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RICE STRAW-CEMENTITIOUS BRICKS: ANALYTICAL STUDY ON MECHANICAL PROPERTIES AND SUSTAINABILITY MEASURES

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ABSTRACT

The methods for disposing of the straw remaining in the fields after rice harvest are either burning or baling. Due to the lack of adequate baling machines available to serve most farmers, burning is still the principal disposal method for most of the rice straw residue, as it is efficient, effective and cheap, even after being phased out in the Egyptian law of Environment number 4-1994. As a result most farmers tend to burn the straw in open fields, boosting air pollution and serious human health problems. This research studies the recycling of rice straw in order to produce sustainable light weight cementitious-straw bricks. An experimental and analytical study on the mechanical properties and sustainability of the produced bricks were carried out. Several proportions of rice straw were examined in the production of the brick to reach the best mix proportions under compression strength according to the Egyptian codes of building. It was concluded that the maximum compressive stress values for the cementitious- rice straw bricks increased by decreasing the chopped rice straw content to a value of 40 kg/ 1000 bricks using the same quantity of cement with almost the same amount of fine aggregate. To the contrary, the sustainability measures improved while increasing the amount of rice straw used to substitute the aggregates.

Keywords: cementitious - rice straw brick, agro- wastes recycling, chopped rice straw, sustainability measures.

RESEARCH SIGNIFICANCE AND OBJECTIVES

Rice is one of the major field crops in Egypt. The UN's Food and Agricultural Organization (FAO) has estimated Egypt rice production for 2014 at around 6 million tons (4.14 million tons, basis milled) [1]. These amounts of rice resulted in huge amounts of rice straw as an agricultural residue - over 4 million tons annually - which are highly accused as the most environmental pollutant in Egypt. Although great attempts have been made to use this residue in different industrial needs, yet the remaining amounts tend to cause great problem to the Egyptian Government due to its burning which was phased out in the Egyptian law of Environment number 4-1994 [2].

This paper presents a comprehensive experimental study on the compression strength of a cementitious rice straw brick as compared to a local commercial cement brick. In addition, a sustainability analysis is conducted on the technically passed types of bricks in order to study the feasibility of recycling rice straw - as an agro-waste material - in the civil engineering industry.

The objective of this research is to study the effect of using different percentages of chopped rice straw on the cementitious brick mix. The research studied both the compressive strength and the sustainability of the produced bricks as compared to the commercial cement brick.

EFFORTS TO USE AGRO-WASTE SUSTAINABLE MATERIALS IN THE CONSTRUCTION INDUSTRY

General overview

Sustainability is one of the main focuses of the recent international housing development strategies. At present, vast majority of housing units are reinforced concrete structures with either bricks or cement block infill. [3]. The application of agro-waste for sustainable construction materials provides a solution which offers reduction in natural resource use as well as energy.

Various agro-wastes materials in different proportions were used to produce sustainable construction materials and composites such as particle boards, thermal insulated wall and ceiling panels, bricks, cementitious pozzolana for concretes [3].

In Egypt, Mansour *et al* (2007) recycled a cellulous non wood fibrous material - rice straw - by mixing it with various proportions of cement to form sustainable low cost building materials. The main aim was to reduce atmospheric pollution caused by burning rice residuals. In addition to these benefits, the straw acted as a thermal insulation material for the unpleasant Egyptian weather [4].

Wang and Wu (2013) prepared rice straw coke powder with high carbon content from rice straw using steam carbonization. The physical and chemical properties of the coke powder were measured. The results obtained from this study proved that the addition of rice straw coke could be effective at enhancing the equivalent strength of cement mortar [5].

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Padkho (2012) used rice straw and shell corn as raw materials to develop light wallboard products from agricultural waste. The benefit was to produce a construction material which had no pollution to the environment and earned income for farmers in local communities that grow economic plants using materials from rice straw. It was concluded that mixing the agricultural waste in different ratios and proportions can produce light, heat insulation wall panels used for buildings [6].

Rice husk ashes (RHA) were utilized as a cement replacement material or as a pozzolana with lime/cement to suggest a sustainable option for rural housing. The test results indicated that optimum quantity of RHA increases the mechanical properties of concrete [7, 8]. Another study investigated the possibility of making composite materials by recycling waste tires and rice straw to manufacture insulation boards in construction. The produced rice straw-waste tire particle composite boards had better flexural properties than wood particleboard, insulation board, fiber board, plywood and various other construction materials [9].

Research attempts on brick and block production

Ling and Teo (2011) had developed the bricks from the waste rice husk ash (RHA) and expanded polystyrene (EPS) beads. RHA was used as partial replacement for cement while EPS was used as partial aggregate replacement in the mixes. It was found that the properties of the bricks were mainly influenced by the content of EPS and RHA in the mix and also the curing condition used [10].

Raut *et al*., (2011) reviewed various waste materials in different compositions that were added to the raw material at different levels to develop waste-create bricks (WCB). Various physico-mechanical and thermal properties of the bricks incorporating different waste materials were reviewed. Enhanced performance in terms of producing lighter density, lower thermal conductivity and higher compressive strength of the various WCB gives an economical option to design the green [11].

Chiang *et al.* (2009) produced the lightweight bricks from the sintering mixes of dried water treatment sludge and rice husk. Samples containing up to 20 wt. % rice husks had been fired using a heating schedule that allowed effective organic burn-out. It was observed that addition of rice husk below 15 wt. % and sintered at 1100 _C produced the low density and relatively high strength bricks compliant with relevant Taiwan standards for lightweight bricks [12].

Lertsatitthanakorn *et al*. (2009) had developed rice husk ash based sand–cement block. Its performance was compared with that of a standard commercial clay brick. It was concluded that the RHA based sand-cement block reduces solar heat transfer by 46 W [13].

Akmal (2006) conducted a preliminary simple laboratory study on preparing and examining the compression stress on several mix proportions to produce a straw- cement brick to be used as a filling block in the skeleton traditional building technique [14].

MECHANICAL COMPRESSIVE STRENGTH TEST

Materials used

The cementitious rice straw bricks were produced using a mobile semi- mechanized egg-laying machine with vibrator and steel manual moulds. The standard brick size was 25 × 12 × 6 cm. Those units were made of cementitious mixes that were placed into steel moulds, vibrated and compacted, then de-molded and cured. Ordinary Portland cement (OPC) from local market was used to produce all the bricks samples. Fine aggregate siliceous sand with a maximum size of 5 mm was well graded and freed from impurities. The coarse aggregate with maximum nominal size of 10 mm was used. Chopped straw with a length ranging between 1.5- 2.5 cm was used in the mixes with various proportions. Table-1 presents the constituents of the three mixes of the cementitious rice straw bricks as compared to the local commercial cement brick.

Table-1. Mix components and proportions of rice straw-cement bricks.

Type of mix			Cement	Fine aggregate		Coarse aggregate		Chopped rice straw
			ton	m^3	ton	m^3	ton	ton
Group 1	Commercial	Cement brick	0.5	0.90	1.47	0.90	1.44	0.00
Group 2	Rice Straw-Cementitious	Mix type (A)	0.4	0.90	1.47	0.90	1.44	0.04
		Mix type (B)	0.4	0.85	1.39	0.40	0.64	0.07
		Mix type (C)	0.4	0.85	1.39	0.20	0.32	0.09

Sample casting and curing

Coarse and fine aggregates were batched by volume using wooden boxes with the desired volume. Cement was added by weight using whole bags of 50 kg to ensure uniform proportions of mix. The chopped rice straw was added to the mixture according to the

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previously mentioned quantities. The dry mixes were batched outdoors in rotating power-driven resolving mixer of 100 litres capacity before adding water. Then the bricks were molded and vibrated using 'egg-laying' mobile machines and then de-molded immediately after compaction. The samples were carried away on pallets to the curing place and they were regularly sprayed with water twice a day for a period of 7 days to gain sufficient strength. From visual inspection, it was clear that mix C with the highest straw content 90 kg was non-consistent. Accordingly, bricks of mix (C) were excluded.

Experimental testing and results

For each mix of the rice-straw cement bricks A and B, three samples were tested in the laboratory. In addition, three samples of a standard commercial cement brick (Techno Crete Brick) were tested to compare the compression stress of each brick. The dimensions of bricks for each sample tested were checked out for conformance to the size and readability requirements according to the ASTM Standards [15] on which the work was based as follows: C67-07a, C1093-07, and E4-07 and the readings were listed in Table-2. The Shumadsu 1000 KN universal tension- compression machine was used in testing the bricks for compression. After measuring and recording dimensions of each specimen, bricks were placed, one by one, flat wise on the platen of the testing machine. A 0.5 mm/sec rate of loading was applied on each of the specimen shown in Figure-1 until failure and the maximum compression loads were recorded.

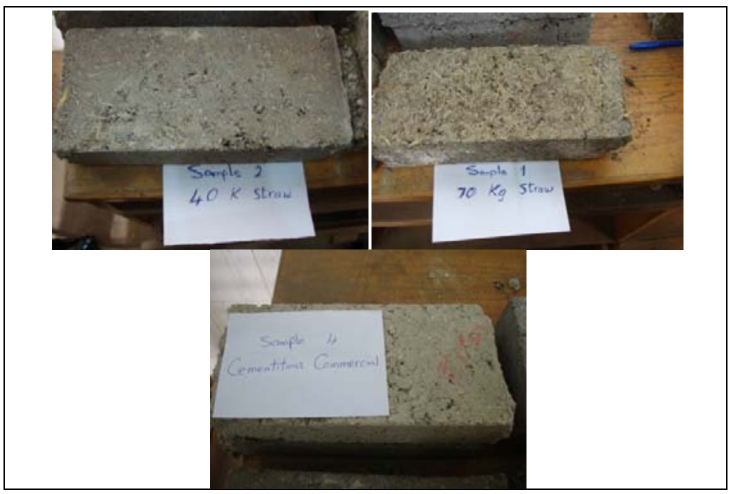

Figure-1. Rice straw cementitious and commercial cement brick samples under testing.

The compressive strength results were compared to the values specified by the Egyptian Code of Practice ECOP 204-2005 which states that the stress of bricks should not be less than 70 kg/cm^2 for solid cement bricks used for load bearing walls and 25 kg/cm^2 for solid cement bricks used for non-load bearing walls [16].

The maximum compression loads applied on the three mixes showed wide variance. The specimens of mix (B) containing 70 kg/1000 brick of chopped rice straw, showed non homogeneity in its maximum compressive stress values 97.8, 72.5 and 49.0 kg/cm^2 for samples 1, 2 and 3 respectively. These values are considered to be relatively low according to the specified values stated by the Egyptian Code of Practice ECOP 204-2005. This can be due to the partial loss of bond among the mix components as a result of the excessive amount of chopped straw existing in the mix.

The maximum compressive stress values for specimens of mix (A) increased by decreasing the chopped rice straw content to a value of 40 kg/1000 bricks using the same quantity of cement with almost the same amount of fine aggregate. The maximum compressive stress values for mix (A) were 114.4, 116.7 and 113.6 kg/cm^2 for samples 1, 2 and 3 respectively showing homogeneity in its results. These results are considered relatively higher than the values obtained in Garas *et al*. [17], which reached stresses of 36.6kg/cm^2 for the same mix (A) proportions produced by a different supplier. This could be due to the lack of quality control measures and inadequate curing time. Standard commercial samples obtained from the local market were considered to be very homogeneous with maximum compressive stress values of 177.9, 204.3 and 177.6 kg/cm^2 for samples 1, 2 and 3 respectively.

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Table-2. Brick samples (Dimensions and compression test results).

Mix type	Sample No.	Dimensions (cm)			Max. load (ton)	Max. stress (Kg/cm^2)
		length	width	height		
Mix (A)	1	25.5	12.0	5.9	35	114.4
	2	25.7	12.0	6.0	36	116.7
	3	25.9	11.9	6.0	35	113.6
Mix (B)	1	26	11.8	6.0	30	97.8
	2	25.5	11.9	6.1	22	72.5
	3	25.5	12.0	6.0	15	49
Commercial Sample	1	25.5	11.9	6.0	54	177.9
	2	25.7	12.0	5.9	63	204.3
	3	25.8	12.0	5.9	55	177.6

SUSTAINABILITY ANALYSIS

Introduction

A Sustainable Decision Support System (SDSS) by Bakhoum and Brown [18] was used to study and analyze the sustainability of the three brick types under study (Cement Commercial brick, cementitious rice straw Brick type "A" and Brick type "B").

Sustainable decision support system (SDSS) evaluates the sustainability of alternatives using a developed sustainable scoring system based on life cycle assessment technique. In addition, ranking and selecting alternatives based on the sustainability scores depends on Multi-Criteria decision analysis methods [19, 20]. SDSS considers three phases of materials life cycle for sustainability evaluation: manufacturing, construction and demolition. However, in this study the manufacturing phase only was considered in the system due to the similarity of the alternatives through the other two phases.

SDSS includes a developed flowchart of ten sustainable factors - with their indicators - that cover the four aspects of sustainability (environmental, economic, social and technological) during the total life cycle of the material. The factors are divided into two groups; each group has five sustainable factors as follows:

- **Group (1):** Sustainable Factors related to structural element design including climate change, pollution, energy consumption, resource consumption and waste, and cost.
- **Group (2):** Sustainable Factors related to general material properties including recyclability, local economic development, health and safety, human satisfaction, and practicability.

Elements of alternatives under sustainability study

The components and weights of the three alternatives under the sustainability study: cemented brick, brick type "A", and brick type "B" are presented in table (1). The studied element is a brick wall of 18 m^2 (1000 bricks) of each alternative. The weight of the wall is 3400, 3300 and 2100 kg for the cement brick, brick type (A) and brick type (B) respectively.

Data collection and assumptions

Group (1): Sustainable factors related to structural element design

Life Cycle Inventory (LCI) data for alternatives' components (cement, aggregate, rice straw) were collected from different sources to fulfill the required input data of the first group of SDSS factors for manufacturing phase as indicated:

a) Climate Change includes global warming (embodied CO_2 is an indicator to measure it)
b) Pollution includes air pollution and acidification (DALY index and acidification index are indicators to measure them respectively)
c) Energy Consumption (initial embodied energy is an indicator to measure it)
d) Resources and Waste includes raw materials consumption and solid waste (weight of raw materials consumption and solid waste generated through manufacturing are indicators to measure them respectively)
e) Cost (market price is an indicator to measure it)

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Table-3 presents the collected LCI data of CO_2, SO_x, NO_x, particulates, embodied energy, raw material consumption and solid waste for used materials. Data was based on the results of different sources: reports of Portland Cement Association (PCI), Athena Sustainable Materials Institute, and concrete centre [21-23], Fact Sheet of National Ready Mixed Concrete Association [24], BEES Technical Manual and User Guide of National Institute of Standards and Technology [25], Published paper by Baird, *et al* [26], and SPINE database [27]. Average values were considered for the different sources' values of the same indicator.

Rice straw is a waste material, therefore, it was assumed that it has no emissions, energy, or waste for manufacturing phase. Cost of all materials is based on actual market price in Egypt.

Table-3. Life Cycle Inventory (LCI) data for used materials.

Indicator	Unit	Cement	Aggregate	Rice straw
CO_2	Kg/ton	852	3	0
SO_x	g/ton	635	1	0
NO_x	g/ton	2069	8	0
Particulates	g/ton	2152	101	0
Energy	MJ/ton	4641	41	0
Raw material consumption	Kg/ton	1602	1000	0
Solid waste	Kg/ton	17	0	0

Group (2): Sustainable factors related to general material properties

Data for alternatives' components (cement, aggregate, rice straw) were assumed to fulfill the required input data of the second group of SDSS factors for manufacturing phase as indicated:

f) Recyclability includes recycled content is an indicator to measure it.

g) Local Economic Development includes locality and employment (local material/equipment and contribution to employment and skills improvement are indicators to measure them respectively)

h) Health/Safety includes health and safety (environmental quality and safety against labors accidents are indicators to measure them)

i) Human Satisfaction includes climate/culture and noise/vibration (appropriateness for climate "habitability" and level of noise and vibration insulation are indicators to measure them)

j) Practicability includes constructability and resource depletion (degree of off-site manufacture and renewability of resources are indicators to measure them)

It was assumed that rice straw - as a waste material - has 100% recycled contents. Virgin aggregate and cement had no recycled components. Therefore, the recycled content of cement and/or aggregate was considered 0%. All materials used are local materials. Therefore, the proportion of locality and employment sub-factors were assumed to be 100% for all materials.

Rice straw is better than traditional materials for indoor insulation by 15% [28]. Therefore, the proportion of environmental quality and appropriateness for climate were assumed 100% for rice straw and 85% for cement and aggregated. The proportion of safety, level of noise and vibration insulation as well as degree of off-site manufacturing was assumed 100% for all used materials due to the similarity. As rice straw is the only the renewable material used, its renewability was therefore assumed to be 100%. For other materials, it was assumed 0%.

Sustainability study results and discussion

Based on estimated materials' quantities and collected/assumed data for used materials, the SDSS was used to study the sustainability of three elements of alternatives (cemented brick wall, brick type "A" wall, brick type "B" wall).

In order to prepare a reliable sustainability analysis, the study was performed on four steps:

- **Step 1:** Sustainability analysis considering all SDSS factors (i.e., ten factors). System default weights of factors were considered.

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- **Step 2:** Sustainability analysis considering the first group of SDSS factors (i.e., five factors related to the element design). Equal weights of factors were considered.
- **Step 3:** Sustainability analysis considering the second group of SDSS factors (i.e., five factors related to general material properties). Equal factors weights were considered.
- **Step 4:** Sustainability analysis considering each factor from the first group of SDSS factors (i.e., each factor - separately - from five factors related to the element design). In each process, weight of considered factor was 100%.

Step 1: Sustainability analysis considering all SDSS factors

The results showed that the overall sustainability ranks are 53.96%, 54.66%, and 55.66% based on the SDSS measurement scale as presented on Figure-2(a). It means that the brick type (B) is better than both cement brick and brick type (A) by 1.7% and 1.0% respectively. In addition, brick type (A) is better than cement brick by 0.7% as presented on Figure-2(b).

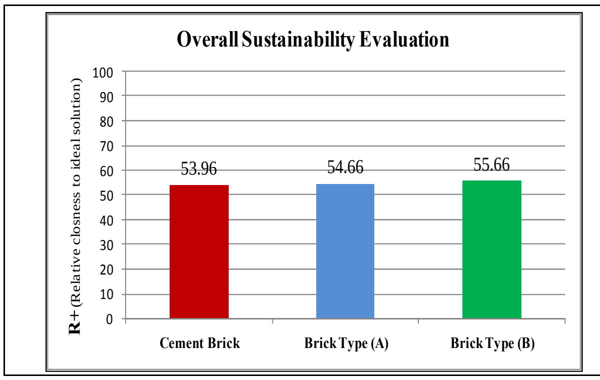

Figure-2(a). Sustainability ranks considering all SDSS factors.

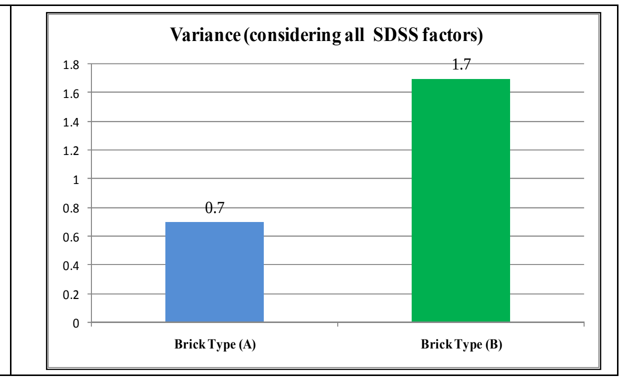

Figure-2(b). Increase of bricks types (A) and (B) than cement brick considering all SDSS factors.

Step 2: Sustainability analysis considering the first group of SDSS factors

The results showed that the sustainability ranks are 90.01%, 90.90%, and 93.84% based on the SDSS measurement scale as presented on Figure-3(a). It means that the brick type (B) is better than both cement brick and brick type (A) by 3.83% and 2.94% respectively. In addition, brick type (A) is better than cement brick by 0.89% as presented on Figure-3(b).

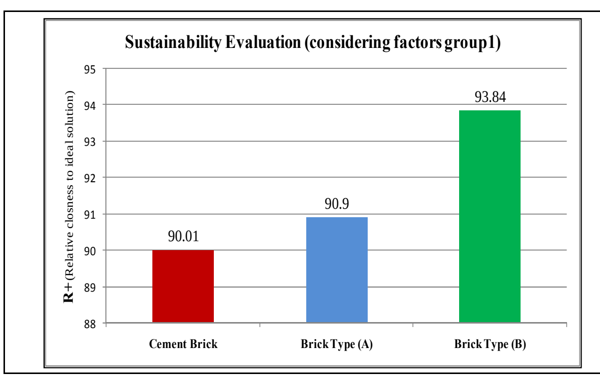

Figure-3(a). Sustainability ranks considering first group of SDSS factors.

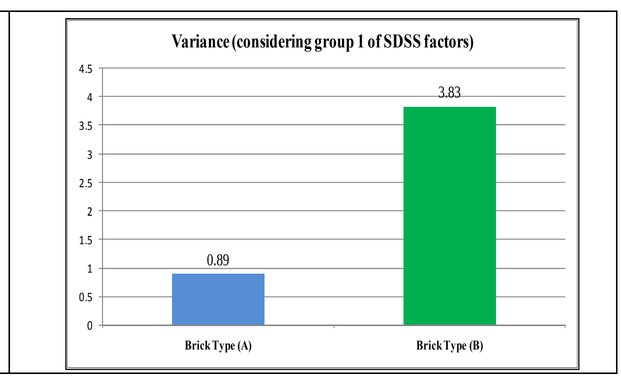

Figure-3(b). Increase of bricks types (A) and (B) than cement brick considering first group of SDSS factors

Step 3: Sustainability analysis considering the second group of SDSS factors

The results showed that the sustainability ranks are 46.72%, 47.33%, and 48.15% based on the SDSS measurement scale as presented on Figure-4(a). It means that the brick type (B) is better than both cement brick and brick type (A) by 1.43% and 0.82%, respectively. In

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addition, brick type (A) is better than cement brick by 0.61% as presented on Figure-4(b).

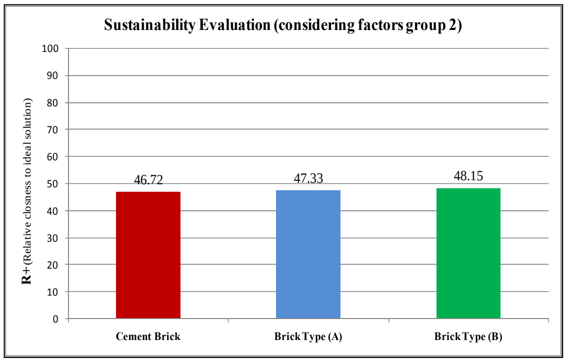

Figure-4(a). Sustainability ranks considering second group of SDSS factors.

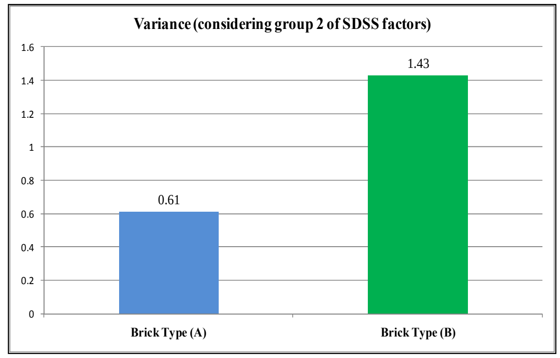

Figure-4(b). Increase of bricks types (A) and (B) than cement brick considering second group of SDSS factors.

Step 4: Sustainability analysis considering each factor from the first group of SDSS factors

Climate change factor

The results showed that the sustainability ranks are 95.1%, 96.1%, and 96.7% based on the SDSS measurement scale as presented on Figure-5(a). It means the brick type (B) is better than both cement brick and brick type (A) by 1.60% and 0.60%, respectively. In addition, brick type (A) is better than cement brick by 1.00% as presented on Figure-5(b).

Pollution factor

The results showed that the sustainability ranks are 94.07%, 95.22%, and 96.04% based on the SDSS measurement scale as presented on Figure-5(a). It means the brick type (B) is better than both cement brick and brick type (A) by 1.97% and 0.82%, respectively. In addition, brick type (A) is better than cement brick by 1.15% as presented on Figure-5(b).

Energy consumption factor

The results showed that the sustainability ranks are 97.76%, 98.21%, and 98.50% based on the SDSS measurement scale as presented on Figure-5(a). It means the brick type (B) is better than both cement brick and brick type (A) by 0.74% and 0.29% respectively. In addition, brick type (A) is better than cement brick by 0.45% as presented on Figure-5(b).

Resources and waste factor

The results showed that the sustainability ranks are 81.55%, 82.61%, and 88.79% based on the SDSS measurement scale as presented on Figure-5(a). It means the brick type (B) is better than both cement brick and brick type (A) by 7.24% and 6.18% respectively. In addition, brick type (A) is better than cement brick by 1.06% as presented on Figure-5(b).

Cost factor

The results showed that the sustainability ranks 91.25%, 92.62%, and 94.35% based on the SDSS measurement scale as presented on Figure-5(a). It means the brick type (B) is better than both cement brick and brick type (A) by 3.1% and 1.73%, respectively. In addition, brick type (A) is better than cement brick by 1.37% as presented on Figure-5(b).

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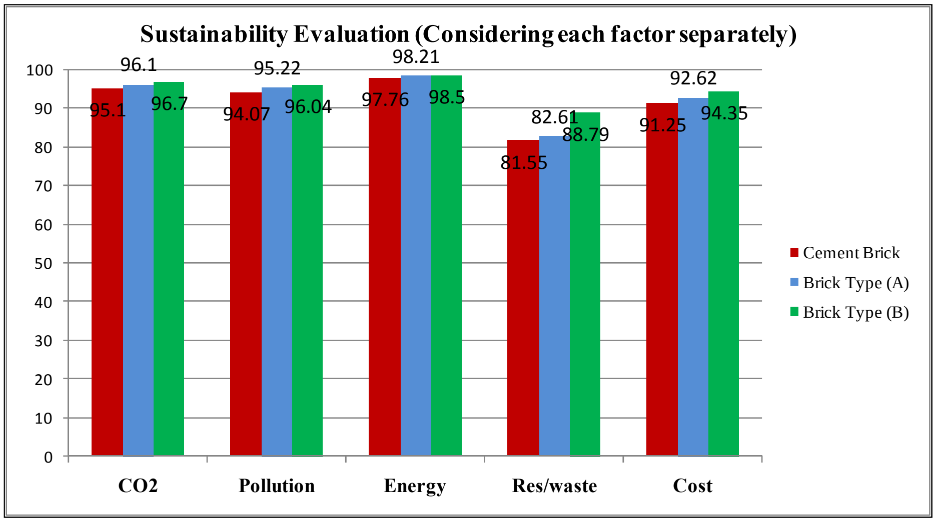

Figure-5(a). Sustainability ranks considering each factor from the first group of SDSS factors.

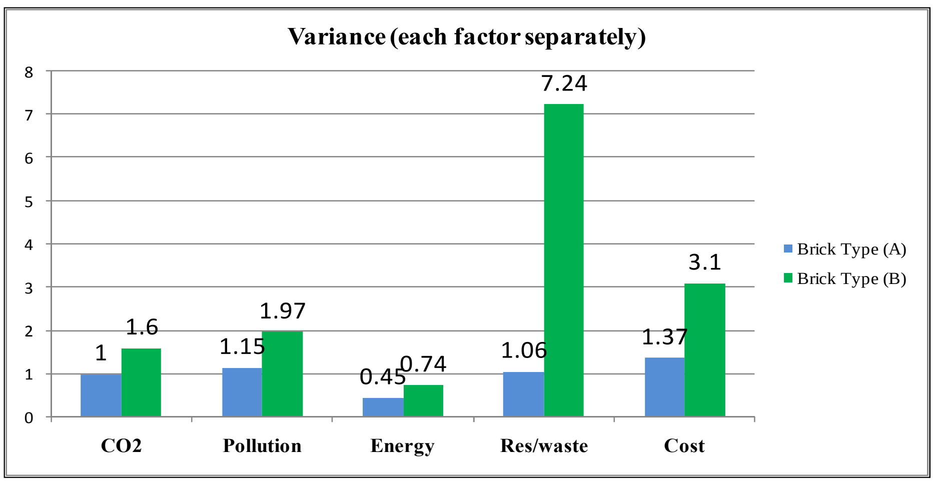

Figure-5(b). Increase of bricks types (A) and (B) than cement brick considering each factor from the first group of SDSS factors.

Based on the above presented results, it is clear that - in all steps of the study - brick type (B) had higher sustainable scores than both brick type (A) and cemented brick. In addition, brick type (A) had higher sustainable scores than cemented brick. The reasons can be summarized as follows:

- The weight of cement brick (3.4 kg for one brick) is more than brick type "A" (3.3 kg for one brick) and brick type "B" (2.1 kg for one brick) as stated in Table-1.
- Cement brick has a quantity of cement more than brick type "A" and brick type "B" - as stated in table (1) - which reduces the sustainability scores due to its high environmental emissions, energy consumption and cost.
- Brick type "B" has a quantity of rice straw more than cement brick and brick type "A" - as stated in table (1) - which increases the sustainability scores due to its better recyclability, renewability, indoor insulation, cost, and less environmental emissions, energy consumption and resource consumption.

It can be noticed that when considering the first group of SDSS "Step 2", the increase in sustainability scores values for brick type "B" than both cement brick and brick type (A) by 3.83% and 2.94%, respectively (Figure-3b). These values exceed than the scores recorded

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when considering the second group of SDSS "Step 3" which are 1.43% and 0.82% (Figure-4b). It can be referred to the effects of environmental emissions, energy consumption, resource consumption, and cost as well as the lower weight of brick type "B" which is linked to the first group of SDSS factors.

Results of step (4) - when considering each factor separately showed that the bigger difference in sustainability between brick type "B" and cement brick appears when considering the factor of resource consumption and solid waste (7.24%) then the cost factor (3.1%). In addition, the bigger difference in sustainability between brick type "A" and cement brick appears when considering the cost factor (1.37%) then the pollution factor (1.15%). Conversely, the lower difference between bricks types "A", "B" and cement brick appears when considering the energy consumption factor (0.74% and 0.45%, respectively) as presented in Figure-5(b).

CONCLUSIONS

The following conclusions can be drawn from this study:

- Addition of 90 kg of chopped rice straw per quantities of materials required to produce 1000 bricks (25×12×6 cm) adversely affects the bond strength of the bricks produced. It was noticed that after 7 days curing time, the bricks seem to be very week and need additional time for curing and setting.
- Optimizing the amount of chopped rice straw to 40 kg/1000 brick gives a maximum compressive stress of 115 kg/cm^2 which is considered to be reasonably adequate for building purposes. In addition, the bricks' curing period does not exceed 7 days.
- High insulation properties of rice straw adds another indirect cost saving value for using chopped rice straw- brick instead of traditional local market product.
- Sustainability analysis study showed that the sustainability scores increased by using rice straw in the mix of the cementitious bricks when compared to the commercial cement brick.
- Despite the increase of sustainability scores for the rice straw bricks than the local cementitious brick, these values were low due to the small proportions of rice straw in the bricks types "A" and "B" which present 1.19% and 2.8% of the total weight of the bricks respectively.
- The biggest difference in sustainability scores appeared in the factors of resource consumption and solid waste, cost, pollution and climate change respectively within a range from 7.24% to 1.00%. Conversely, the lowest difference appeared in the energy consumption factor (0.45 to 0.74%).

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