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The effects of using agricultural waste as partial substitute for sand in cement blocks

Navaratnarajah Sathiparan[a,*], H.T.S.M. De Zoysa[b]

[a] Department of Civil Engineering, Faculty of Engineering, University of Jaffna, Ariviyal Nager, Killinochchi, Srilanka
[b] Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Hapugala, Galle, Srilanka

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ABSTRACT

The disposal of agricultural waste is a serious environmental problem. Use of agricultural wastes in the production of cement block may reduce the global environmental pollution. This study analyzes the feasibility of using agricultural waste like rice husk, sawdust, peanut shell, rice straw and coconut shell as a partial sand replacement in the manufacture of cement blocks. The experiments have been conducted to determine the physical, strength and durability properties of cement block. Test results show that cement blocks with agricultural waste were satisfied the strength requirement according to the ASTM standard but durability is the major issue for these blocks. Cement block with coconut shell and peanut shell shows reasonable strength and durability properties.

1. Introduction

Environmental pollution increases with increasing population due to waste generation and unlimited consumption of raw materials. Open dumping of agricultural wastes is becoming a major issue. Because open damping destroying the aesthetic appearance of nature and harmful to public health. To reduce the negative effect on the environment, agricultural waste materials have to be converted into useful materials [1].

Unlimited consumption of earth resources is another reason for environmental pollution. In developing countries like Sri Lanka, due to the recent growth in the construction industry, the demand for fine aggregates is escalating rapidly. River sand is mainly used for all kinds of civil engineering constructions. The annual sand demand for the construction industry in 1992 is 9.4 million metre cubes [2]. Studies by Katupotha [3] and Dias et al. [4] have attempted to estimate sand demand and however, it has been found to be incomplete, as these have covered only a part of the country or a section of the construction industry. Based on cement usage and engineering computations (i.e. cement consumption and the ratio of cement to sand for various construction purposes), sand demand for 2007 was estimated to be 17.37 million metre cubes. River sand has been the most widely used fine aggregate in Sri Lanka, and over-exploitation of river sand to meet the demand has led to various harmful consequences. This kind of large river sand consumption very badly impacts on the environment as follows;

- The depth of the river bed is increased.
- The water table is lowered.
- Aquatic lives are disappeared from freshwater.

Artisanal sand mining was the norm until the introduction of the current Mines and Minerals Act No. 33 [2] established by the Geological Survey and Mines Bureau (GSMB) of Sri Lanka, which regulates the exploration for and mining of minerals, including sand. The Geological Survey and Mines Bureau (GSMB) of Sri Lanka currently keeps records of all the licenses issued for sand mining and transportation. According to these records, the approximate annual sand supply is 7.99 million metre cubes, which is far below the estimated demand [5].

Considering the environmental issue due to waste materials and scarcity of sand, many research works have been carried out to investigate the possibilities of using the waste materials in the production of masonry block. Recycling waste materials by incorporating them into building materials is a practical solution for pollution problems. These waste materials can be divided into three categories: construction and demolition waste, industrial waste and agricultural waste. Sabai et al. [6] reported that, it is possible to produce the concrete blocks with a compressive strength of at least with 7 MPa by replacing fine aggregates with construction and demolition waste in the content of 89%. However, concrete blocks produced with 100% construction and demolition waste were weaker than control blocks. Raut et al. [7] stated that enhance performance in terms of achieved lighter density, lower thermal conductivity and higher compressive strength of the various waste-

* Corresponding author.
E-mail address: sakthi@eng.jfn.ac.lk (N. Sathiparan).

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create bricks gives an economical option to design the green building. A wide variety of industrial waste materials for production of masonry block has been studied, including fly ash [8], coal bottom ash [9], waste marble powder [10], granite sawing waste [11], glass powder [12], crumb rubber [13], paper mill waste [14–16], cotton waste [17] and cigarette butts [18]. In these studies, compressive strength and water absorption rate are two common parameters considered. Study on published literature shows that using these industrial waste materials as partially replaced for sand, allows the production of masonry blocks with compressive strengths comparable to those obtained on control masonry blocks.

While several studies have been conducted on the production of masonry block with construction wastes and industrial wastes, a very limited study conducted on the production of masonry block from agricultural wastes. Several researchers have studied the utilization of waste materials such as processed waste tea for bricks [19], straw fibers for adobe [20] and sawdust [21] to produce masonry blocks. Salas et al. [22] investigated the substitution of sand and gravel with rice husk in concrete. The used rice husk was in the natural state or treated with a 5% lime solution. They concluded that concrete containing rice husks could be used as a material with hybrid characteristics between structural lightweight concrete and insulating concrete. Salas et al. [23] introduced a lightweight block that was made of rice husks as an agricultural waste and fly ash as an industrial by-product. The blocks had a density of about 1100 kg/m^3 and a thermal conductivity of 0.20 W/mk.

Gunasekaran et al. [24] investigated various mechanical properties such as compressive strength, flexural tensile strength, splitting tensile strengths and impact resistance of concrete with coconut shell as the coarse aggregate. Authors concluded that coconut shell can be used as a lightweight aggregate for producing lightweight concrete. In addition, Gunasekaran et al. [25] reported that the ultimate bond strength of this concrete was much higher compared to the theoretical bond strength. Also, a recent study conducted by Gunasekaran et al. [26] shows the satisfactory performance of coconut shell reinforced concrete beam in flexure. According to this study, the flexural behavior of a coconut shell lightweight concrete beam is comparable to other types of lightweight concrete.

Parisi et al. [20] reported about adobe brick production by a mixture of soil, water and straw fibers. The straw fiber reinforced adobe bricks under study were 100 × 200 × 400 mm^3 in size and had a mean unit weight equal to 16.80 kN/m^3 . Based on test results, straw fiber reinforced adobe bricks compressive strength, tensile strength, and secant young's modulus in a compression fall in the ranges 0.2–2.5 MPa, 0.17–0.75 MPa and 15–287 MPa, respectively. Kanagalakshmi et al. [27] carried out series of tests to find out the suitability of peanut shells for cement block production. Compressive strength considered as the major parameter of these tests. It ensures that compressive strength decreased with the increment peanut shell nut content.

Past studies [28–30] show that, by using plant waste that is abundantly found in rural areas, it may be possible to construct cheaper and good quality constructions. For the production and utilization of masonry blocks from agricultural waste materials, further study is needed considering strength properties and durability properties of these blocks. Also, there were no comparative studies of waste materials. Therefore, it is unable to find the most suitable waste material which can be used in the block preparation. Considering that, this study is focused on finding out the most suitable agricultural waste materials for the production of cement block.

The present study focuses on the possibility of using agricultural waste as a partial replacement for sand in the production of cement block. While these waste materials can be put to use as fertilizer, insulation material or fuel; still, a large amount of these wastes is disposed to overcome large accumulation. These wastes generally dump on land or burn in the open air, creating land dereliction problems and water contamination. To overcome these problem, agricultural wastes has to be decided to use as an alternative for sand in the production of cement blocks [28–30]. Rice husk, sawdust, peanut shell, rice straw and coconut shell are considered for partial sand replacement. The effects of these agricultural waste materials on the density, water absorption rate, compressive strength, flexural tensile strength and durability of cement blocks were investigated.

Table 1
Physical properties and chemical composition of material used.

		Cement	Sand
(a)	Physical properties		
	Bulk density (kg/m^3)	1362	1476
	Specific gravity	3.15	2.67
	Fineness	0.55	3.43
(b)	Chemical composition		
	SiO_2	19.21	80.78
	CaO	66.55	3.21
	MgO	1.17	0.77
	Al_2O_3	3.91	10.52
	Fe_2O_3	3.62	1.75
	SO_3	3.23	–
	Na_2O	0.40	1.37
	K_2O	0.39	1.23

2. Material and methods

2.1. Material used

2.1.1. Cement

Ordinary Portland cement (OPC) grade 42.5 based on SLS107 [31] was used in concrete as a cementitious material. The bulk density and specific gravity of the cement are 1362 kg/m^3 and 3.15, respectively. Table 1 is summarized the physical properties and chemical composition of the cement.

2.1.2. Sand

The sand used for the masonry block is local natural river sand. It is classified as silica sand and supply as bulk. The bulk density and specific gravity of the sand are 1476 kg/m^3 and 2.67, respectively. A sieve analysis was carried out in order to determine this local river sand complies with the ASTM C136 / C136M [41]. The fineness modulus of the local river sand was calculated to be 3.43. Fig. 1 show the local river sand grading curve from the analysis and it is observed that 100% sand passed through 4.75 mm and 100% retained on the 75 μm sieve. The particle size distribution curve is also steeper as the particle size range is smaller. Which describes that the river sand used in this experiment is poorly graded sand.

2.1.3. Agricultural wastes

Based on availability of waste materials in Sri Lanka, five types of agricultural wastes were selected as rice husk, sawdust, peanut shell, straw, and coconut shell (Fig. 2). Rice husk, sawdust and peanut shell are used as raw without any pre-preparation or treatment. Coconut shells are crushed into 2 cm × 2 cm pieces and straw are cut into pieces which length less than 25 mm before added to mortar mix. Table 2 describes the physical properties of waste materials used for the production of cement blocks. Sieve analysis tests were carried out for each material. Particle size distribution curves of the materials used are shown in Fig. 2. Test for bulk density, specific gravity and fineness modulus were conducted according to ASTM C29/C29M [42], ASTM C128 [43] and ASTM C136/C136M [41], respectively.

2.2. Mix design

A suitable proportion of cement mix was selected based on volume percentage. Since the main aim of the research was investigated using

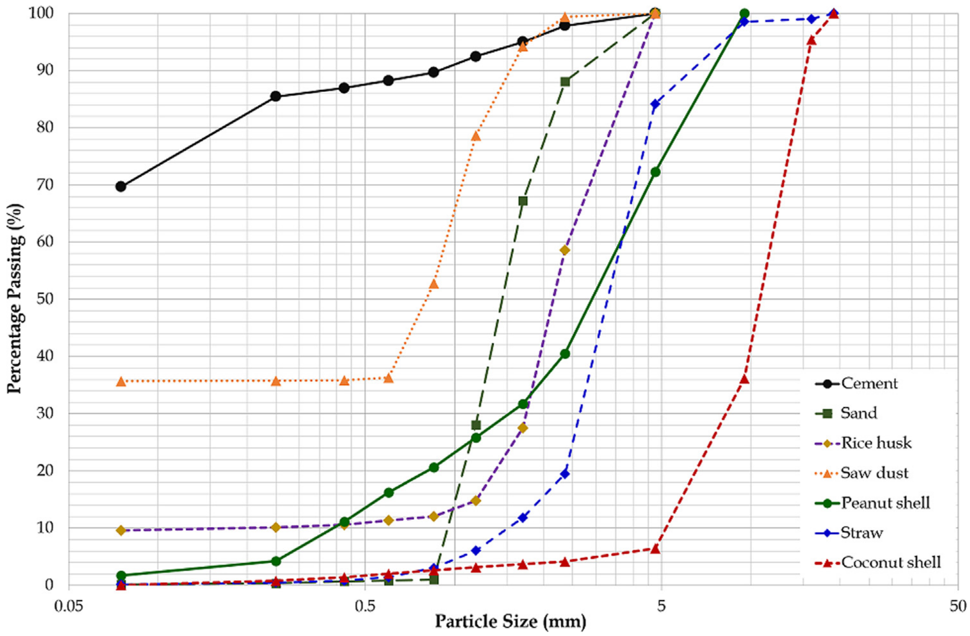

Fig. 1. Sieve analysis data for materials used.

agricultural waste as partial substitute for sand for cement blocks production in developing country like Srilanka; it was thought the same mix proportion used in the sites was suitable and adequate for meeting the aims of the research. Therefore, for control blocks, 1:6 cement: sand proportion in volume was used. In addition to control cement block, cement blocks with five different agricultural wastes were studied in this comparison. In each agricultural waste case, three mix proportion as cement: sand: agricultural waste volume ratio of 1:5:1, 1:4:2 and 1:3:3 were cast. Fig. 3 shows the slump values corresponds to water added to the mix of different agricultural waste materials and mix proportions. It can be observed that in the case of agricultural waste-based cement blocks, the water/cement ratio for the particular slump increased in increasing the content percentage of agricultural wastes. This type of behavior in water required value was due to the high waste absorption of agricultural wastes which declined the flowability of the mortar mix. However, it can be observed that the water requirement for rice husk and peanut shell added mortar mix was close to control mortar mix. This may be due to less density and water absorption rate of these materials compare with other agricultural waste materials. A similar observation was reported by Ozturk and Bayrakl [44] on tobacco waste added concrete. Further, sawdust and straw showed high water requirement for particular slump value. This type of behavior was

Fig. 2. Agricultural waste materials used for cement block production.

Table 2
Material used for production of cement block.

Materials	Bulk density (kg/m^3)	Specific gravity	Fineness modulus	Containments (by weight)	Water absorption capacity (%)	Remarks
Rice husk	134	0.71	3.82	35% cellulose, 25% hemicellulose, 20% lignin, 17% ash [32]	160–180 [37]	Unprocessed material was used.
Sawdust	397	1.31	1.98	61–65% of hemicellulose, 25–28% lignin, 4–9% extractives, 4% ash [33]	435–445 [37]	Unprocessed material was used.
Peanut shell	127	1.15	4.29	8.2% of protein, 28.8% lignin, 37.0% cellulose, 2.5% carbohydrate [34]	161 [38]	Unprocessed material was used.
Straw	85	0.36	4.82	39% of cellulose, 23% hemicellulose, 36% lignin, and 12% ash [35]	300–517 [39]	They were cut into small pieces which less than 25 mm length.
Coconut shell	539	1.41	6.51	14% of cellulose, 32% hemicellulose, 46% lignin [36]	8–25 [40]	Coconut shells were crushed into small pieces nearly 15 mm × 15 mm.

due to when the substitution of sawdust and straw increased, the mortar mix became unworkable. A similar observation was reported by Modani and Vyawahare [45] for sugarcane bagasse ash added concrete.

For a selection of the cement/water ratio; the slump value was fixed as 50 mm for constant workability. Water requirement for mortar mix depends on aggregate particle size and grading and dust content. For mortar with rice husk, coconut shell, and peanut shell, the water-cement ratio requirement to achieve the 50-mm slump was varying between 0.75 and 1.10. However, for cement mortar with sawdust and rice straw showed a higher water required to achieve the 50-mm slump. It has been seen that the high-water absorption of sawdust and straw as shown in Table 2 was the factor for reducing the workability. It shows that sawdust and rice straw negatively influence the workability of the mortar mix.

Table 3 summarizes the material mix and amount of water required for achieving that slump value. For the higher percentage of agricultural waste in the mortar mix, the amount of water required was changing dramatically. Generally, the addition of agricultural wastes to cement mortars led to a reduction in workability. So, that's worse compaction of the mortar was occurring. Therefore, water requirement for set workability was increased with the addition of waste material. The method of production for the masonry blocks in this experimental program was through simple manual blending and compressing. First, cement, sand and waste materials were measured and blended in order to obtain a homogenous mixture. Next, water was constantly added into the mixture until a homogenous mixture was obtained. The entire mixing process takes approximately 20–30 min. Masonry blocks having the size of 215 mm × 105 mm × 65 mm was cast with each mix proportion summarized in Table 3. The procedure of preparation of cement blocks is shown in Fig. 4. Wet mortar was used for block casting for proper distribution mix. Hand compaction was done using a temping rod by giving 25 strokes in each of three layers.

2.3. Testing

In this study, total 400 samples were prepared which were 25 for control blocks and 375 for waste material added blocks (75 blocks for each agricultural waste type). For each waste type, 25 blocks were prepared for each mortar mix ratio (1:5:1, 1:4:2, 1:3:3 - cement: sand: waste). For each mix ratio, five cement blocks each were used to determine the compression strength and flexural tensile strength, while three cement blocks each were used for density, water absorption rate, acid attack resistance and alkaline attack resistance. Cement blocks were left under the open shed for curing up to a period of 28 days before they were taken to the laboratory for testing. Room temperature was around 30 °C and Humidity around 90% during the curing period.

2.3.1. Compression test

The compressive strengths of cement blocks at the age of 28 days were measured according to the European standard EN 772-1 [46]. Cement blocks, having the size of 215 mm × 105 mm × 65 mm, were tested under axial loading. The test was carried out using a universal testing machine under displacement control method at the rate of 2 mm/min. The load was applied to the cement blocks until failure occurred and the ultimate load was recorded.

2.3.2. Three-point bending test

The tensile strength of the cement block was evaluated by means of three-point bending test according to the European standard EN 1015-11 [47]. Cement blocks, having the size of 215 mm × 105 mm × 65 mm, were tested. Each cement blocks were placed over the steel rod in a way to obtain a clear span of 175 mm and the concentrated load was applied at the mid-span. The test was carried out using a universal testing machine under displacement control method at the rate of 2 mm/min.

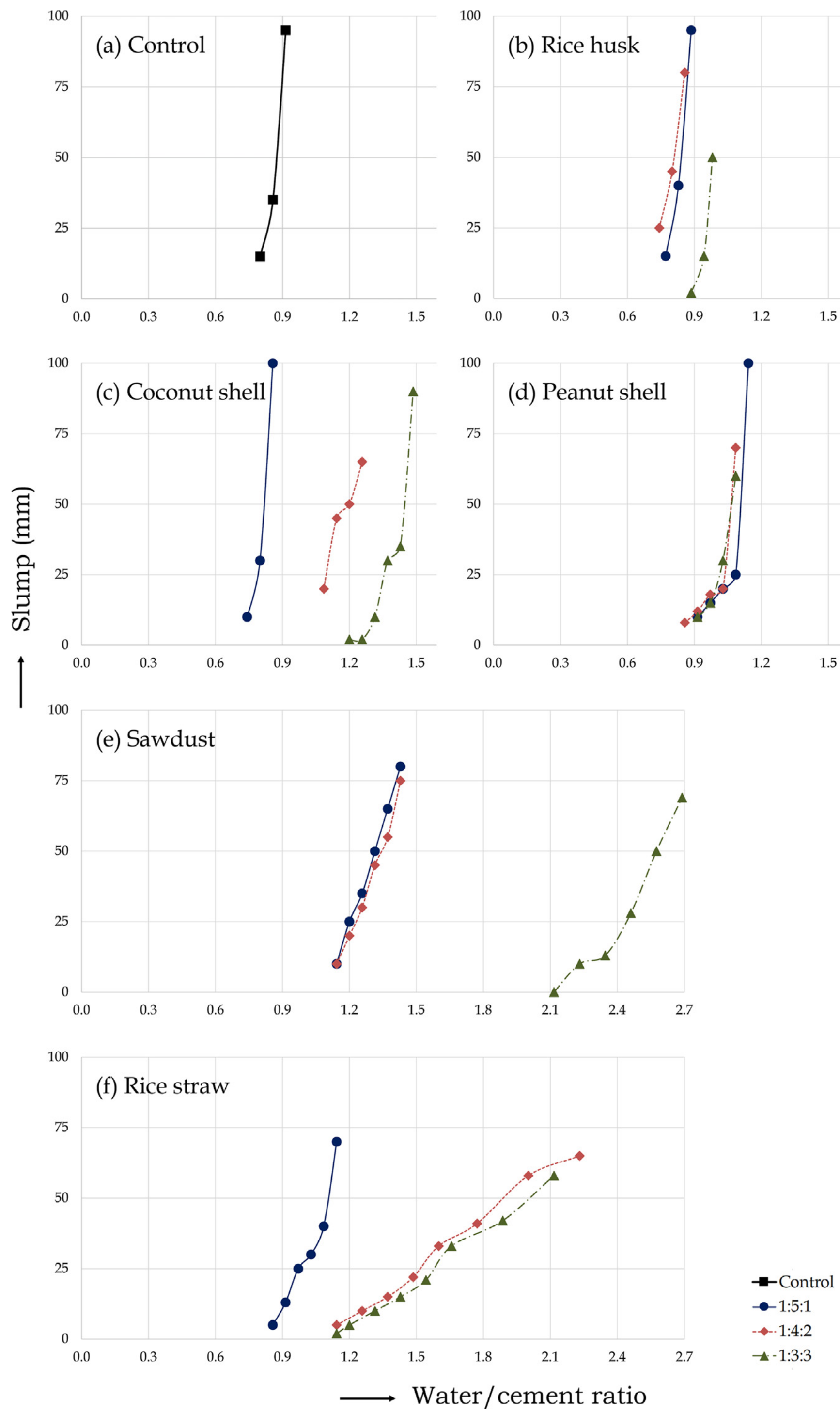

Fig. 3. Water requirement for mortar mix with different agricultural waste materials.

2.3.3. Water absorption test

To obtain the density and water absorption of the blocks, the weight and dimensions of the cement mortar blocks and those containing different agricultural waste were measured according to ASTM C140 [48]. Cement block at the age of 28 days, were dried in an oven at 100 °C for 24 h. Then, the blocks were stored in indoor laboratory environment until the surface temperature of the specimen becomes room temperature. The dried cement blocks are immersed completely in clean water at room temperature for 24 h. After removing the cement blocks from the submerged condition, the surface water wiped off and the weight of the blocks was recorded. The water absorption rate was calculated by Eq. (1).

$$\text{Water absorption rate} = (W_S - W_d)/V \tag{1}$$

where W_S is the weight of the specimen at the fully saturated condition, W_d is the weight of the oven-dried specimen and V is the volume of the specimen.

2.3.4. Acid and alkaline test

The specimens were immersed in 3% of H_2SO_4 solution for acid test and 3% of NaOH solution for an alkaline test for 30 and 60 days as per ASTM C1152M-04 [49] and ASTM C289-07 [50], respectively. The

Table 3
Volume proportion for prepared test specimen.

Mix type		Volume ratio (cement: sand: waste material)	Weight (g)			
			Cement	Sand	Waste material	Water
Control		1:6:0	1000	6503	-	895
Waste material	Rice husk	1:5:1	1000	5419	098	860
		1:4:2	1000	4335	196	815
		1:3:3	1000	3251	295	980
	Sawdust	1:5:1	1000	5419	291	1315
		1:4:2	1000	4335	583	1305
		1:3:3	1000	3251	875	2585
	Peanut shell	1:5:1	1000	5419	093	1095
		1:4:2	1000	4335	187	1060
		1:3:3	1000	3251	280	1065
	Straw	1:5:1	1000	5419	063	1095
		1:4:2	1000	4335	125	1815
		1:3:3	1000	3251	187	1990
	Coconut shell	1:5:1	1000	5419	396	820
		1:4:2	1000	4335	792	835
		1:3:3	1000	3251	1189	1030

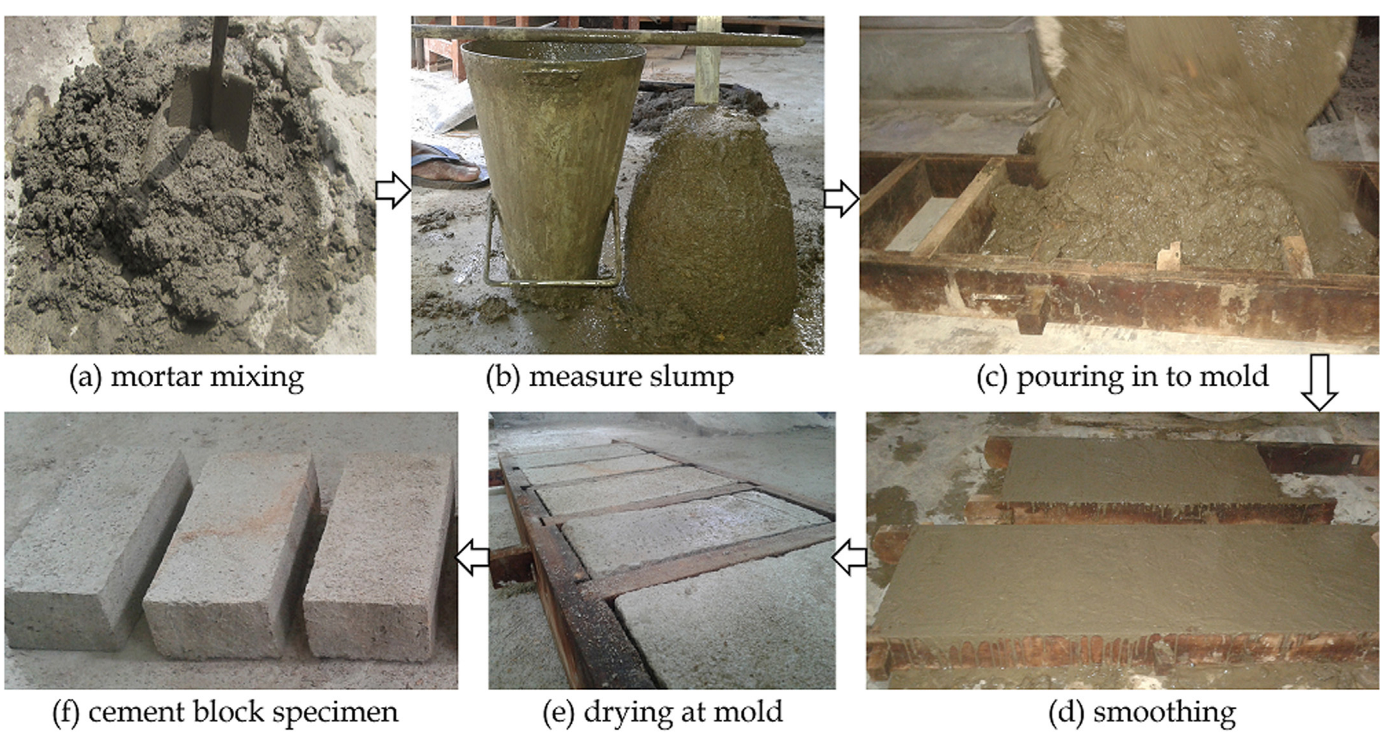

Fig. 4. Procedure for preparation of cement blocks.

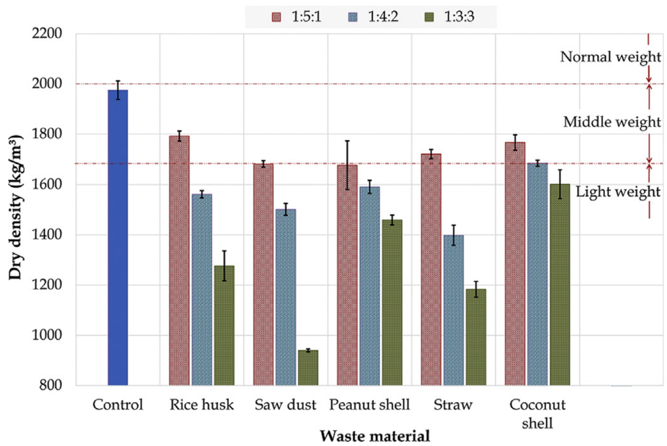

Fig. 5. Dry density variation with different mix proportion.

weight of the specimen was taken before (W_i) and after immersion (W_a) and weight loss was determined by Eq. (2).

$$\text{Density loss} = (W_i - W_a)/\text{Volume of the block} \quad (2)$$

3. Results

3.1. Density

Density depends on various factors like the specific gravity of the materials used, cement-water ratio, sand types and its content, amount of replacement of waste material, water absorption, etc. From the results, it can be observed that in every case density decreases with the inclusion of agricultural waste materials on account of their lower unit weight. The reason for the decrease in density owes to the relatively low specific gravity of agricultural waste. According to a dry density of cement block with each proportion of waste material as shown in Fig. 5, blocks are classified based on ASTM Specifications for Concrete Masonry Units [51] and summarized in Table 4. According to Table 4, cement blocks can be categorized under the lightweight blocks and medium weight blocks. Control blocks are shown the dry density almost close to normal weight categories. Cement block with 1:4:2 and 1:3:3 proportion of each waste material are categories as a lightweight block.

3.2. Strength of cement blocks

3.2.1. Compressive strength

Nowadays, the uses of masonry unit in construction are limited to non-load-bearing structural elements. Even for non-load bearing masonry units, to monitor the quality of cement block, American Society for Testing and Materials [52] sets a minimum criterion of 4.14 MPa, as the average of three specimens. However, in Sri Lankan standard [53], this minimum value set as 1.2 MPa, as an average of three specimens.

Compressive strength depends on the strength of the matrix, particle strength of aggregate, cement content and water/cement ratio. It can be observed from previous studies published by various researchers [54–57] that, in every experiment, the compressive strength decreased by increasing the percentage of aggregate replacement by any agricultural waste materials. Kanagalakshmi et al. [27] reported the compressive strength of concrete reduced by 24% than the control concrete at 15% replacement of peanuts shell as coarse aggregates. Adewuyi and Adegoke [58] also reported similar observations using the periwinkle shell as its cube compressive strength was 26 MPa at 0% and 18 MPa at 50% inclusion of periwinkle shell. Even though, these experiments performed as agricultural waste for coarse aggregate replacement, it is shown that agricultural waste added concrete strength less than the control concrete.

Table 4
Classification based on density.

Type of block		Mix ratio			
		1:6	1:5:1	1:4:2	1:3:3
Control block		Medium	–	–	–
Waste material	Rice husk	–	Medium	Light	Light
	Sawdust	–	Medium	Light	Light
	Peanut shell	–	Light	Light	Light
	Straw	–	Medium	Light	Light
	Coconut shell	–	Medium	Light	Light

Sada et al. [38] performed an experiment using groundnut shells as a fine aggregate replacement having a mix ratio of 1:2:3, in which they observed that the compressive strength reduced by 49% and 64% than the control concrete at 25% and 50% sand replaced by groundnut shell, respectively. Bras et al. [59] tested the compressive strength of mortar containing cork as fine aggregate and results indicated that the compressive strength reduced by 34% and 69% than the control harden mortar at 20% and 50% replacement, respectively. These results show good agreements with present experimental test results.

The compressive strength of the cement blocks in this experimental program is shown in Fig. 6. The results show that the compressive strength of the cement blocks is affected by the type of waste materials and replacement percentage. In general trend, the compressive strength of the block gradually reduced with increased in waste content. These results may be explained by a higher water/cement ratio used in agricultural added mortar as compared to the reference mortar and an increase of agricultural waste content which have much lower mechanical resistance as a sand replacement.

Furthermore, the low density of agricultural waste as compared with that of river sand may also contribute to the reduction of the compressive strength as shown in Fig. 6. In the present experiment, considering the waste material type, cement block with coconut shell, have a higher compressive strength and cement block with straw have a lower compressive strength. The higher density of coconut shell compares with other agricultural waste material contribute to the higher compressive strength of the block. Similarly, a lower density of straw compares with other agricultural waste material shows the lowest compressive strength block. According to the ASTM C129 [52], cement blocks satisfy the specified minimum requirement, except 1:3:3 mix proportion cement blocks. Even for 1:3:3 mix proportions, a cement block with coconut shell satisfies the ASTM C129 minimum requirement. However, according to the Sri Lankan Standard [53], each type of cement blocks except 1:3:3 proportions of sawdust, satisfy the specified minimum requirement.

Fig. 7 shows the normalized compressive strength of block variation

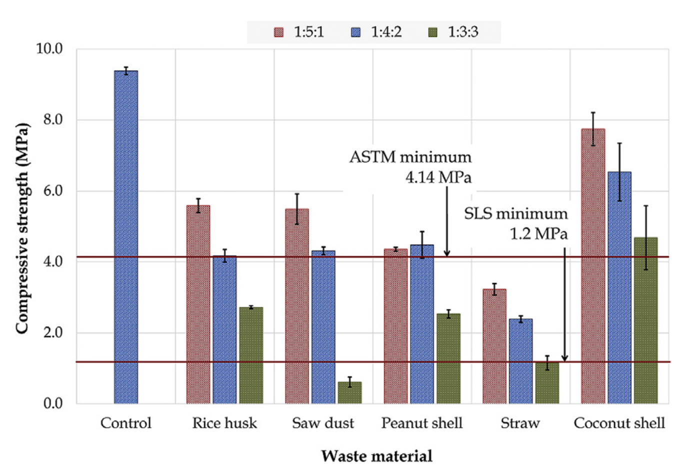

Fig. 6. Compressive strength variation with different mix proportion.

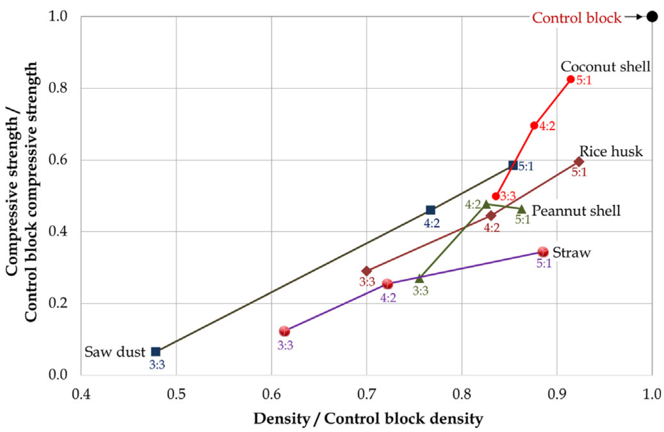

Fig. 7. Normalized compressive strength variation with normalized density.

with normalized block density. Control block was used as a reference to calculate the normalized strength. Each mix proportion of coconut shell and 1:5:1 proportion of rice husk, sawdust, and peanut shell have at least 50% of the compressive strength of cement block.

3.2.2. Flexural tensile strength

Flexural tensile stress is a measure, which used to measure the ability of blocks to withstand that flexural load. Generally, crack initiated at the tensile side of the block and failed in middle cross-section. The flexural tensile strength of the cement blocks is shown in Fig. 8. Results show that flexural tensile strength decreased with respect to increase in the waste material content. The flexural strength is largely influenced by type, particle size and density of the waste material used and the diffused moisture distribution in the cement mortar [60]. Similar to compressive strength, the low density of agricultural waste also contributes to the reduction of the flexural strength.

Adewuyi and Adegoke [58] also reported similar observations using the periwinkle shell and were found to reduce the effective bond with the periwinkle shell as aggregate and reduce flexural strength. Sada et al. [38] performed an experiment using oil palm shell as a coarse aggregate, in which they observed that the compressive strength reduced by 39% at 30% replacement than the control concrete. These results show good agreements with coconut shell added cement mortar in present experimental. Bras et al. [59] tested the flexural tensile strength of mortar containing cork as fine aggregate and results indicated that the flexural tensile strength reduced by 23% and 46% at 20% and 50% replacement respectively than the control harden mortar. In the present experiment, consider the waste material type, cement block with coconut shell have a higher flexural tensile strength and cement block with straw have a lower flexural tensile strength.

The results from the present experimental study are also analyzed by using linear regression analysis to derive proportionality equation to relate cement block flexural tensile strength (f_t) to compressive strength (f_{cu}) in the standard form of $f_t = a f_{cu}^{\,b}$. Eq. (3), relating flexural strength to compressive strength of cement blocks at the coefficient of determination (R^2) value of 0.89 was employed in calculating the flexural strength of cement block.

$$f_t = 0.13 f_{cu}^{1.2} \tag{3}$$

The standard error of the estimate for above equation is 0.02 MPa shows that the proposed equation provides a good correlation with the experimental values.

3.3. Durability

3.3.1. Water absorption rate

The water absorption rate of cement block depends on the nature of the pore system. The more pore in the cement block, the vulnerability towards the water and chemicals is high. The main problem of using the waste material as a sand replacement in cement block is the high-water absorption of waste materials. Generally, the water absorption rate of waste material added cement block is significantly greater than the one of the control cement blocks. It can be observed from previous studies by researchers that, the water absorption is increased by increasing the agricultural waste as a replacement for fine or coarse aggregates. Olanipekun et al. [55] reported that the percentage of water absorption increases by increasing the percentage replacement of oil palm shell and coconut shell as a coarse aggregate. Also, they find that value of water absorption of the cement mortar depends on water absorption capacity of agricultural waste. Kuo et al. [61] also reported the same observation. Kuo et al. [61] reported that the absorption rate of replacing waste oyster shell sand is increased by 1.1–1.6% than the control concrete.

The water absorption rate of the blocks is shown in Fig. 9. Results show that the water absorption rate is increased with respect to increases in waste material content except for coconut shell. Blocks with coconut shell have approximately equal water absorption rates for all mix proportion and it's less than control block. A possible reason for the water absorption with agricultural waste material replacement may be the lower bond strength between the agricultural waste and cement led to a tendency for more spring back after water immersion and high hydrophilic nature (water absorption of the waste material itself) of waste materials. Another possible reason could be attributed to the low bulk density of agricultural waste materials, which cause more void space in the mortar mix. Notations gave in Fig. 9 shows the satisfactoriness of the water absorption rate of each mortar mix with

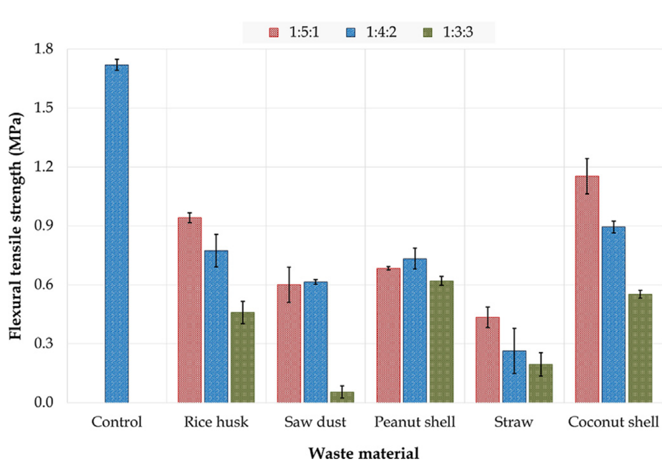

Fig. 8. Flexural tensile strength variation with different mix proportion.

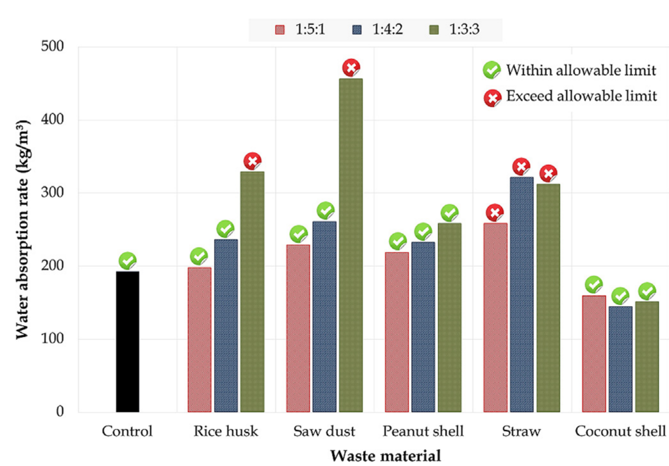

Fig. 9. Water absorption rate variation with different mix proportion.

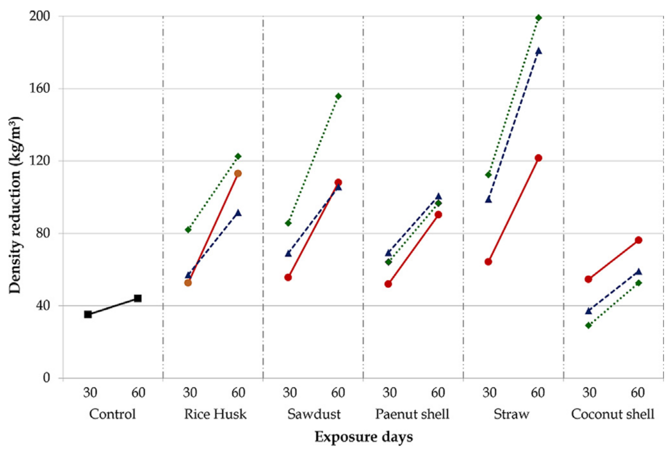

Fig. 10. Density reduction due to acid attack for different mix proportion.

various waste material proportions, as considering values given in ASTM C55-11 [62]. The allowable water absorption rate is 208 kg/m^3 for normal weight masonry block, 240 kg/m^3 for medium weight masonry block and 320 kg/m^3 for lightweight masonry block in accordance with ASTM C55-11 [62]. According to the results, blocks with rice husk and sawdust in 1:3:3 mix proportion and all the mix proportion of straw have a higher water absorption rate than the allowed value. This indicated that the vulnerability towards the penetration of external agents was high for blocks with rice husk, sawdust, and straw than compare with blocks with peanut shell and coconut shell.

3.3.2. Acid resistance

Density reductions of control blocks and blocks with agricultural waste materials, due to acid attack were summarized in Fig. 10. From the results, it can be observed that density reduction in the exposure of 30 and 60 days gradually increased as the proportion of agricultural waste increased. It shows that in the case of cement blocks with straw, the density reduction was very steep and at 60 days for 1:3:3 mix proportion, the density reduced by 200 kg/m^3 compared to 40 kg/m^3 for control blocks. Also, cement blocks with rice husk, sawdust, and peanut shell show the density reduction between 90 and 120 kg/m^3 at 60 days. However, cement blocks with coconut shell, the reduction in density was between 40 and 80 kg/m^3, the value that can be considered moderate and relatively closer to control block.

3.3.3. Alkaline resistance

Density reductions of control blocks and blocks with agricultural waste materials, due to alkaline attack were summarized in Fig. 11. The results show that density reduction in the exposure of 30 and 60 days

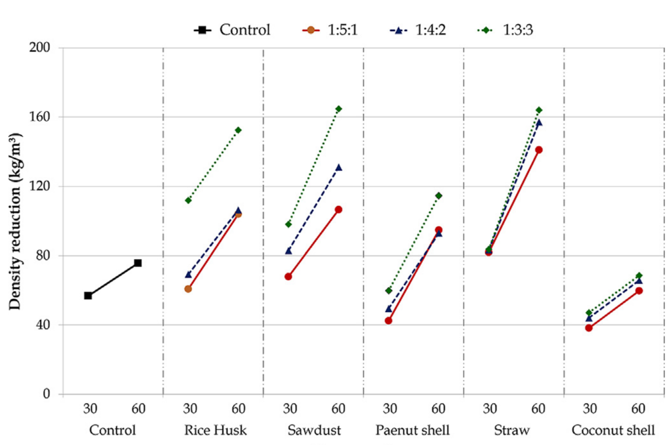

Fig. 11. Density reduction due to alkaline attack for different mix proportion.

gradually increased as the proportion of agricultural waste increased. It shows that in the case of cement blocks with rice husk, straw and sawdust, the density reduction was very steep and at 60 days for 1:3:3 mix proportion, the density reduced by more than 150 kg/m^3 compared to 75 kg/m^3 for control block. However, cement blocks with coconut shell, the reduction in density was between 40 and 70 kg/m^3, the value that can be considered moderate and relatively closer to control block.

3.4. Parametric correlation analysis

Pearson correlation coefficients are calculated to determine the relationship between mechanical properties included density, compressive strength and flexural bending strength, as well as durability included water absorption rate, acid attack resistance and alkaline attack resistance. Pearson coefficients of parametric correlations are summarized in Table 5 and significant (2-tailed) are provided in square bracket. The agricultural waste content was positively related to the dry density (dry density reduced with the addition of agricultural waste replacement) and negatively related to compressive strength, flexural bending strength, acid attack resistance and alkaline attack resistance. The beneficial effect of agricultural waste addition was more on the density than that of strength or durability.

4. Cost analysis

During the course of this work, it was decided to measure mortar consumption for block construction. To determine the agricultural waste influences mortar consumption, the amount of mortar used to construct each case of the cement blocks was calculated. The material usage was calculated in terms of the amount of cement and sand required and total cost per 1000 cement blocks reported in Fig. 12. For cost calculation, SLR 920 (US$ 5.98) for 50 kg bag cement, SLR 13,920 (US$ 90.53) for one-metre cube sand and SLR 157 (US$ 1.02) per one-metre cube per 1 km for aggregate transport according to building schedule of rates of Sri Lanka [63] were used. Total cost calculated by considering 10% material wastage and the labor cost at unskilled labor wage rate proposed by labor unit rates for construction works [63]. Waste material preparation cost is not considered for calculation. By replacing sand by one-sixth of agricultural waste, the mortar total cost decrease by approximately 10% and when the replacement increases to one-third, the cost decrease by 20–30%. Due to cement cost contribute around 50% of the total material cost, increasing the agricultural did not result inversely proportion in a reduction in total cost.

5. Discussion

As results described earlier, the compressive strength of the cement blocks reduced as more agricultural waste materials were incorporated. Blocks with rice straw had a compressive strength that was lower than ASTM minimum requirement of 4.12 MPa. Considering that, cement blocks with the agricultural waste of 1:3:3 ratio will probably be unfavorable for house construction. However, for local Sri Lankan Standard [53], non-load bearing wall blocks can have a compressive strength of 1.2 MPa. Therefore, for non-construction purposes or low-story houses, these bricks are still acceptable.

Even though, cement blocks with agricultural waste satisfied the strength requirement according to the ASTM C55-11 [62]; durability is the major issue for these blocks. Another issue that arises cement blocks with a high content of the agricultural waste material is the worsening of the block's appearance and shape. Cement blocks with a high content of agricultural waste were seen to have an irregularly shaped surface as shown in Fig. 13. Especially cement block with rice straw and sawdust shows poor appearance and will be difficult to apply the joint mortar and surface plastering when these blocks used for construction.

On the other hand, cement blocks with agricultural waste have some advantage such as low cost, low density, and high porosity compared

Table 5
Pearson coefficients of parametric correlations between parameters.

	Dry Density	Water absorption	Compressive strength	Flex. bending strength	Acid attack (density reduction)	Alkaline attack (density reduction)
Sand replacement	−0.822 [0.000**]	0.561 [0.024*]	−0.749 [0.001**]	−0.691 [0.003**]	−0.640 [0.008**]	−0.425 [0.101]
Dry Density		−0.911 [0.000**]	0.797 [0.000**]	0.547 [0.028*]	−0.820 [0.000**]	−0.696 [0.003**]
Water absorption			−0.679 [0.004**]	−0.397 [0.128]	0.719 [0.002**]	0.748 [0.001**]
Compressive strength				0.679 [0.004**]	−0.697 [0.003**]	−0.467 [0.068]
Flex. bending strength					−0.162 [0.548]	0.037 [0.893]
Acid attack (density reduction)						0.737 [0.001**]

Note: .
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

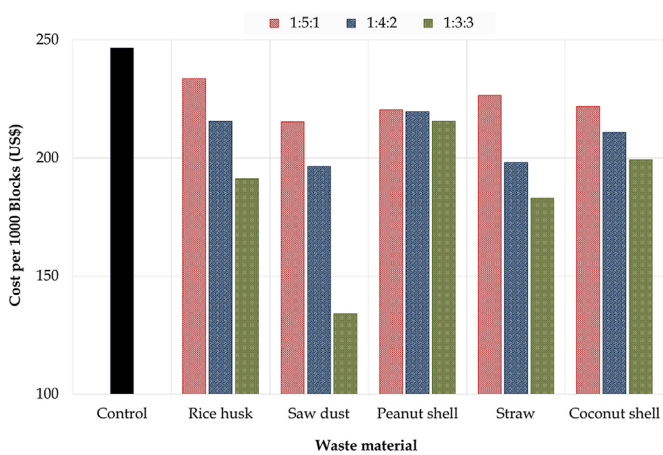

Fig. 12. Cost analysis per 1000 cement blocks production.

with control cement blocks. By incorporating agricultural waste in cement blocks, it saves the time of construction and labor cost due to lightweight and easier to handle. Also, a cement block with higher porosity had a lower thermal conductivity and it improves insulation [40,64].

Even though technically attractive block production from waste material is developed, if public awareness is poor and the absence of relevant standards, production of these type blocks cannot be popular. Also, while people build houses freely with the materials which are available locally, some standardization is required. Local standardization code not available for cement block with agricultural waste and there is a restriction to implement in house construction. Therefore, further research would be required, especially in public education and local standardization of block production from waste materials.

6. Conclusion

The aim of this study was investigating the possibility of recycling the agricultural waste as a sand replacement for cement block, which can use as building construction material in rural areas of Sri Lanka. In this study, five types of waste materials; rice husk, sawdust, peanut shell, rice straw and coconut shell were used as sand replacement material in a cement block. A number of experiments were carried out to determine the most suitable waste material. The following conclusions can be made on the basis of current experiment results.

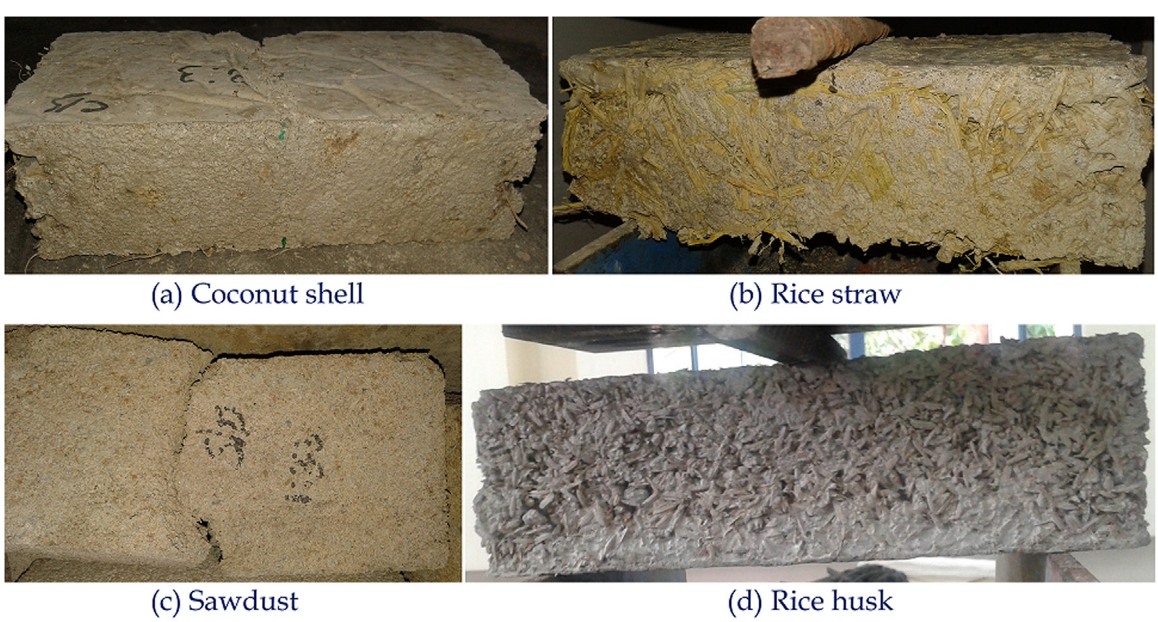

Fig. 13. Appearance of cement block with different agricultural waste for 1:3:3 mix ratio.

- Based on density, cement blocks with 1:3:3 and 1:4:2 mix proportion falls under light weight cement block according to the ASTM C55-11 [62]. Cement block 1:5:1 proportion is categorized as medium weight and control cement block density almost closer to normal category.
- Cement blocks with agricultural waste were found to be weaker in terms of both compressive and flexural tensile strength than those produced by 1 (cement): 6 (sand) ratio mix cement block. However, most of the cement blocks with agricultural waste except straw shows that the compressive strength more than a minimum strength requirement recommended by ASTM standards.
- Both coconut shell and peanut shell added cement blocks have a water absorption rate less than the allowable value accordance with C55-11 [62]. However, 1:3:3 mix proportion cement blocks with rice husk, sawdust and straw have higher water absorption rate than allowable value.
- In terms of acid and alkaline resistance, only cement blocks with coconut shell and peanut shell show the relatively lower density reduction, which is closer to control blocks. But, cement blocks with rice husk, sawdust and straw show the at least three times higher density reduction than control blocks at 60 days' exposure to acid or alkaline.

Based on these results, even cement blocks with agricultural waste satisfied the strength requirement according to the ASTM C55-11 [62], durability is the major issue for these blocks. Cement block with coconut shell and peanut shell shows reasonable strength and durability properties. Therefore, it can be used as construction material, where applications required low strength cement blocks. More research on the long-term durability of this kind of cement block would give more confidence to the construction industry for using them for housing projects.

Also, this study only compressive strength and flexural tensile strength for mechanical properties and acid and alkaline resistance for durability were investigated. However, other mechanical properties (such as elastic modulus, UPV) and durability properties (such as carbonation, permeability, freezing and thawing, erosion) could be investigated for cement blocks with these agricultural waste materials.

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References

[1] U.G. Tomas, Sustainable management of waste coconut shells as aggregates in concrete mixture, J. Eng. Sci. Technol. Rev. 6 (2013) 7–14.
[2] Delft Hydraulic and Netherlands Economic Institute, Draft final report, 1, National Sand Study for Sri Lanka-Phase one. Delft, The Netherlands, 1992.
[3] K.N.J. Katupotha, Survey on Economic-Environmental Linkages between the Demand and Supply of Sand and Coral in the West and Southwest Coasts of Sri Lanka, National Sand Survey. Environment Action 1 Project, Ministry of Forestry and Environment, Sri Lanka, 1998.
[4] W.P.S. Dias, A.A.D.A.J. Perera, S.M.A. Nanayakkara, S.J.M. Sahayan, I.M.S. Sathyaprasad, Interim Sand Study, Draft Final Report, Department of Civil Engineering, University of Moratuwa, 1999.
[5] L.H.P. Gunaratne, Policy options for sustainable river sand mining in Sri Lanka, in: D. James, H. Francisco (Eds.), Cost-Benefit Studies of Natural Resource Management in Southeast Asia, Springer, Singapore, 2015.
[6] M.M. Sabai, M.G.D.M. Cox, R.R. Mato, E.L.C. Egmond, J.J.N. Lichtenberg, Concrete block production from construction and demolition waste in Tanzania, Resour. Conserv. Recycl. 72 (2013) 9–19.
[7] S.P. Raut, R.V. Ralegaonkar, S.A. Mandavgane, Development of sustainable construction material using industrial and agricultural solid waste: a review of waste-create bricks, Constr. Build. Mater. 25 (2011) 4037–4042.
[8] S. Kumar, A perspective study on fly ash-lime-gypsum bricks and hollow blocks for low cost housing development, Constr. Build. Mater. 16 (2012) 519–525.
[9] M. Singha, R. Siddiqueb, Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete, J. Clean. Prod. 112 (2016) 620–630.
[10] N. Bilgin, H.A. Yeprem, S. Arslan, A. Bilgin, E. Gunay, M. Marsoglu, Use of waste marble powder in brick industry, Constr. Build. Mater. 29 (2012) 449–457.
[11] R.R. Menezes, H.S. Ferreira, G.A. Neves, H.D.L. Lira, Use of granite sawing wastes in the production of ceramic bricks and tiles, J. Eur. Ceram. Soc. 25 (2005) 1149–1158.
[12] P. Turgut, Properties of masonry blocks produced with waste limestone sawdust and glass powder, Constr. Build. Mater. 22 (2008) 1422–1427.
[13] P. Turgut, B. Yesilata, Physico-mechanical and thermal performances of newly develop rubber-added bricks, Energy Build. 40 (2008) 679–688.
[14] S.P. Raut, R. Sedmake, S. Dhunde, R.V. Ralegaonkar, S.A. Mandavgane, Reuse of recycle paper mill waste in energy absorbing light weight bricks, Constr. Build. Mater. 27 (2012) 247–251.
[15] S. Rauta, R. Ralegaonkara, S. Mandavgane, Utilization of recycle paper mill residue and rice husk ash in production of light weight bricks, Int. J. Arch. Civ. Mech. Eng. 13 (2013) 269–275.
[16] D. Rajput, S.S. Bhagade, S.P. Raut, R.V. Ralegaonkar, S.A. Mandavgane, Reuse of cotton waste and recycle paper mill waste in building material, Constr. Build. Mater. 34 (2012) 470–475.
[17] Y. Fang, Y. Gu, Q. Kang, Q. Wen, P. Dai, Utilization of copper tailing for autoclaved sand–lime brick, Constr. Build. Mater. 25 (2011) 867–872.
[18] A.K. Aeslina, M. Abbas, R. Felicity, B. John, Density, strength, thermal conductivity and leachate characteristics of light weight fired clay bricks incorporating cigarette butt, Int. J. Civ. Eng. Environ. Eng. 2 (2010) 179–184.
[19] An Demir, investigation on the production of construction brick with processed waste tea, Build. Environ. 41 (2006) 1274–1278.
[20] F. Parisi, D. Asprone, L. Fenu, A. Prota, Experimental characterization of Italian composite adobe bricks reinforced with straw fibers, Compos Struct. 122 (2015) 300–307.
[21] P. Turgut, H.M. Algin, Limestone dust and wood sawdust as brick material, Energy Build. 42 (2007) 3399–3403.
[22] J. Salas, M. Alvarez, J. Veras, Lightweight insulating concretes with rice husk, J. Cem. Compos. Lightweight Concr. 8 (1986) 171–180.
[23] J. Salas, M. Alvarez, J. Veras, Rice husk and fly ash concrete blocks, J. Cem. Compos. Lightweight Concr. 8 (1987) 177–182.
[24] K. Gunasekaran, P. Kumar, M. Lakshmipathya, Mechanical and bond properties of coconut shell concrete, Constr. Build. Mater. 25 (2011) 92–98.
[25] K. Gunasekaran, R. Annadurai, P. Kumar, Long term study on compressive and bond strength of coconut shell aggregate concrete, Constr. Build. Mater. 28 (2012) 208–215.
[26] K. Gunasekaran, R. Annadurai, P. Kumar, Study on reinforced lightweight coconut shell concrete beam behavior under flexure, Mater. Des. 46 (2013) 157–167.
[27] A.S. Kanagalakshmi, S. Velu, R. Tamilnathan, Study of peanut shell beams on shear and flexure, in: International Conference on Engineering Trends and Science & Humanities (ICETSH-2015), Tamilnadu, India, 2015, 2015.
[28] J. Khedari, B. Suttisonk, N. Pratinthong, J. Hirunlabh, New lightweight composite construction materials with low thermal conductivity, Cem. Concr. Comp. 23 (2001) 65–70.
[29] M.A. Mannan, C. Ganapathy, Engineering properties of concrete with oil palm shell as coarse aggregate, Constr. Build. Mater. 16 (2002) 29–34.
[30] M.V. Madurwar, R.V. Ralegaonkar, S.A. Mandavgane, Application of agro-waste for sustainable construction materials: a review, Constr. Build. Mater. 38 (2013) 872–878.
[31] SLS 107, Specification for Ordinary Portland Cement Part 1: Requirements, Sri Lanka Standards Institution, Colombo, Sri Lanka, 2008.
[32] H.G.B. Premalal, H. Ismail, A. Baharin, Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites, Polym. Test. 21 (2002) 833–839.
[33] M. Poletto, J. Dettenborn, V. Pistor, M. Zeni, A.J. Zattera, Materials produced from plant biomass. Part I: evaluation of thermal stability and pyrolysis of wood, Mater. Res. 13 (2010) 375–379.
[34] N.S. Trivedi, A.K. Rhushikesh, A.M. Sachin, 2,4-Dichlorophenoxyacetic acid adsorption on adsorbent prepared from groundnut shell: effect of preparation conditions on equilibrium adsorption capacity, Arab. J. Chem. (2016), http://dx.doi.org/10.1016/j.arabjc.2016.07.022.
[35] T.S. El-Tayeb, A.A. Abdelhafez, S.H. Ali, E.M. Ramadan, Effect of acid hydrolysis and fungal biot reatment on agro-industrial wastes for obtainment of free sugars for bioethanol production, Braz. J. Microbiol. 43 (2012) 1523–1535.
[36] U. Hasanah, B. Setiaji, T. Triyono, C. Anwar, The chemical composition and physical properties of the light and heavy tar resulted from coconut shell pyrolysis, J. Pure Appl. Chem. Res. 1 (2012) 26–32.
[37] G.C. Ahn, S.S. Jang, K.Y. Lee, W.S. Kwak, Y.K. Oh, K.K. Park, Characteristics of sawdust and cocopeat beddings, and their usefulness according to the fan and pen location for rearing hanwoo cattle, Asian-Australas. J. Anim. Sci. 29 (2016) 444–454.
[38] B.H. Sada, Y.D. Amarteyb, S. Bakoc, An investigation into the use of groundnut shell as fine aggregate replacement, Niger. J. Technol. 32 (2013) 54–60.
[39] J. Li, J. Lu, X. Li, T. Ren, R. Cong, L. Zhou, Dynamics of potassium release and adsorption on rice straw residue, PLoS One 9 (2014) e90440.
[40] J.K. Prusty, S.K. Patro, Properties of fresh and hardened concrete using agro-waste as partial replacement of coarse aggregate – A review, Constr. Build. Mater. 82

(2015) 101–113.
[41] ASTM C136/C136M, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM International, West Conshohocken, PA, 2014.
[42] ASTM C29 / C29M - 17a, Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate, ASTM International, West Conshohocken, PA, 2017.
[43] ASTM C128 – 15, Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate, ASTM International, West Conshohocken, PA, 2015.
[44] T. Ozturk, M. Bayrakl, The possibilities of using tobacco wastes in producing lightweight concrete, Agric. Eng. Int.: CIGR J. 7 (2005) 1–9.
[45] P.O. Modani, M.R. Vyawahare, Utilization of bagasse ash as a partial replacement of fine aggregate in concrete, Procedia Eng. 51 (2013) 25–29.
[46] BS EN 772-1:2011 + A1, Methods of Test for Masonry Units. Determination of Compressive Strength, Comité Européen de Normalisation, Brussels, 2015.
[47] BS EN 1015–11, Methods of Test for Mortar for Masonry - Part 11: Determination of Flexural and Compressive Strength of Hardened Mortar, Comité Européen de Normalisation, Brussels, 1999.
[48] ASTM C140/C140M - 17a, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units, ASTM International, West Conshohocken, PA, 2017.
[49] ASTM C1152M-04, Standard Test Method for Acid-soluble Chloride in Mortar and Concrete, ASTM International, West Conshohocken, PA, 2012.
[50] ASTM C289-07, Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method), ASTM International, West Conshohocken, PA, 2007.
[51] ASTM C90, Standard Specification for Loadbearing Concrete Masonry Units, ASTM International, West Conshohocken, PA, 2011.
[52] ASTM C129, Standard Specification for Nonloadbearing Concrete Masonry Units, ASTM International, West Conshohocken, PA, 2006.
[53] SLS 855, Specification for Cement Blocks: part 1: Requirements, Sri Lanka Standards Institution, Colombo, Sri Lanka, 1989.
[54] M.H. Nensok Adefemi, E.T. Kaase, I.A. Wuna, Exploratory study of date seed as coarse aggregate in concrete production, Civ. Environ. Res. 3 (2013) 85–92.
[55] E.A. Olanipekun, K.O. Olusola, O. Ata, A comparative study of concrete properties using coconut shell and oil palm shell as coarse aggregates, Build. Environ. 41 (2006) 297–301.
[56] F. Falade, E.E. Ikponmwosa, N.I. Ojediran, Behaviour of lightweight concrete containing periwinkle shells at elevated temperature, J. Eng. Sci. Technol. 5 (2010) 379–390.
[57] M.A. Mannan, C. Ganapathy, Concrete from an agricultural waste-oil palm shell (OPS), Build. Environ. 39 (2004) 441–448.
[58] A.P. Adewuyi, T. Adegoke, Exploratory study of periwinkle shells as coarse aggregate in concrete works, ARPN J. Eng. Appl. Sci. 3 (2008) 1–5.
[59] M. Leal Bras, P. Faria, Cement-cork mortars for thermal bridges correction comparison with cement- EPS mortars performance, Constr. Build. Mater. 49 (2013) 315–327.
[60] W. Kinniburgh Short, Lightweight Concrete, 3rd ed., Applied Science Publishers Ltd., London, 1978.
[61] W.T. Kuo, H.Y. Wang, C.Y. Shu, D.S. Su, Engineering properties of controlled low-strength materials containing waste oyster shells, Constr. Build. Mater. 46 (2013) 128–133.
[62] ASTM C55 − 11, Standard Specification for Concrete Building Brick, ASTM International, West Conshohocken, PA, 2011.
[63] BSR - Building schedule of rates, Engineering Organization Western Province - Provincial Council, Sri Lanka, 2016.
[64] J.K. Prusty, S.K. Patro, S.S. Basarkar, Concrete using agro-waste as fine aggregate for sustainable built environment – A review, Int. J. Sustain. Built Environ. 5 (2016) 312–333.