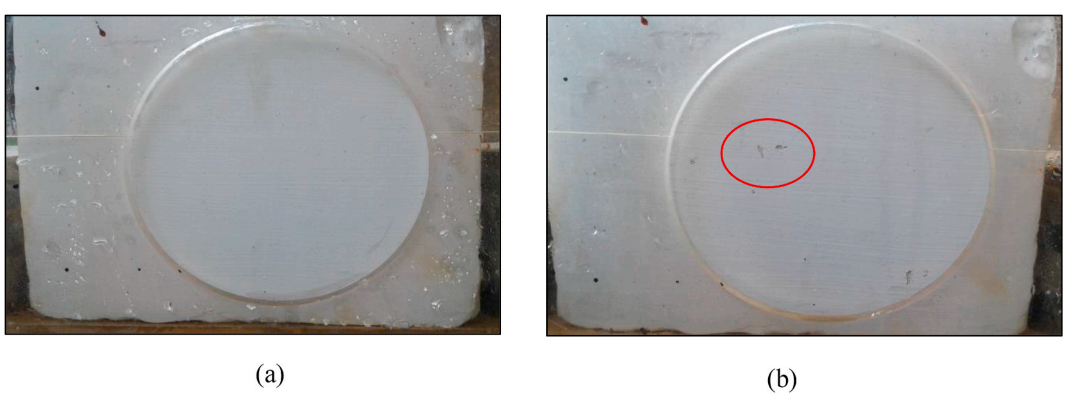

Fig. 5. Spray erosion test: (a) Sample before testing, (b) Samples after the spray erosion test; red circle denotes an area with a pit depth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

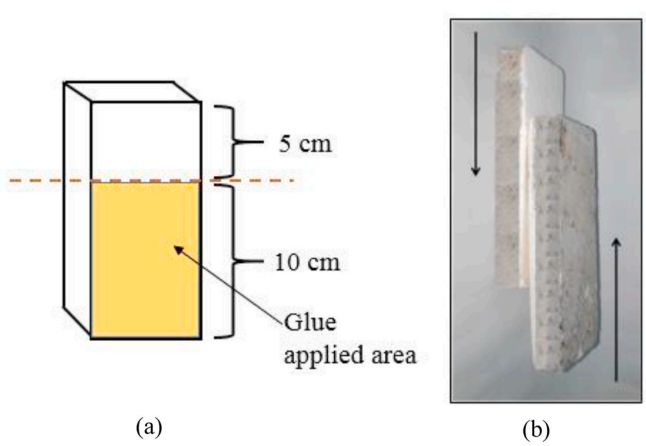

Fig. 6. Samples of the shear strength test (a) Dimensions of the block with glue applied area, (b) Finalized sample with the direction of force application.

adhesive and substrates can be critically analyzed [27].

2. Experimental methodology

2.1. Materials selection

In order to meet the aims and objectives of the research study, a comprehensive three phase experimental procedure was implemented (Fig. 2). The most common walling materials used in Sri Lanka (bricks and cement blocks) and similarly sustainable walling materials (cement stabilized earth blocks and mud concrete blocks) were used. Rough cement plaster is commonly used as a sealer in tropical building construction [28]. Therefore, blocks made out of rough cement plaster were also selected. Selected walling materials are given in Table 1. Three varieties of commercially available white cement based wall care putty materials were selected. Test specimens were prepared in their pure form (without cement) as well as by adding 5% and 10% cement. Additionally powder hydrated lime putty was also used. The 10 wall care putty mixtures tested are shown in Table 2.

Fig. 7. Conducting lap shear strength test using compressive strength testing machine.

2.2. Samples preparation

MCB were cast according to Ref. [22]. Blocks of rough cement plaster were cast by mixing sand and cement at the ratio of 5:1. Bricks, cement blocks and CSEB were commercially available. The dimensions of the walling materials used are shown in Table 3. 10 putty mixtures were prepared according to the putty mixing composition shown in Table 2. Freshly mixed putty mixtures were spread over the samples with a handheld masonry trowel in cross layers from corner to corner up to a thickness of 5 mm. Samples were left for drying at 30 °C and in a relative humidity of 75% for 2 days and after that, their surfaces were sanded using 120 and 360 sand papers in order to become smooth. After this process, there can be dust particles and small residues remaining loose in the wall surface, so a thin layer of acrylic wall filler was applied to finish the surface of the test specimens. (Fig. 3).

2.2.1. Durability performance by spray erosion test

For the spray erosion test, each wall care putty mixture was applied over 3 test specimens of each walling material. A total of 150 test specimens (10 × 3 × 5) were prepared. Prepared samples are shown in Table 4.

Once the test specimens were finalized, the spray erosion test was conducted (Fig. 4a) to determine the durability performance (resistance to weathering) of wall care putty materials. Samples were placed at a distance of 500 mm away from a spray nozzle and water was sprayed (Fig. 4b) horizontally with a pressure of 50 kPa. Each sample was exposed to water for 1 h with a surface area of 150 mm diameter. Both pit depths and scale off material weight (Figs. 4c and 5) were measured after 1 h. Pit depths were measured using a vernier caliper as shown in Fig. 4c. During 1 h of spray, particles are scaling off from the surface area which was exposed to the water spray. This was a very small quantity ranging from 5g to 0.5g. This scale off particles get collected to the small cloth bag which is fixed at the bottom hole of the sink. After 1 h, cloth bag is removed and scale off particles are measured. Then the cloth bag

Table 5
Average values for measured pit depths of the samples.

Walling materials	Putties									
	Pit depth values (mm)									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Brick	0.16	1.17	1.05	0.18	2.14	1.13	1.08	1.11	0.11	0.08
Cement block	0.21	2.05	0.97	1.98	1.15	1.16	1.06	0.67	1.07	0.84
RCP	0.25	0.15	0.78	1.06	2.43	1.24	1.15	1.67	0.67	0.97
CSEB	0.19	1.29	1.12	1.05	1.64	1.27	1.53	2.24	1.58	0.97
MCB	0.20	2.08	0.09	0.25	0.15	1.12	0.03	0.08	0.27	1.20

(RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block, P1= Lime putty, P2= Putty A (pure), P3= Putty A+5% cement, P4= Putty A+10% cement, P5= Putty B (pure), P6= Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement).

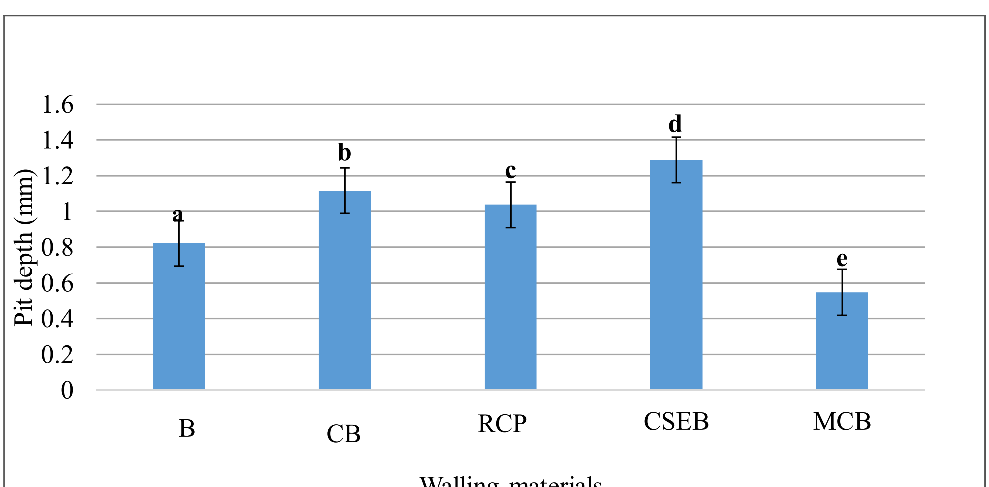

Fig. 8. Mean values of pit depths related to the walling materials
(B= Brick, CB= Cement Block, RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block) (*Vertical bars indicate the standard errors of the mean pit depth, n = 3).

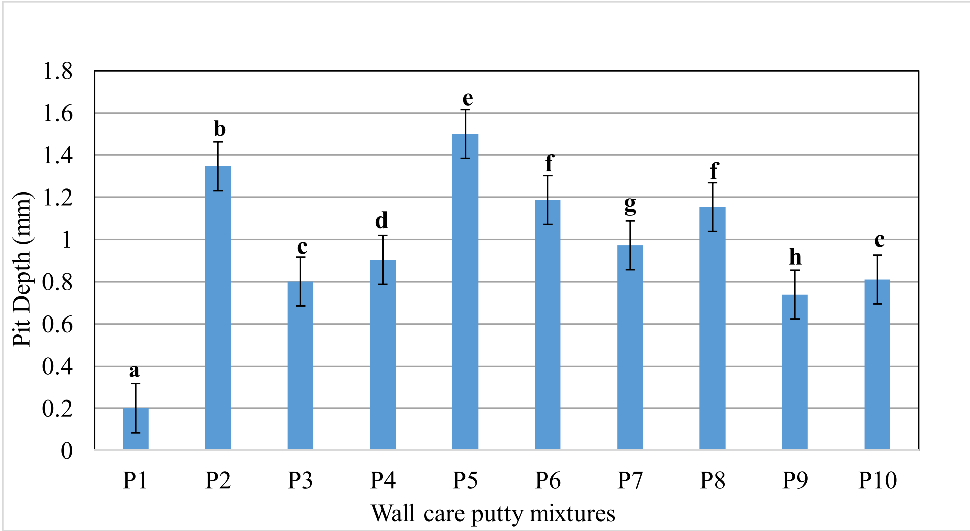

Fig. 9. Mean values of pit depths based on wall care putty mixtures
(P1 = Lime putty, P2 = Putty A (pure), P3 = Putty A+5% cement, P4 = Putty A+10% cement, P5= Putty B (pure), P6 = Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement) (*Vertical bars indicate the standard errors of the mean pit depth, n = 3).

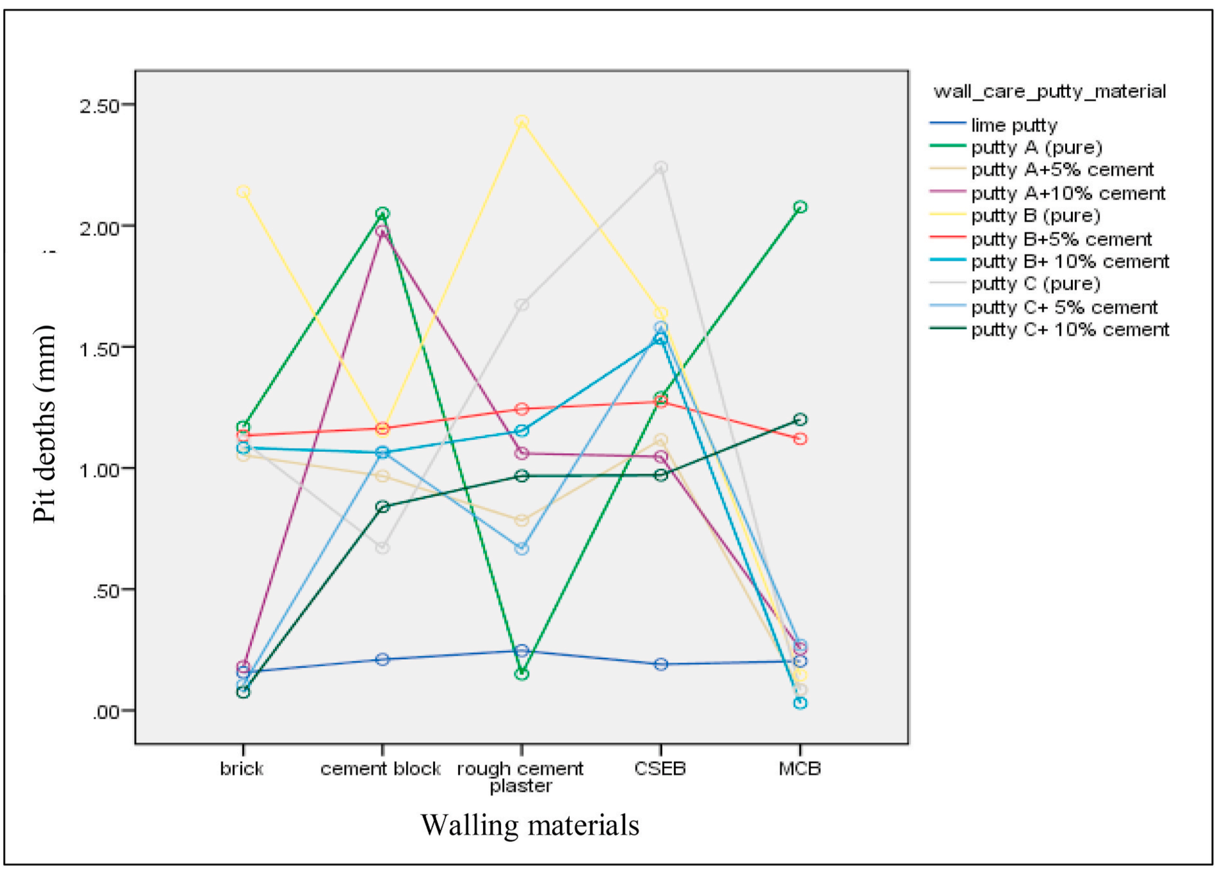

Fig. 10. Combinations of walling materials and wall care putty mixtures according to the mean values of pit depths
(CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block).

is cleaned and fix to the next testing. In spray erosion test, scale off factor (SOF) is used to assess the durability performance. SOF was calculated to determine the amount of material that is scaled off by unit area of material surface using equation (1) [22]. Material mass which was scaled off from the surface was measured in g and calculated the scaled off factor as gm^{-2}.

$$\textit{Scaled off factor (SOF)} = \frac{\textit{scaled off mass } (g)}{\textit{Area of the test specimen } (m^2)} \qquad \text{Equation 1}$$

2.2.2. Bonding strength by shear test

MCB and blocks of RCP were casted to the size of 15 × 6 × 3 cm^3. Bricks, cement blocks and CSEB were cut into the size of 15 × 6 × 3 cm^3.

Table 6
Average values for calculated SOF of the samples.

Walling materials	Putties									
	Scale off values (gm^{-2})									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Brick	10.34	260.2	243.23	237.58	254.55	248.89	118.79	107.47	22.63	11.31
Cement block	9.8	208.16	185.54	112	166.87	149.33	122.18	115.96	54.3	36.77
RCP	11.31	200.24	170.83	116.53	240.4	219.47	212.69	225.13	177.62	116.53
CSEB	13.2	170.83	162.91	143.68	184.44	177.62	167.43	257.94	201.37	115.96
MCB	10.23	266.98	168.56	107.47	183.83	138.58	90.5	172.52	35.23	14.63

(RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block, P1= Lime putty, P2= Putty A (pure), P3= Putty A+5% cement, P4= Putty A+10% cement, P5= Putty B (pure), P6= Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement).

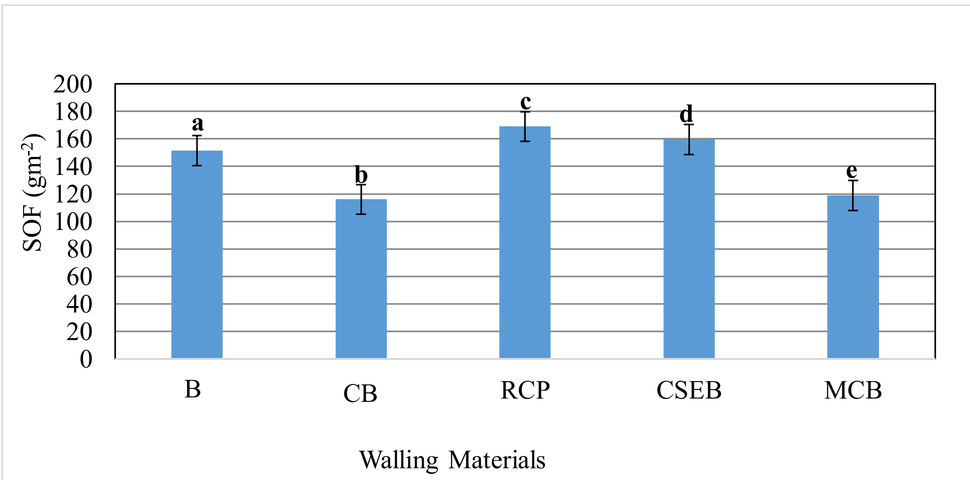

Fig. 11. Mean values of SOF related to the walling materials
(B= Brick, CB= Cement Block, RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block) (*Vertical bars indicate the standard errors of the mean SOF, n = 3).

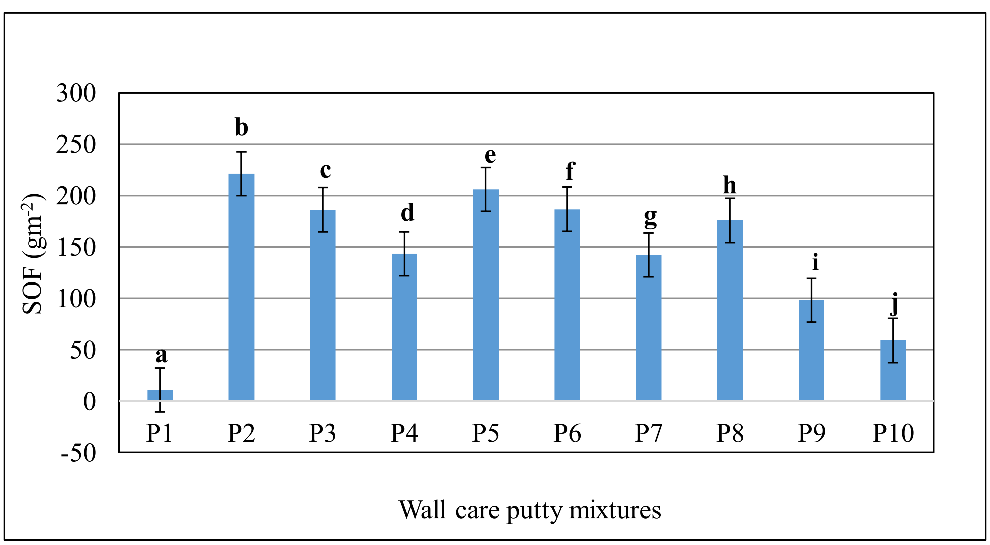

Fig. 12. Mean values of SOF based on wall care putty mixtures
(P1 = Lime putty, P2 = Putty A (pure), P3 = Putty A+5% cement, P4 = Putty A+10% cement, P5= Putty B (pure), P6 = Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement) (*Vertical bars indicate the standard errors of the mean SOF, n = 3).

Putty mixtures were applied. High solid epoxy glue was applied to each block as shown in Fig. 6a and couples of similar blocks were stuck together, constituting one test specimen. (Fig. 6). Three test specimens were considered for each sample. Lap shear strength tests were conducted using a compressive strength testing machine (Fig. 7). The test specimens were placed at the load cell as shown in Fig. 7. The force was applied according to the directions shown in Fig. 6. Loads at the bond breaking point were recorded. Bond breaking patterns of the

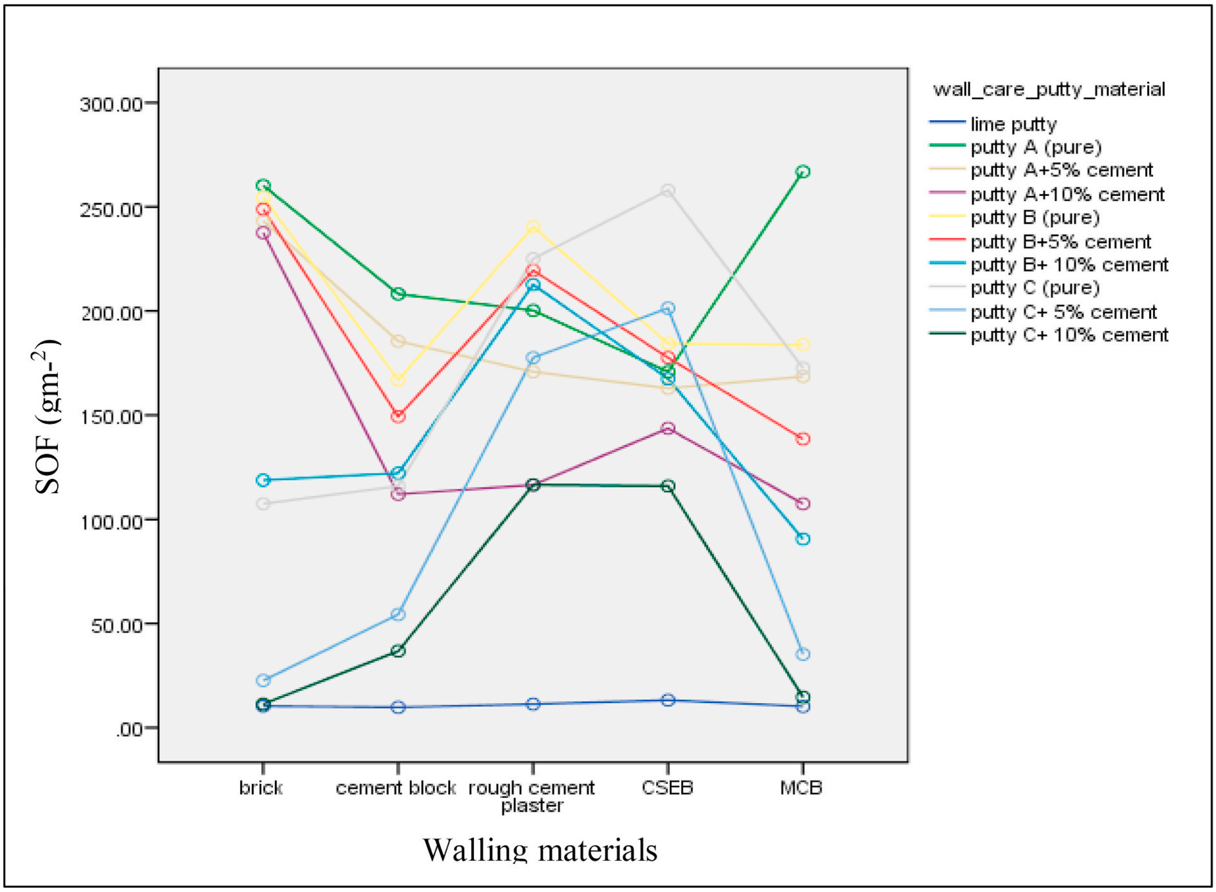

Fig. 13. Combinations of walling materials and wall care putty mixtures according to the mean values of SOF CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block).

Table 7
Average load values for bond breaking point.

Walling materials	Putties									
	Load at the bond breaking point (kN)									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Brick	2.32	2.12	2.13	1.41	1.31	1.12	1.81	1.32	2.12	2.71
Cement block	3.41	2.25	1.41	3.82	1.81	2.12	2.41	0.84	2.13	3.22
RCP	3.22	2.51	2.72	2.81	1.81	1.32	2.31	1.68	1.71	2.13
CSEB	3.05	3.61	2.62	2.03	0.81	0.92	1.93	1.91	2.03	1.22
MCB	1.73	1.21	1.62	1.42	1.31	1.32	1.42	1.05	1.23	1.32

(RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block, P1= Lime putty, P2= Putty A (pure), P3= Putty A+5% cement, P4= Putty A+10% cement, P5= Putty B (pure), P6= Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement).

samples were visually observed and recorded.

2.3. X-ray diffraction analysis

X-ray powder diffraction (XRD) analysis was conducted using X-ray diffractometer- Eco D8 Advance for Structure Analysis, to determine the chemical composition of the putty materials. It uses Co, Cu and Mo radiation, 2 theta from 20° to 130°, step size of 0.03° and 10 s per step. The total run time for each sample was 30 min. Bruker diffrac. EVA version 4.2 software package was used to collect data and interpret diffraction patterns of the samples. Samples were prepared by sieving 100g of each sample in its dry form through 100μ sieve. Homogeneized powdered form of the putty materials; A, B, C, lime putty and cement were separately fed into the Powder X-ray diffractometer and crystalline chemical compounds of each material were identified [29].

3. Results and discussion

3.1. Durability performance of wall care putty materials along with walling materials by spray erosion test

After conducting the spray erosion test pit depth values were measured in the tested samples and those values are given in Table 5. The data were statistically analyzed using SPSS software. Durability performance was assessed by comparing the mean values. Pit depth and durability performance are inversely correlated; the durability performance decreases with the increase of the pit depth. Pit depth measures the length of the cavity created by the spray erosion. The maximum length of the cavity depends on erosion test parameters such as particle acceleration pressure, erodent particle size and standoff distance [30]. During the spray erosion, cavities are formed at the places of the surface

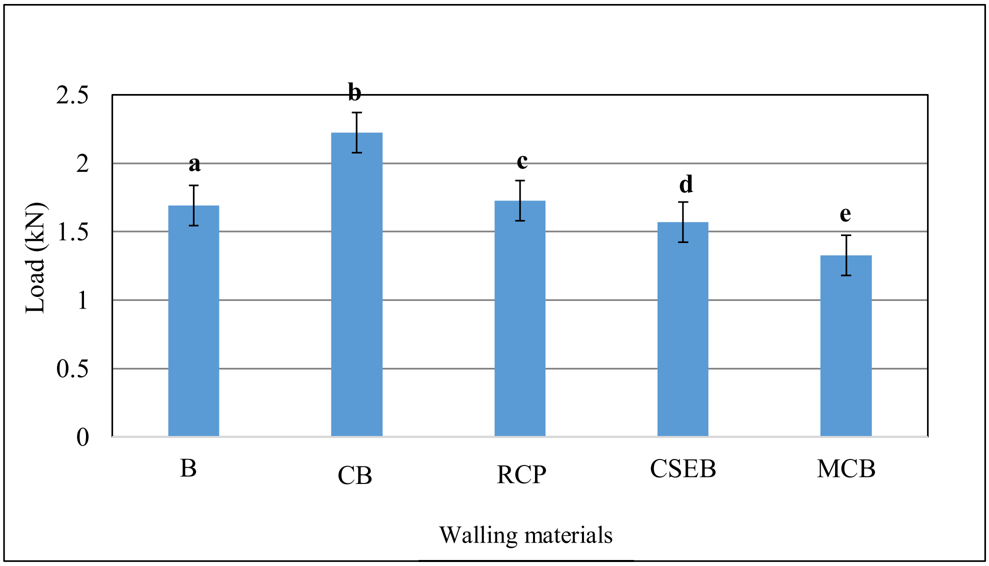

Fig. 14. Mean values of load at the bond breaking points related to the walling materials
(B= Brick, CB= Cement Block, RCP = Rough Cement Plaster, CSEB= Cement Stabilized Earth Block, MCB = Mud Concrete Block) (*Vertical bars indicate the standard errors of the mean load, n = 3).

Table 8
Load values of the samples that resulted in stock-break failure.

Samples	Load at the bond breaking point (kN)
W1P1	2.32
W1P2	2.12
W1P9	2.12
W2P1	3.41
W3P1	3.22
W3P2	2.51
W3P3	2.72
W3P4	2.81
W3P7	2.31
W3P9	1.71
W4P1	3.05
W4P2	3.61
W4P4	2.03
W4P7	1.93
W4P9	2.03
W4P10	1.22
W5P1	1.73
W5P3	1.62

(W1= Brick, W2= Cement block, W3 = Rough Cement Plaster, W4= Cement Stabilized Earth Block, W5 = Mud Concrete Block, P1= Lime putty, P2= Putty A (pure), P3= Putty A+5% cement, P4= Putty A+10% cement, P5= Putty B (pure), P6= Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement).

which have the least bonding strength resulting a hole in the material surface [31].

Comparison of the mean values for pit depths of putty applied to walling materials are given in Fig. 8 (with values being in the range of 0.54–1.29 mm). Out of five putty applied to walling materials, the walling material which leads to the highest resistance to pit depths was identified. According to the results MCB produced the best durability performance as it gave the lowest mean value. Similarly, CSEB showed the worst performance as its highest mean value implies. All walling materials significantly differed from each other.

Comparison of the mean values for pit depths based on wall care putty mixtures are given in Fig. 9 (with the values being in the range of 0.201–1.501 mm). According to the results lime putty showed the highest durability performance as it gave the lowest mean value. However, lime putty is not widely used in Sri Lanka, due to the conspicuous environmental implications such as depleted water quality, large scale habitat clearance, emission of dust and noise due to the processes of quarrying, blasting, processing and transportation in limestone mining [32]. P9 (Putty C+5% cement) showed the second highest durability performance as the second lowest mean value indicates. P5 (Putty B (pure)) showed the worst durability as the highest mean value indicates. According to the results, cement added putty mixtures gave lower pit depths than putty in pure forms. Therefore, it is clear that the pit depth was significantly decreased with the addition of cement to the putty mixture. When cement is added to the mixture, the strength and the binding ability of the mixture increased. This reduces the length of the cavities resulting in lower pit depths.

By considering the combinations of mean values for pit depths in both walling materials and wall care putty mixtures, MCB with lime putty is the best combination (Fig. 10). But lime putty is not considered sustainable in several Asian countries [33]. Therefore, MCB with P9 (putty C+ 5% cement) can be considered as the best combination of walling material and wall care putty mixture which showed the lowest pit depth values.

In addition, scale off weight was measured after conducting the spray erosion test and SOF was calculated for all the samples. Those values are given in Table 6. SOF values were statistically analyzed by using SPSS software. Durability was assessed by comparing the mean values for walling materials and wall care putty materials. SOF and durability are inversely correlated as durability performance decreases with the increase of the SOF. SOF measures the amount of mass eroded per unit area of the material surface [22]. Cavities induced by the accelerated spray test continue to collapse during the whole time period of the test. This process results in fatigue in the material surface and considerable mass is removed from there [30]. Induced cavities continue to break through places with more voids. When the porosity of the material is high, there is a tendency of more mass to be eroded from the surface [31].

Mean values of SOF for putty applied to walling materials are given in Fig. 11 (values are in the range of 116.096–169.076 gm^{-2}). Out of five putty were applied to walling materials, and the walling materials which show the lowest SOF were identified. According to the results, CB had the best durability performance as it gave the lowest SOF mean value. Similarly MCB has the second highest durability with a second lowest SOF mean value which is numerically close to the value of cement block. RCP has the lowest durability as it gave the highest SOF mean value. CB are made of a mixture of cement, sand and stone chips and they are considered as a high strength and durable masonry unit [34]. Mud concrete bricks are made from soil in the same way as traditional mud bricks, but contain gravel and sand to improve their strength [34,35].

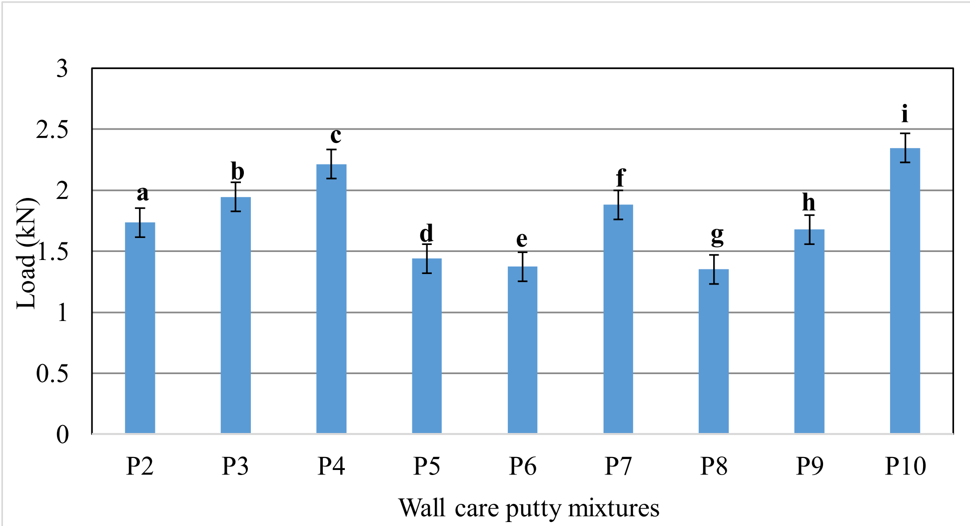

Fig. 15. Mean values of load at the bond breaking points based on wall care putty mixtures (P2 = Putty A (pure), P3 = Putty A+5% cement, P4 = Putty A+10% cement, P5= Putty B (pure), P6 = Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement) (*Vertical bars indicate the standard errors of the mean load, n = 3).

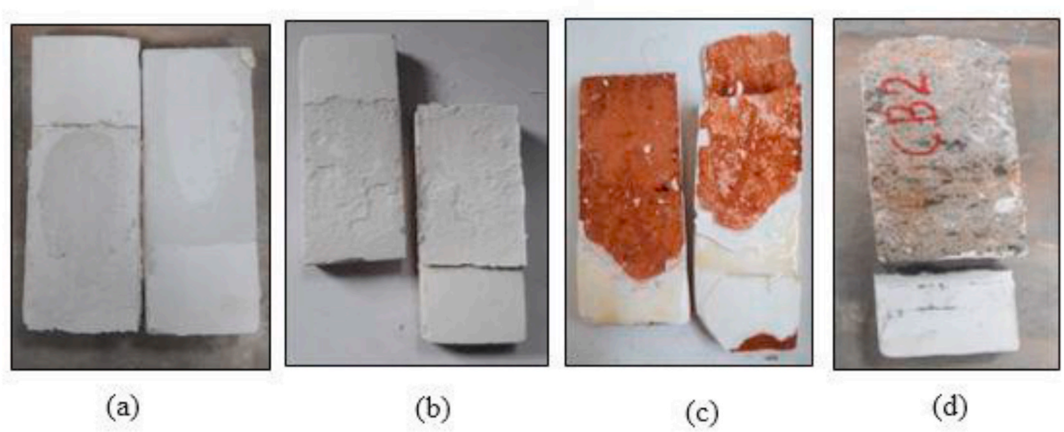

Fig. 16. Failure types; (a) Adhesive failure, (b) Cohesive failure, (c) Fiber-tear failure, (d) stock break failure.

Table 9
Resulted failure types.

Failure Type	Samples
Adhesive failure	W1P10, W2P3,W5P2, W5P8, W5P9
Cohesive failure	W1P3, W1P4, W1P7, W3P6, W3P10, W4P3, W4P5, W4P6
Fiber-tear failure	W1P5, W1P6, W1P8, W2P2, W2P4, W2P5, W2P6, W2P7, W2P8, W2P9, W2P10, W3P5, W3P8, W4P8, W5P4, W5P5, W5P6, W5P7, W5P10
Stock break failure	W1P1, W1P2, W1P9, W2P1, W3P1, W3P2, W3P3, W3P4, W3P7, W3P9, W4P1, W4P2, W4P4, W4P7, W4P9, W4P10, W5P1, W5P3

(W1= Brick, W2= Cement block, W3 = Rough Cement Plaster, W4= Cement Stabilized Earth Block, W5 = Mud Concrete Block, P1= Lime putty, P2= Putty A (pure), P3= Putty A+5% cement, P4= Putty A+10% cement, P5= Putty B (pure), P6= Putty B+5% cement, P7= Putty B+10% cement, P8= Putty C (pure), P9= Putty C+5% cement, P10 = Putty C+10% cement).

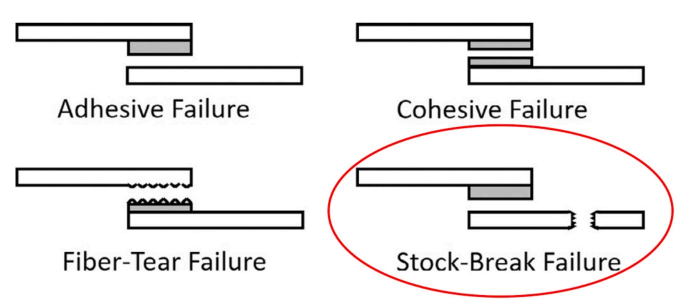

Fig. 17. Stock break failure
Source- Garcia, R., & Prabhakar, P. (2017). Bond interface design for single lap joints using polymeric additive manufacturing. Composite Structures, 176, 547–555. https://doi.org/10.1016/j.compstruct.2017.05.060.

Similarly all five walling materials were significantly different from each other.

Mean values of SOF for wall care putty mixtures given in Fig. 12 showed that lime putty has the highest durability with the lowest SOF mean value. P10 (Putty C+10% cement) has the second highest durability with the second lowest SOF mean value. P2 (Putty A (pure)) has the lowest durability with the highest SOF mean value. According to the results, it is clear that the durability has gradually increased with the addition of cement to the wall care putty mixtures. Similarly all ten wall care putty mixtures are significantly different from each other.

By considering the combinations of mean values for SOF in both

Table 10
Results of XRD analysis.

Putty materials						Lime		Cement	
A		B		C					
Chemical Compound	Formulae	Chemical Compound	Formulae	Chemical Compound	Formulae	Chemical Compound	Formulae	Chemical Compound	Formulae
Dolomite	$CaMg(CO_3)_2$	Dolomite	$CaMg(CO_3)_2$	Dolomite	$CaMg(CO_3)_2$	Brucite	$Mg(OH)_2$	Calcium Silicate	Ca_3SiO_5
Minrecordite	$CaZn(CO_3)_2$	Minrecordite	$CaZn(CO_3)_2$	Minrecordite	$CaZn(CO_3)_2$	Cobalt Tantalum Fluoride Hydrate	$CoTaF_7{\cdot}_6H_2O$	Hatrurite	$Ca_3(SiO_4)O$
Carlinite Calcium Silicate	Tl_2S Ca_3SiO_5	Carlinite, Niocalite	Tl_2S $NbCa_7(Si_2O_7)_2O_3F$	Carlinite, Calcium Silicate	Tl_2S Ca_3SiO_5	Calcite Portlandite	$CaCO_3$ $Ca(OH)_2$	Calcite Calcium Magnesium Aluminum Oxide Silicate	$CaCO_3$ $Ca_{54}MgAl_2Si_{16\ O90}$
Larnite	$Ca_2(SiO_4)$	potassium decacalcium iron heptaphosphate, whitlockite | Potassium Calcium Iron Phosphate	$K0{\cdot}_8Ca_{98}$ $Fe_0{\cdot}_2(PO_4)_7$	Larnite,	$Ca_2(SiO_4)$	Cesium Magnesium Manganese Fluoride	Cs_2MgMnF_6	magnesium calcite	$(Mg_0{\cdot}_{03}Ca_{0.97})$ (CO_3)
Hatrurite	$Ca_3(SiO_4)$ O	Sinnerite,	$Cu_{12}(As_3S_7)$ $(As_5$ $S_{11})$	Sinnerite, Calcite, magnesian Seidozerite	$Cu_{12}(As_3S_7)$ $(As_5$ $S_{11})$ $(Mg_{064}Ca_{936})$ (CO_3) $Na_{16}Ca_0{\cdot}_{275}$ $Mn_0{\cdot}_{425}Ti0._{575}$ $Zr0{\cdot}_{925}(Si2O_7)$ OF			Inyoite	$CaB_3O_3(OH)_5{\cdot}_4H_2O$

walling materials and wall care putty mixtures (Fig. 13), cement block with lime putty is the best combination. But lime putty is not sustainable. Therefore, cement block with P10 (putty C+ 10% cement) can be considered as the best combination according to the SOF.

3.2. Bonding strength of wall care putty materials along with walling materials by shear test

The loads at the bond breaking points were measured (Table 7) after conducting the lap shear strength test and the bond breaking patterns of the samples were observed. Load values were statistically analyzed by using SPSS software and bonding strengths were assessed by comparing mean values for the different combinations of walling materials and wall care putty mixtures. Load values and bonding strength are directly correlated.

Comparison of the mean values of load at the bond breaking points related to the walling materials are given in Fig. 14 (values are in the range of 1.32–2.22 kN). Out of five putties applied to walling materials, walling material which has the highest bonding strength with putty mixtures was identified. According to the results, cement block has the highest bonding strength for a given wall care putty mixture with the highest mean value. MCB has the lowest bonding strength for a given wall care putty mixture with the lowest mean value. Similarly all five walling materials were significantly different from each other. Load values that resulted in stock-break failure were not taken into account because, it is considered as a sample failure. Those values are given in Table 8. They are in the range of 1.22–3.61 kN, which is above the other failure types. Stock break failures occur due to the poor bonding strength within the adherend. Therefore, in these samples, bonding strength between the walling materials and wall care putty mixtures are greater than the cohesive strength within the walling materials.

Comparison of mean values of load at the bond breaking points for wall care putty mixtures are given in Fig. 15 (values are in the range of 1.35–2.34 kN). Samples with lime putty resulted in stock-break failure and load values were in a range of 1.73–3.41 kN where the values were higher than the load values of other bond types (Fig. 16d). According to the results, P10 (putty C+10% cement) gave the highest bonding strength with highest mean value for load and P8 (Putty C (pure)) gave the lowest bonding strength. It becomes clear that the bonding strength of the wall care putty mixtures have gradually increased with the addition of cement. Similarly, all nine wall care putty mixtures were significantly different from each other. Determination of the failure point of the adhesive bond can be very important for the material coating and the surface [36]. Failure load or the stress distribution at the interface is very heterogeneous. The bond breaking takes place due to stress concentration around a critical size flaw, or void at the interface that makes a crack. The actual stress level where the crack propagation is initiated is several times higher than the average stress value [8],12]. When considering the bond strength, cohesion and adhesion are important to determine the interaction of the bonding interface [37]. Cohesion is the property of molecules to stick to each other due to mutual attraction and adhesion is the bonding of one material to another specifically an adhesive to a substrate due to a variety of interactions [26].

After conducting lap shear strength test four types of failures were evident in the samples (Table 9). Those are the adhesive failure (Fig. 16a), cohesive failure (Fig. 16b), fiber tear failure (Fig. 16c) and the stock break failure (Fig. 16d). Adhesive failure occurred when the cohesion strength within adhesive is greater than the bond between adhesive and adherent; the bond region separates from the adherent completely. Cohesive failure occurred when the bond between the adhesive and adherent is greater than cohesion of the adhesive; the failure region passed through the bond material. When the rupture occurs within the adherent near the interface, fiber tear failure is the result. Stock-break failures occur due to the high bending near the overlap region which results in the sample break outside the bonded region (Fig. 17). This is most likely to occur due to poor cohesive bond within the walling material. Bonding strength of the wall care putty mixtures do not account for such a failure.

3.3. XRD analysis

Results of the XRD analysis are given in Table 10. Dolomite, Minrecordite and Carlinite, are common to all three putty materials. Calcite, Brucite, Cobalt Tantalum Fluoride Hydrate, Portlandite and Cesium Magnesium Manganese Fluoride were available in lime. Calcium Magnesium Aluminum Oxide Silicate and Inyoite, were only available in cement. According to the results, it is evident that commercial putty materials have more or less similar constituents and that the constituents found in lime were not found in any of the putty materials. Therefore composition of lime is totally different from putty materials.

4. Conclusions

Cement blocks and lime putty are the best combination of walling material and wall care putty mixture regarding durability performance in terms of surface decaying caused by spray erosion. However, due to the unsustainable procedures of lime production in Sri Lanka, lime putty is not a viable choice in Sri Lanka. Therefore, cement blocks and P10 (Putty C+10% cement) is the best combination that can be used in practice.

Cement blocks and P10 (Putty C+10% cement) can be also considered as the best combination of walling material and wall care putty mixture concerning bonding strength in terms of shear testing. Similarly, cement added putty mixtures showed higher durability and bonding strength than putties in their pure form. Further research studies should be conducted to identify the accurate proportions of cement and putty materials that should be mixed to give the highest durability and bonding strengths.

Declaration of competing interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

References

[1] C. Udawattha, H. Galkanda, I.S. Ariyarathne, G.Y. Jayasinghe, Mold growth and moss growth on tropical walls, Build. Environ. 137 (2018) 268–279, https://doi.org/10.1016/j.buildenv.2018.04.018.

[2] A. Warnasooriya, Meteorological component Sri Lanka, in: *First Steering Committee Meeting Of South Asia Flash Flood Guidance System Project (SAsiaFFG),* 26-28 April, India, 2016 [Online].Available:https://www.wmo.int/pages/prog/hwrp/flood/ffgs/SAsiaFFG/documents/presentations/day1/countries/SriLanka/MeteorologicalComponent.pdf. (Accessed 20 July 2019).

[3] C. Udawattha, R. Halwatura, Life cycle cost of different Walling material used for affordable housing in tropics, Case Studies in Construction Materials 7 (November 2017) 15–29, https://doi.org/10.1016/j.cscm.2017.04.005.

[4] M. Rochikashvili, J.C. Bongaerts, Multi-criteria decision-making for sustainable wall paints and coatings using analytic hierarchy process, Energy Procedia 96 (October 2016) 923–933, https://doi.org/10.1016/j.egypro.2016.09.167.

[5] L.J. Carter, Industrial minerals: *New study of how to avoid a supply crisis*, Science 170 (3954) (October 1970) 147–148, https://doi.org/10.1126/science.170.3954.147.

[6] G. Zhang, L. Mo, J. Sun, J. Chen, J. Liu, Preparation and experimental study on a new type of exterior wall putty, Adv. Mater. Res. 671–674 (2013) 1914–1917, https://doi.org/10.4028/www.scientific.net/AMR.671-674.1914.

[7] P. Mira, V.G. Papadakis, S. Tsimas, Effect of lime putty addition on structural and durability properties of concrete, Cement and Concrete Rearch 32 (2002) 683–689, https://doi.org/10.1016/S0008-8846(01)00744-X.

[8] B. Istegun, E. Celebi, Triplet shear tests on retrofitted brickwork masonry walls, Int. J. Civ. Environ. Eng. 11 (9) (2017) 1250–1255, https://doi.org/10.5281/zenodo.1132170.

[9] V. Vliet, Shear Tests on Masonry Panels ; Literature Survey and Proposal for Experiments, TNO Building and Construction Research, 21 October 2004. TNO report. 2004-CI-RO171.

[10] K. Uehara, M. Sakurai, Bonding strength of adhesives and surface roughness of joined parts, J. Mater. Process. Technol. 127 (2) (2002) 178–181, https://doi.org/10.1016/S0924-0136(02)00122-X.

[11] R. Miniotaitė, V. Stankevičius, The durability of paints on sand-lime brick walls considering water sorption and water permiability in a two layer system, Civ. Eng. Manag. 3730 (2012) 110–114, https://doi.org/10.1080/13923730.2003.10531313.

[12] M.O. Huertas, G. Cultrone, E. Sebastian, Durability of masonry systems : a laboratory study, Construction and Buidling materials 21 (2007) 40–51, https://doi.org/10.1016/j.conbuildmat.2005.07.008.

[13] A.G. Kerali, T.H. Thomas, Simple durability test for cement stabilized blocks, Build. Res. Inf. 32 (2) (2004) 140–145, https://doi.org/10.1080/0961321032000148479.

[14] ASTM, ASTM E241-09(2014)e1,Standard Guide for Limiting Water-Induced Damage to Buildings, 2014.

[15] Q.B. Bui, J.C. Morel, B.V. Venkatarama Reddy, W. Ghayad, Durability of rammed earth walls exposed for 20 years to natural weathering, Build. Environ. 44 (5) (2009) 912–919, https://doi.org/10.1016/j.buildenv.2008.07.001.

[16] G. Frohnsdorff, L.W. Masters, J.W. Martin, An Approach to Improved Durability Tests for Building Materials and Components, National Bureau of Standards, Washington D.C., 1980.

[17] C. Jayasinghe, Structural performance of composite walls made out of recycled construction waste and stabilized rammed earth, in: Proc. Innovations for Resilient Environment- NBRO Symp., Colombo, Sri Lanka, December 2015 [Online]. Available: https://www.nbro.gov.lk/images/content_image/pdf/symposia/22.pdf. (Accessed 15 June 2019).

[18] H. Galkanda, R.U. Halwatura, C. Udawatthe, Improve intrinsic properties of walling materials to create occupant comfort, in: Proc. Of the 11th Int. Conf. of Faculty of Architecture Research Unit, (FARU), University of Moratuwa, Sri Lanka, December, 2018, pp. 66–73.

[19] R. Emmanuel, Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka, Build. Environ. 40 (12) (2005) 1591–1601, https://doi.org/10.1016/j.buildenv.2004.12.004.

[20] E. Johansson, R. Emmanuel, The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka, Int. J. Biometeorol. 51 (2) (2006) 119–133, https://doi.org/10.1007/s00484-006-0047-6.

[21] C.D. Udawattha, G.A.H.H. Galkanda, R.U. Halwatura, A study on natural rain surface erosion of different walling materials in tropics, MERCon 2018 - 4th Int. Multidiscip.Moratuwa Eng. Res. Conf. (i) (2018) 84–89, https://doi.org/10.1109/MERCon.2018.8421938.

[22] F.R. Arooz, R.U. Halwatura, Mud-concrete block (MCB): mix design & durability characteristics, Case Stud. Constr. Mater. 8 (November 2017) (2018) 39–50, https://doi.org/10.1016/j.cscm.2017.12.004.

[23] S. Fang, K. Zhang, H. Zhang, B. Zhang, A study of traditional blood lime mortar for restoration of ancient buildings, Cement Concr. Res. 76 (2015) 232–241, https://doi.org/10.1016/j.cemconres.2015.06.006.

[24] C. Williams, S. Goodhew, L. Watson, The feasibility of earth block masonry for building sustainable walling in the United Kingdom, J. Build. Apprais. 6 (2010) 99–108, https://doi.org/10.1057/jba.2010.15.

[25] N.M. Rahman, C.T. Sun, Strength calculation of composite single lap joints with Fiber-Tear-Failure, Compos. PART B 62 (2014) 249–255, https://doi.org/10.1016/j.compositesb.2014.03.004.

[26] R. Garcia, P. Prabhakar, Bond interface design for single lap joints using polymeric additive manufacturing, Compos. Struct. 176 (2017) 547–555, https://doi.org/10.1016/j.compstruct.2017.05.060.

[27] M. Derikvand, H. Pangh, A modified method for shear strength measurement of adhesive bonds in solid wood, BioResources 11 (1) (2016) 354–364.

[28] N.H.V.T.N. Nanayakkara, C. Udawattha, R. Halwatura, Investigation on elements and their fraction of building construction cost, Moratuwa Eng. Res. Conf. (2017) 277–282.

[29] J.A.B. Tech, A. Chauhan, P. Chauhan, powder XRD technique and its applications in science and technology, J. Anal. Bioanal. Tech. 5 (2014) 1–5, https://doi.org/10.4172/2155-9872.1000212.

[30] B.A. Onen, Y. Yıldıran, E. Avcu, A. Cınar, Investigation of the erosion test parameters on the particle impengement velocity by using CFD analysis, Acta Phys. Pol. 127 (4) (2015) 1225–1229.

[31] Y. Wang, G. Serge, B. Lebon, I. Tzanakis, T. Poirier, Experimental and numerical investigation of cavitation-induced erosion in thermal sprayed single splats, Ultrason. Sonochem. 52 (no) (2019) 336–349, https://doi.org/10.1016/j.ultsonch.2018.12.008.

[32] A. Kumarasighe, et al., "An attempt to reduce impacts of limestone quarries through biodiversity assessment and translocation : a case study at the Holcim Limestone Quarry Site in Puttalam, Sri Lanka, Asian Journal of Conservation Biology 2 (1) (2013) 3–22.

[33] O.P. Singh, R.E. Lamare, Limestone mining and its environmental implications in Meghalaya, India, ENVIS Bull. Himal. Ecol. 24 (2016) 87–100.

[34] S. Rizaee, M.D. Hagel, N. Shrive, P. Kaheh, Comparison of compressive strength of concrete block masonry prisms and solid concrete prisms, in: 16th International Brick and Block Masonry Conference, IBMAC, Padova, Italy, 26-30 June 2016, https://doi.org/10.1201/b21889-242.

[35] C. Udawattha, R. Halwatura, Thermal performance and structural cooling analysis of brick, cement block, and mud concrete block, Adv. Build. Energy Res. 12 (2) (2018) 150–163, https://doi.org/10.1080/17512549.2016.1257438.

[36] M.A. Sherafati, M.R. Sohrabi, An investigation into the time dependency of shear strength of clay brick walls; an approximate approach, Construct. Build. Mater. 155 (2017) 88–102, https://doi.org/10.1016/j.conbuildmat.2017.08.055.

[37] C. Fewins, The pros and cons of different construction systems, Home Building & Renovating (2006) 1–11 [Online]. Available:https://www.cyprus-property-buyers.com/files/constructionmethods.pdf. (Accessed 24 May 2019).