Consuming Agricultural and Industrial Wastes in Manufacturing Eco-Friendly Bricks

Atif Moussa Ibrahim[1] and Nazeer Mohamed El-Bialee[2]*

[1]Lecture of Agric. Eng. Faculty, Al-Azhar Univ. Cairo. Egypt.
[2]Senior Researcher of Agric. Eng. Inst. (AEnRI)., Agric. Res. Center (ARC)., Giza. Egyp.

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Abstract: *Egypt, produce about 1.35 and 5 Tg., of sugarcane bagasse "SB" and cement kiln dust "CKD" as a solid waste and by-products from sugarcane and cement industries. Adding economical value of these wastes by incorporating them, as green construction materials, is an efficient method to diminish the environmental pollution, and protect the raw materials from depletion, leading towards sustainable and economical solution. The experiment was carried in order to create a new mix, to produce eco- friend bricks, by incorporated "SB" at different sizes "PS" + CKD in different ratio, with main components of cement bricks mixture. Bulk density "ρ" and superficial density "ρ_S", sound insulation "S_i", expansion rate "E_p", water absorption "W_A" and initial rate of absorption "IRA", and compressive strength "δ" of these bricks were evaluated. Increasing sugar cane bagasse replacement percentage "SBrp" and "PS" reduced bricks "ρ" and "S_d", and increasing "S_i", resulting in lighter bricks with more soundproofed. Both "E_p", "W_A" and "IRA" were increased by increasing "SBrp" and "PS". So, all bricks can be effectively used as moderate weathering resistant, except only bricks with 10 and 15%., of SBrp at PS2, also, all bricks must be wetted before laying to avoid water suction from past of cement mortar, except specimen with 5%., SBrp at PS1. Thus, all bricks are accepted as non-carrying building bricks, and as carrying bricks (for load bearing), except bricks with 5%., of SBrp at PS2.*

Key words: Bagasse, CKD, densification parameters, sound insulation, and suction behavior.

1. Introduction

Agricultural and industrial activities are generating increasing in quantity and a variety of wastes and by-products. Agro-wastes are rich in organic matter with biodegradable nature. Adding an economic value of different wastes by recycling them, as a sustainable construction material appears to be a viable solution not only to the pollution problem, but also the problem of increasing landfill costs, increase the revenues and enhance the environment, and high cost of building materials [1, 2].

Egypt produces about 15.26 Tg., of sugarcane that in turn gives about 1.35Tg., sugarcane bagasse "SB" as solid waste from the sugar cane refining process [3,4]. Where, cane stalk is crushed in sugar mills, generating bagasse as waste left after crushing [5]. Bagasse fiber performs similarly to hardwood fiber [6,7]. In fact, the SB is considered either as a waste, utilizing as biofuel in the industries, resulting in sugarcane bagasse ash (SBA). Ashes are disposed of in landfills or into the river, causing very harmful for the environment, fertile land, water sources over and above, our health [8]. Also, it can use as a resource when appropriate valorization technologies are implemented [9], due to their low or zero cost, easy availability and their potential properties, i.e., high porosity, low self-weight, very high specific surface area, and noise isolation [10]. Therefore, it considered suitable materials for produce high-valued product i.e., paper, bio-based products, particleboards, and sustainable fibers [11, 12].

On the other hand, cement production is one of the most important industries, responsible for the generation of huge by-products (solid waste) like cement kiln dust (CKD) or bypass. It is a fine powdery material (grayish in color) similar in appearance to Portland cement, consists predominately of micron silt-sized, non-plastic particles [13,14]. Fresh CKD can be classified as belonging to one of four categories, depending upon the kiln process used, i.e., wet-process, and dry-process [15] and the degree of separation in the dust collection system, i.e., part of the dust can be separated and returned to the kiln by a cyclone, or total quantity of generating dust recycled or discarded [16]. About 5Tg., of CKD is produced annually in Egypt as a byproduct, that can spread over a large area through the wind, becoming accumulated in plants, animals, and soils, and consequently negatively affecting the environment and human health [17,18]. Eliminated of CKD in the environment typically in landfill causing direct contamination of soil due to metals, contaminating groundwater resources as well, became a significant threat to surrounding superficial environment [19]. At many facilities all or a major portion of CKD is recycled back into the kiln to supplement the raw feed or reused this byproduct material is to reciprocate it in the cement making process [20]. One of the most common beneficial uses of CKD is a soil stabilization by improving soil properties, as an activator in pozzolanic stabilized base mixtures, reducing moisture content and increases the bearing capacity of the soft soil, and also to reduce construction time and costs [21]. As well, it is used as a raw material for cement production like vitrified sewer pipes [22] and its use as a component in cement mortar/concrete (Building walls) and bricks [23]. The beneficial uses of CKD include using it in asphalt road pavement applications in the highway construction industry as a filler material mixed with asphalt [24], also as filters in removing color, turbidity, organic substances, heavy metals from textile wastewater, and removal of direct dyes from an aqueous solution [25].

Therefore, incorporating agricultural and industrial waste materials (SB and CKD) in green construction materials is an efficient method to diminish the environmental pollution, reduce the amount of generating wastes and protect the raw materials from depletion, leading towards a sustainable and economical solution.

Officially, the term brick is used to denote a building unit made of shaped clay, which they are the classic form of a brick. Brick created by pressing wet clay into molds, then drying and firing them in kilns. It is a very old building material found in many of the ancient structures of the world dated back to Indus valley civilization (2500–1500BCE) [26]. Nevertheless, in modern times brick is used to refer to any stone- or clay-based building unit that is joined with cementations mortar when used in construction. Common bricks are categorized according to their component materials and method of manufacture into five common types; burnt clay bricks, sand-lime bricks (calcium silicate bricks)**,** concrete, bricks**,** fly ash clay bricks **(**self-cementing**),** and Firebrick **(**refractory bricks**).**

In Egypt, burnt clay bricks (clay from the Nile River) are considered one of the most basic building materials, until recent decades. However, the annual renewal of clay from river flooding ceased with the construction of the darn at Aswan, and because of the necessity of retaining the arable land along the Nile for agricultural purposes. Nile clay rapidly became unsuitable for brick production and the Egyptian Government placed a ban on its use for that purpose, by the promulgation of Law No. 116/1983 which criminalizing the use of clay in brick production to counter threats caused by the erosion of the agricultural area. On the other hand, a large demand has been placed on building material industry (consequently for brick, increased accordingly) owing to increasing population rapidly and housing demand needs, that causes a chronic shortage of building materials, excessive usage of the earth materials, massive depletion and also high energy consumption which is destroying natural resources. There is an exponential need for produce and encourage alternative construction materials like eco-friendly bricks to construct green buildings [27, 28]. Several efforts were made to convert agro-waste to eco-friendly bricks [29, 30, 31].

In the light of the above, this research aimed to create a new mix by incorporated SB + CDK in different ratio in order to produce green construction material (eco-friendly bricks) and studied their characterizes in terms of densification parameters [bulk density "ρ" (kgm^{-3}), and superficial density "ρ_S" (kgm^{-3})] sound insulation, resistance to water penetration [expansion rate "E_p"(%), water absorption "W_A"(%), an initial rate of absorption "IRA" (gcm^{-2}min^{-1}), and compressive strength "δ"(Nmm^{-2}).

2. Materials and Methods

The experiment was carried out at laboratory of Agic. Eng. Fac., Al- Azhar Univ., Cairo, Egypt. Base materials for the specimen brick manufacturing are made from a mixture of locally cement, sand, hydrated lime, and wastes i.e., bypass, sugarcane bagasse, and sugarcane bagasse ash. Cement is a main binding material. Ordinary Portland Cement "OPC", type "CEM I" - 42.5 N Grade - with the commercial name of "Tourah", is used. It is manufactured as described in Egyptian Standards [32], which satisfied the quality requirements of [33].

Fine mine sand "S", spherical and clean (liberate from clay, loam, dirt and any organic or chemical matter), was well graded. The average sand particle size was below 5mm., where, 100%., passing through 4.75 mm., mesh sieve, liquid limit ≤ 45%., and plasticity index ≤ 18% with bulk density ≈ 1640 kgm^{-3}., while, the moisture content recorded was 2.36%. Consequently, it is deemed suitable for brick production. It was complying with the requirements of [34].

Hydrated lime "HL" available in the market and satisfied the quality requirements of [35], was used for manufacturing work.

Cement Kiln Dust "CKD" or bypass is a fine powder like material made up of particles that are relatively uniform in size. The chemical composition of CKD depends on the raw materials used to produce the clinker and on the type and source of the carbon-based fuel used to heat the material in the rotary kiln.

Sugarcane bagasse "SB" is the cellular fibrous waste product after the sugar juice extraction, acquired from a different sugar mill with about 48~50%., moisture content "MC". Then, spread on the floor to sun-dried for two weeks, to solidify the bagasse, till a final humidity of 5% (wet basis). Subsequently, the SB was ground to powder by hammer mill machine and sieved into two particle sizes "PS1" (≤ 2.8mm) and "PS2" (2.8 ≤ PS_2 ≤ 4mm) which used in the experiment (Fig.1).

It contains approximately 52.62%., of cellulose, 25.8%., of hemicellulose, 20.23%., of lignin and 1.35%., of ash. Chemical composition determined according previously described by [36].

Sugarcane bagasse ash "SBA" was obtained by burning well-dried bagasse in an open environment and then cooling. Fine pure ash was sieved and has been protected in tightly glass containers to avoid dampness ingestion and other pollution. The chemical composition of OPC, S, HL, CKD and SBA were investigated in Housing and Building National Research Center (HBNRC) and tabulated hereinafter in Table 1.

PS1 ≤2.8 2.8 ≤ PS2 ≤ 4 mm.,
Fig-1: SB particle sizes.

Water was used to mix the materials. It helps to activate the chemical reaction in the cement and with other materials and forms cement gel. Fresh, colorless, odorless, tasteless, free of acids, organic matter, suspended solids, alkalis and impurities with PH value of 7.0 confirming to [37], was used for curing specimen. It was collected from the pipe borne water by Holding Company for Water and Wastewater "HCWW. The chemical composition of water was analyzed in the central laboratory of Soil, Water and Environment Research Institute "SWERI" and recorded in Table 2.

Table- 1: Chemical composition of raw materials.

Oxides	Cement "OPC" (%)	Sand "S" (%)	Hydrated lime "HL" (%)	Cement kiln dust "CKD" (%)	Sugar cane bagasse ash (SBA) (%)
SiO_2	20.29	93.32	2.88	13.75	65.77
Al_2O_3	5.40	0.51	5.4	3.8	16.12
Fe_2O_3	2.66	0.84	0.25	2.16	13.06
CaO	64.17	0.49	62.58	49.8	2.41
MgO	1.5	1.62	1.006	1.7	1.53
Na_2O	0.47	0.09	0.6	1.59	----
K_2O	0.12	0.87	0.12	2.75	----
P_2O_5	0.05	0.05	0.01	----	----
SO_3	2.93	0.03	0.534	1.85	1.11
*IR	1.05	----	----	1.5	----
**LOI	1.36	2.18	26.62	21.1	----
*I R: Insoluble residues ,				**LOI: Losses on Ignition	

Table- 2: Chemical compositions of water

Chlorides (Cl^-)" ppm"	Sulphates "ppm"		Total dissolved salts (TDS) "ppm"	Na_2O + 0.658 K_2O., "ppm"
	(SO_3)	(SO_4)		
12.5	63	21	528.6	22.8

Brick specimen preparation processes include mixing, pressing, and wrapping. The quantities of the materials for each specimen about 2000 g., were batched by weight. About 50% of the overall quantities of constituents were constant mass, such as OPC, S, HL, and SBA, were 360, 300, 100 and 240 g., respectively. As well as, the SB with PS1 and PS2, varied from 5, 10 and 15%., in the other 50%., of quantities and the rest of CKD. OPC, S and HL were mixed beforehand in a laboratory, before they were mixed with SBA and CKD. Later, it mixed with SB manually, on a piece of plywood, using an ergonomic hand trowel, with adding water (550 ml) to prepare the wet mixture. The mixing process takes about 20 min., for each specimen to achieve the homogeneity and to ensure an even dispersion of all the matrix and SB. After mixing, the mixture was poured in a rectangular frame size 250 ×120×100 mm., to make a brick. Then, pressing apparatus (calibrated hydraulic cylinder) used to press out the mixtures, with formation pressure about 76.64 kNm^{-2}., for 30 min. The block diagram below (Fig. 2) illustrates the methodology followed in the manufacturing of eco-brick specimens containing wastes. About 60 pieces of bricks were manufactured and prepared on 6 sample groups, with 10 bricks in each group.

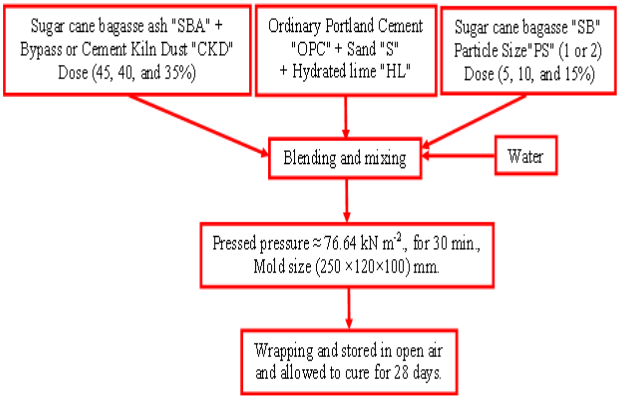

Fig- 2: Eco-friendly brick (specimen) manufacturing methodology.

Every 30 bricks were prepared using different PS (1 or 2) with various ratios of SB contents ranging from 5, 10 and 15%., (Fig. 3). Later, brick specimens were wrapped with a plastic film to avoid rapid drying on timber pallets and marked. The bricks were then stored in open air for 28 days prior to use in the sequence of laboratory tests. Generally, bricks are hardened from a chemical reaction and from mechanical compaction. Chemical reactions occur when the added OPC reacts with other components. When compacted by mechanical force, all components are bonded tightly, decreasing the pore rate of the bricks and increasing their density.

Fig-3: Brick samples.

Afterward, a serious measurement was conducted at room temperature to determine physio-mechanical and functional brick properties, i.e., bulk density "ρ" (kgm^{-3}), superficial density "ρ_S" (kgm^{-2}), sound insulation percentage "S_i"(%), expansion "E_p"(%), water absorption "W_A"(%), initial rate of absorption "IRA" (gcm^{-2}min^{-1}) and compressive strength "δ" (Nmm^{-2}) were executed. The five randomly brick sample dimensions were measured by digital vernier caliper and mass recorded by a digital balance with an accuracy of 0.01g. Then, there were established in the following formula to obtain, ρ and ρ_S as [38, 39].

$$\rho = \frac{M}{V}$$

$$\rho_S = \frac{M}{A}$$

Where, M is mass of sample (kg), V is the volume (= l × w × t, m^3), l is the length (m), w is the width (m), t is the thickness (m) and A is average of surface area (= l × w, m^2). Digital sound level meter, range 50 to 126 dB., with ±2dB., accuracy was used to measure acoustic insulation percentage "S_i" (%) as described by [40]. On the other hand, the E_p, W_A and IRA were calculated according to Heirnafter equations as described [41, 38, 42].

$$E_p = \frac{(t_d - t_w)}{(t_w)} \times 100$$

$$W_A = \frac{(M_W - M_d)}{(M_d)} \times 100$$

$$IRA = \frac{(M_T - M_0)}{(L_2 - L_1)} \times 100$$

Where, t_d is the thickness of oven–dried sample (mm), t_w is thickness of dry sample in air after immersion (mm), M_w is mass of sample after immersion (g), M_d is mass of dried sample (g), M_T is sample mass at time T (g), W_0 is sample initial mass (g), L_1 is sample average length (mm), and L_2 is sample average width (mm). Compressive strength "δ" determined by digital hydraulic UTM (Universal Testing Machine) with accuracy 10 N., as described by [43], and calculated as follows:

$$\delta = \frac{P}{l \times w}$$

Where, P is max. Compressive load, N.
All E_p, W_A, IRA and δ testes were performing in HBNRC labs.

3. Results and Discussion

Sugarcane bagasse replacement percentage "SBrp" (%) and particle size "PS" effects on densification parameters in terms of bulk density "ρ"(kgm^{-3}) and superficial density "S_d"($kg\ m^{-2}$) for manufacture specimen bricks were tabulated in Table 3.

Generally, adding "SB" reduced bricks "ρ"(kgm^{-3}) and "S_d"($kg\ m^{-2}$). The ρ of bricks was ranged from 1060.79 to 1428.92kgm^{-3}. The maximum of ρ values 1428.92 and 1269.47kgm^{-3}., were obtained with 5% of SBrp at PS1 and PS2. Meanwhile, Minimum values 1080.94 and 1060.79 kgm^{-3}., were scored with 15% of SBrp at the same arrangement. With regard to attained results established in Table (3) revealed that both of PS and SBrp had negative effects on ρ of brick. The values of ρ at PS1 were higher than the PS2. Where increasing PS from PS1 to PS2 lead to a reduction on ρ. These reductions were slightly at 10 and 15 %., of SBrp and sharply at 5%., of SBrp. The ρ values of the specimen were declined slightly 1080.94, 1224.16 and 11428.92 kgm^{-3}., at PS1, to 1060.79, 1220.38 and 1269.47 kgm^{-3}., at PS2, i.e., about 1.86, 0.3 and 11.16 %., with 15, 10 and 5 %., of SBrp. These results expected as pressure effect on specimen volume, because the small particle size PS1 can compact, easier than large particle size PS2 and have less pores. [40] was pointed out that ρ values of the specimen, incorporated with small chops are more than large chops. Moreover, increasing of SBrp from 5 to 10 and from 10 to 15%., tended to reduction on ρ (not more 13.08%) where, it decreases about 14.33 and 11.70%., at PS1, and about 3.87 and 13.08%., at PS2. Decreases on ρ of bricks with increasing SBrp (light material) ought to replace the heavier constituent materials, resulted in an increase of the total volume of the mixture even after compaction. Increase compacted mixture volume with decrease bricks mass resulted in a decrease in bricks density. The standard of ρ for sand, silt, clay and cement bricks were 600 to 650, 1130, 1300 to 2200 and 1940 kgm^{-3}., respectively [44,45]. Consequently, based on these references all manufactured bricks were led to classify as a medium-class weight with an acceptable range of standards and within the limit. Therefore, the ρ of brick increase with increasing CKD (%), meanwhile, added more waste inside brick specimen, tended to reduce ρ of specimen, these results corroborated finding of [46,47]. As well, results show that the ρ of concrete, brick decreasing by increased rice-straw percentage [45]. On the other hand, these remarks were conflicted with [48] who noted that ρ of bricks increases with the increase agro-waste content (RHA), and decreased as the amount of CKD used increased.

Table 3: Bricks bulk density and superficial density affected by "SBrp" and "PS".

"SBrp" (%)	"ρ"(kgm^{-3})		"S_d"($kg\ m^{-2}$)	
	PS1	PS2	PS1	PS2
5	1428.92	1269.47	69.52	64.27
10	1224.16	1220.38	66.15	63.78
15	1080.94	1060.79	64.93	63.38

Results of manufacture brick superficial density "S_d" (kgm^{-2}) or weight per unit area with different SBrp and PS were followed similar trends as ρ. It was observed that lighter bricks (63.38kgm^{-2}) can be prepared with 15%., of SBrp at PS2. Meanwhile, heavy bricks (69.52kgm^{-2}) were produced with 5%., of SBrp at PS1. The SBrp values had limited negative effects on S_d at both of PS1 and PS2. For instance, the S_d of the specimen was decreased from 10 to 15%., of SBrp at PS1 and from 5 or 10 to 15%., of SBrp at PS2 almost 1.84, 2.69 and 0.76%., respectively. On the other hand, obtained results showed decreases in S_d of bricks with increasing the SB size. For instance, about 5.72, 2.84 and 1.77 %., reduction in S_d of bricks were observed after increasing PS from PS1 to PS2 at 5, 10 and 15 %., of SBrp respectively. Similar results were reported by [49], they declared that brick specimens showed a reduction in weight per unit area with an increasing amount of agricultural wastes (SBA and RHA) in clay specimens. Bricks mass controlled by raw materials mass and density for agro-waste, the SB was observed in low values of ρ (≈ 258.6 kgm^{-3}) resulting into light mass bricks. Lighter mass bricks are helpful in reducing the structural load, labor cost and transportation cost.

Concerning of SB obtained results reveal that increasing a SBrp from 5 to 10 and 15%., increased a S_i about 2.15 and 1.87%., at PS1 and about 1.31 and 1.52%., at PS2. The values of S_i were directly increased with increase of SBrp. Where, $S_i \approx 30.211(SBrp)^{0.7652} \approx 28.26$ (SBrp) +1.594, with R^2 =1 and 0.9982 for PS1 and PS2. These results are in harmony with those obtained by [50], they concluded that SB panels prove to be a material with potential for addressing sounds acoustics with max. absorption 55db at 800Hz., (Fig.4). On the same line, [51] reported that the natural fiber (coconut fiber and natural latex) composite shows very good noise insulation properties. [5] came to the same conclusion with paddy fiber, rice straw, and bamboo. Conversely, [52], outline that, the SB may insignificantly perform as a good absorption. In general, S_i of PS1 were higher (3.05, 5.2 and 7.07%) than the PS2 (3.04, 4.5 and 5.87%). Where, the decreasing of PS from PS2 to PS1 leads up to increase the S_i about 0.85 to 1.2%., at 10 and 15%., of SBrp. Whilst, there is a little difference on S_i (3.05 and 3.04%) through using any of the PS size at 5%., of SBrp. A similar observation had been marked by [40, 44] who resulted that the S_i value increases with increasing agro-waste for both small and large chops, and it was high at small chops compared with large. In contrast, decreasing of coconut coir fiber size tended to create less void space in between the panel and thus causing it to absorb less sound [53, 54]. From these results, there is a linear negative correlation between S_i and both of ρ and S_d. Where, decreasing a ρ and S_d of bricks (decreasing brick mass) tended to increase the S_i. So, the lighter bricks (2023 and 1984 g) with 15%., of SBrp are more soundproofed (7.07 and 5.87%). Therefore, the heavy weight bricks (2149 and 2022g) with 5%., of SBrp had a poor effect on S_i at both of PS (3.05 and 3.4%). (Data not shown).

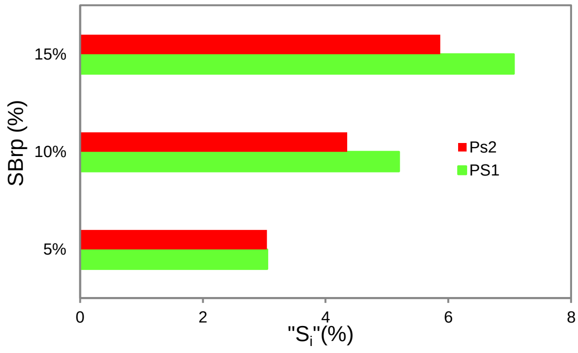

Fig-4: Effects of studied parameters on sound insulation "S_i" (%).

Water based test results was shown clearly resistance to water penetration or bricks suction behaviour in terms of expansion rate "E_p"(%), water absorption "W_A" (%) and initial rate of absorption "IRA" ($gcm^{-2}min^{-1}$) were graphically presented in Figs. 5, 6 and 7.

Expansion rate "E_p" (%) varied from 1.99 to 5.46%., at PS1 and from 6.25 to 10.46%., at PS2. It was affected by increasing SBrp and PS. However, it declines with increase CKD (%) for both PS. Where, increasing CKD (%) from 85 to 90%., and from 90 to 95%., lead to reduced E_p slightly (8.79%) then sharply (60.04%) at PS1, and decline about 23.61 and 21.78 %., at PS2. Moreover, PS of SB had an excited effect on E_p at different SBrp, where, using PS1 as an alternative of PS2 lead to decline the E_p values sharply about two-third (68.16%) and one-half (47.80%) at 5 and 15% of SBrp, whereas, only one-third (26.45%) reduction occurred at 10% of SBrp, [40] came to the same conclusion (Fig. 5).

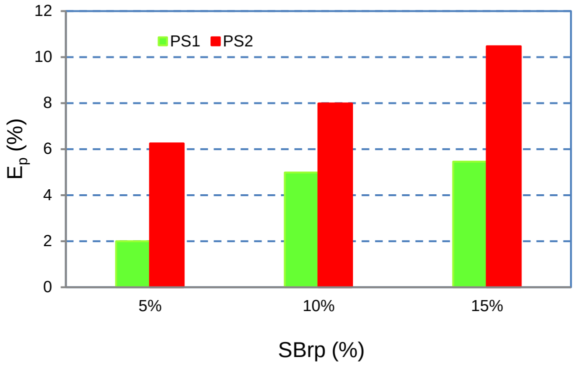

Fig-5: Effect of "SBrp" (%) and "PS" on "E_p" (%) of manufacture bricks.

Water absorption "W_A"(%) is an important property that correlates with bricks durability. Where there had a negative relationship between them. All specimens under study showed an increase in "W_A"(%) as compared to standard cement brick "SCB". Occasionally, the lowest values of W_A were observed, equal to 14.82 and 29.78%., for bricks with 5%., of SBrp at PS1 and PS2. Whereas, the W_A value for SCB was about 9.8%., [45]. Results indicated that decreasing SBrp from 15 to 10 or 5%., decreased the W_A by 5.43 and 38.46%., at PS1, and nearby 19.12 and 21%., at PS2. Where, specimens with 15%., SBrp had a higher value of W_A (24.08 and 37.70%) compared with specimens with 5%., of SBrp (14.82 and 29.78%) for PS1 and PS2. These effects were confirmed by [55]. On the other hand, these remarks were conflicted with [15, 23] who mentioned that W_A increase as the amount of CKD increased. Cement, sand bricks absorption ratios should be less than 26 or 30%. So, based on this fact, it is considered that all bricks can be effectively used as moderate weathering resistant, except bricks with 10 and 15%., of SBrp at PS2 as reported by [56, 57] (Fig. 6).

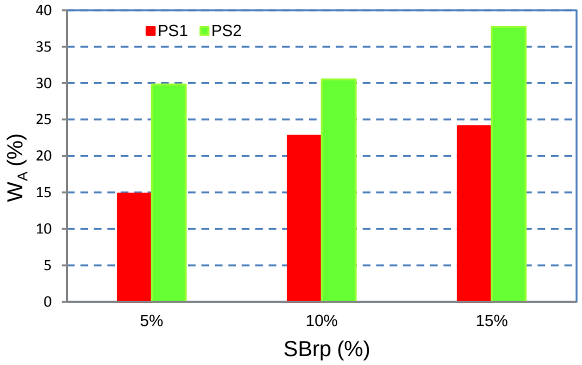

Fig-6:"W_A" results for bricks under studied parameters.

Amount of water absorbed through the bed face of a brick in one minute of IRA (gcm^{-2}min^{-1}) is one of the important factors affecting the flexural bond strength [58]. The values of IRA were ranged from 0.02 to 0.056 gcm^{-2}min^{-1}., for PS1, and from 0.04 to 0.07 gcm^{-2}min^{-1}., for PS2 (Fig.7). These values are lesser than cement brick (0.44 gcm^{-2}min^{-1}), clay brick (0.46 gcm^{-2}min^{-1}) and moderated clay bricks (0.65 gcm^{-2}min^{-1}) which mentioned by [45].

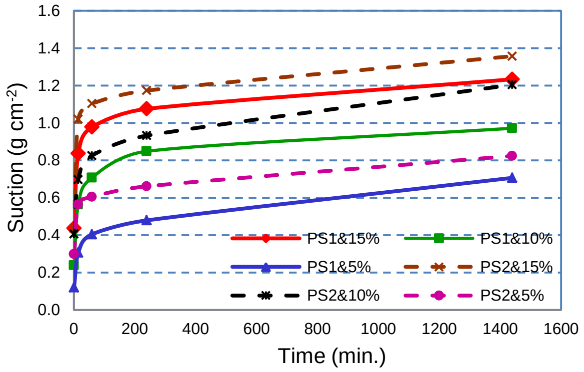

Fig-7: Suction behaviour for manufacture bricks.

Over and above, with exception samples with 15%., of SBrp at both of PS1 and PS2 and with 10%., of SBrp at PS2, all water absorbed values are smaller than dry pressed clay, units of extruded clay, concrete, and calcium silicate, as reported by [59].Generally, it was noticed that the IRA increased with both of SBrp and PS. Suctions were increased sharply during first 15 min about 155, 136.55 and 91.74%., at PS1, and 88.92, 71.42 and 134.25%., at PS2, with 5, 10 and 15%., of SBrp, respectively. Then, it improves slightly, consequently through 45 min., (from 15 to 60 min), about 32.03 and 7.28%., with 5%., of SBrp, and about 25.58 and 18.53%., with 10%., of SBrp and 16.98 and 8.14%., with 15%., of SBrp at PS1 and PS2. Lastly, it augments only about 0.302, 0.264 and 0.255 gcm^{-2}., and about 0.219, 0.379 and 0.255 g cm^{-2}., for PS1 and PS2 with 5, 10 and 15%., of SBrp, through periods of 23h (from 1to 24h). Due to the above reasons, all bricks must be wetted before laying to avoid water suction from a past of cement mortar, except the specimen with 5%., of SBrp at PS1 [60]. These results are well-matched with density theory "The higher original density is less likely to absorb water, and vice versa". Where, the W_A and IRA (suction rate) indicates the presence of interconnected pores, capillaries and voids in the brick body. As well, depends on the distribution of pores and volume [46]. Adding SB by high content, lead to fibers packing and the matrix becomes less efficient, and causes the void volume to increase [61]. Organic matter in SB increases the effect and total open porosity of brick bodies [62]. Whereas, increase SB with low density, as a hydrophilic cellulose fibers, like other ligno-celluloses, is hygroscopic, with a relatively high affinity for water [63] followed by a decrease in density and an increase in both W_A and IRA.

Compressive strength test is important for determining bricks load bearing capacity, and considered the main factor in choosing building's bricks. The attainted results as depicted in (Fig. 8), revealed that compressive strength "δ" (Nmm^{-2}) of all specimens was decreased by decreasing SBrp, at PS1 and PS2. Where, decreased SBrp from 15%., to 10 or 5%., lead to reduce "δ" by 14 and 21.33%., at PS1, and about 11.96 and 29.58%., at PS2. Contrary the former relation, particle size "PS" data showed that reducing PS from PS2 to PS1, lead to increase "δ" about 118, 103.19 and 105.63%., at 5, 10 and 15%., of SBrp, respectively.

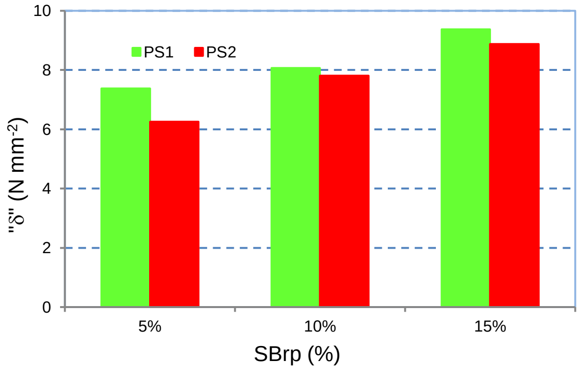

Fig- 8: Compressive stress of manufacture bricks.

Maximum value of δ (9.375 Nmm^{-2}) scored at PS1 with 15%., of SBrp. While, the minimum value (6.25 Nmm^{-2}) scored at PS2 with 5%., of SBrp. [64], indicated that the "δ" of cement, sand bricks should be 2.5 ≤δ≤7 Nmm^{-2}. Thus, all manufacture specimens an accepted as building bricks (non-carrying bricks) where δ should be more than 2.50 Nmm^{-2}. As well, accepted as carrying bricks (for load-bearing) except manufacture specimens with 5%., of SBrp at PS2 (6.25 Nmm^{-2}) where δ not be less than 7Nmm^{-2}.

Subsequently, these bricks can be used in single-storied load-bearing structures, and also in the construction of infill walls in multi-storied framed structures. A similar results were demonstrated by [65]**.** Whilst, all δ of bricks still weakly compared with cement brick (δ ≈ 12 Nmm^{-2}). On the other hand, there were stronger than silt brick (δ ≈8Nmm^{-2}), except specimens with 5% of SBrp at PS1 and PS2, and with 10% of SBrp at PS2 [45]. Furthermore, it still satisfied the min. compressive strength according to Pakistan standards for building bricks (≈ 5Nmm^{-2}) [66], as well, Australian standard for masonary units [67]**.** Therefore, these modified bricks can be used as a more sustainable bricks. These findings were confirmed by [15, 47]**,** they observed that "δ" increases with the increase in agro-waste replacement percentage. On the other hand, all previous results were contrary, with indicated results for modified concrete and clay bricks, where, by increasing agro-waste materials and decreasing CKD (%) tended to decrease the δ values [1, 49]. Contrary the aforesaid results [68], resulted that increasing CKD percentage lead to increase δ value. As well, increase of SB as fine aggregate decreased the strength in concrete as reported by [69,70]**.** Meanwhile, [71] mentioned that using SB did not affect the mortar compressive strength.

Maximum of compressive stress on the bricks was 9.193 Nmm^{-2}., occurring at a strain of 0.192. Mean values of failure strain obtained for bricks found to vary between 0.194 and 0.192, and 0.192 and 0.188 strain, for bricks manufacturing from PS1, and PS2. By adding load about 2Nmm^{-2}., (one-fifth load)., the ascending part of the curves for all bricks were found to behave exponentially except specimens with 15%., of SBrp at PS1. With increasing the load till failure load the ascending curves were found to behave linearly at 10 %., of SBrp at PS1 and 15%., of SBrp at PS2. As well as, the exponential behavior was noted at PS1 with 5 and 15%., of SBrp, and 5% of SBrp at PS2, and too, the power behavior at 10%., of SBrp at PS2 (Fig. 9).

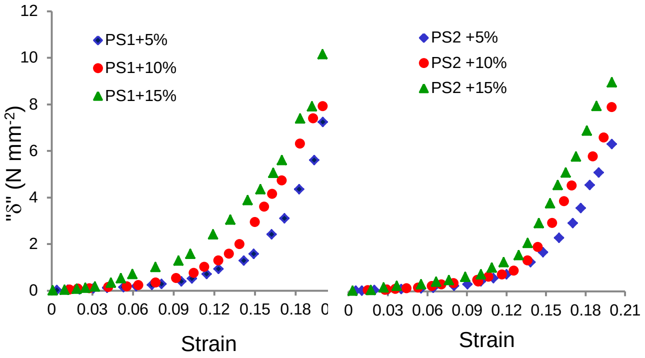

Fig- 9: Compressive stress – strain curves for manufacture bricks.

4. Conclusion

Agricultural and industrial waste utilization in brick manufacturing is an effective way to dispose of them leading to sustainable green constructions. Increasing the SBrp and PS leads to reduced bricks densification parameters in terms of ρ and S_d, and increasing Si resulting in lighter bricks with more soundproofed. Bricks suction behavior in terms of the Ep, W_A and IRA were increased by increasing SBrp and PS. So, based on these facts, it is considered that all bricks can be effectively used as moderate weathering resistant, except only bricks with 10 and 15%., of SBrp at PS2. Moreover, All bricks must be wetted before laying to avoid water suction from a past of cement mortar, except the specimen with 5%., of SBrp at PS1. Thus, all manufacture specimens are accepted as building bricks (non-carrying bricks). As well, accepted as carrying bricks (for load-bearing) except manufacture bricks with 5% of SBrp at PS2. Subsequently, these bricks can be used in single-storied load-bearing structures, and also in the construction of infill walls in multi-storied framed structures. Whilst, it still weak compared with a cement brick. On the other hand, there were stronger than silt brick, except specimens with 5%., of SBrp at PS1 and PS2, and with 10%., of SBrp at PS2. Therefore, these modified bricks can be used as a more sustainable green construction.

5. References

[1] L. M. Luna-Cañas, C. A. Ríos-Reyes, and L. A. Quintero-Ortíz. "Recycling of agroindustrial solid wastes as additives in brick manufacturing for development of sustainable construction materials". Dyna, 81(188) pp. 34-41, 2014
[2] A. T. Figaredo, and M. Dhanya. "Development of Sustainable Brick Materials Incorporating

Agro-Wastes: An Overview". International Research Journal of Engineering and Technology. IRJET, 5 (11) pp. 721-726, 2018.

[3] A. H. Hemmasi, A. Samariha, A. Tabei, M. Nemati, and A. Khakifirooz. "Study of morphological and chemical composition of fibers from Iranian sugarcane bagasse". American Eurasian J. Agric.&Environ. Sci, 11(4) pp. 478-481, 2011.

[4] FAOSTAT. "Production crops: Sugarcane". FAOSTAT Agricultural production database. http://faostat.fao. org. 2017. Accessed on 12th August 2019.

[5] A. Putra, Y. Abdullah, H. Efendy, W. M. F. W. Mohamad, and N. L. Salleh. "Biomass from paddy waste fibers as sustainable acoustic material". Advances in Acoustics and Vibration, 2013.

[6] H. Dashti, S. Salehpur, H. R. Taghiyari, F. A. Far, and S. Heshmati. "The effect of nanoclay on the mass transfer properties of plywood". Digest Journal of Nanomaterials and Biostructures, 7 (2) pp. 853-860, 2012.

[7] F. Stockel, J. Konnerth, J. Moser, W.Kantner, and W. Gindl-Altmutter. "Micromechanical properties of the interphase in pMDI and UF lines". Wood Science and Technology, 46(4) pp. 611-620, 2012

[8] M.J. Ghazali, C.H. Azhari, S. Abdullah, and M.Z. Omar. "Characterization of natural fibers (Sugarcane Bagasse) in cement composites". Proceedings of the World Congress on Engineering, II. London. UK. (2008)

[9] P. H. F. Pereira, H. C. J. Voorwald, M. O. H. Cioffi, D. R. Mullinari, S. M. Da Luz, and M. L. C. P. Da Silva. "Sugarcane bagasse pulping and bleaching: Thermal and chemical char-acteriza-tion". BioResources, 6(3) pp. 2471-2482, 2011.

[10] S. Liuzzi, S, Sanarica, and P. Stefanizzi. "Use of agro-wastes in building materials in the Mediterranean area: A review". Energy Procedia, 126 pp. 242-249, 2017

[11] X. Zhu, B. J. Kim, Q. Wang, and Q. Wu. "Recent advances in the sound insulation properties of bio-based materials". BioResources, 9(1) pp. 1764-1786, 2014.

[12] R.R. Boruah, and M. Konwar. "Utilization of sugarcane fiber waste (Baggase): A review". International Journal of Applied Home Science, 5 (4) pp. 894-897, 2018

[13] K. S. Al-Jabri, R. A. Taha, A. Al-Hashmi, and A.S. Al-Harthy. "Effect of copper slag and cement by-pass dust addition on mechanical properties of concrete". Construction and building materials, 20 (5) pp.322-331, 2006.

[14] W. S. Adaska, and D.H. Taubert. "Beneficial uses of cement kiln dust". In 2008 IEEE Cement Industry Technical Conference Record , pp. 210-228, 2008.

[15] M. A. Ali, and H. S. Yang. "Utilization of cement kiln dust in industry cement bricks". Geosystem Engineering, 14(1) pp. 29-34, 2011.

[16] M. Lachemi, K. M. A. Hossain, M. Shehata, and W. Thaha. "Controlled low strength materials incorporating cement kiln dust from various sources". Cement and Concrete Composites, 30(5) pp. 381-392, 2008.

[17] Y. Askar, P. Jago, M. M. Mourad, and D. Huisingh. "The cement industry in Egypt: Challenges and innovative cleaner production solutions". In Knowledge Collaboration & Learning for Sustainable Innovation: 14th European Roundtable on Sustainable Consumption and Production (ERSCP) conference and the 6th Environmental Management for Sustainable Universities (EMSU) conference, Delft, The Netherlands, October 25-29, 2010. Delft University of Technology; The Hague University of Applied Sciences; TNO. 2010.

[18] A. El-Abssay, M. Hassanien, Y. K. Ibrahim, and N. M. Abdel-Latif. "Health risk assessment of workers exposed to heavy metals in Cement Kiln Dust (CDK)". J.Am.Sci, 7 pp. 308-316, 2011.

[19] T. Yasodha. "Agro–industrial wastes as sustainable resource for the production of bricks". MOJ Civil Eng, 4(5) pp. 403-408, 2018.

[20] M. E. S. I. Saraya, M. E. S. Aboul-Fetouh, H. S. Nassar, and A. M. Abd-El-Rahman. "Removal of direct dyes with cement kiln dust". Journal of Materials Science and Engineering. B, 1(1B) pp. 97. 2011.

[21] A.M. Sharkawi. "Recycling of domestic wastes for various structural applications. Potentials and challenges". Proceedings of 2nd International conference of sustainable construction and project management–sustainable infrastructures and transportation for future cities. Aswan, Egypt. , (2018)

[22] A. A. Rahman, M. Aboul-Fetouh, and K. Shehata. "Utilizing of by-pass cement dust in colored cement preparation". Silicates industriels, (9-10) pp. 261-266, 2009.

[23] M. H. Ghazaly, M. N. Almaghrabi, and E. E. Ebrahiem. "A study on the reuse of cement kiln dust in the production of cement concerts. Minia Journal of Engineering and Technology,(MJET), KSA, 31(2)pp. 63-68, 2012.

[24] T. Sen, and U. Mishra. "Usage of industrial waste products in villageroad construct-ion".

International Journal of Environmental Science and Development, 1(2) pp.122, 2010.

[25] K.M. Esawy. "Cement klin dust and coal filters treatment of textile industrial effluents". Desalination, 255 pp. 175-178, 2010.

[26] L. Zhang. "Production of bricks from waste materials–A review". Construction and building materials, 47, pp. 643-655, 2013.

[27] S. P. Raut, R. V. Ralegaonkar, and S. A. Mandavgane. "Development of sustainable construction material using industrial and agricultural solid waste: A review of waste-create bricks". Construction and building materials, 25(10) pp. 4037-4042, 2011.

[28] R. Paliwal, and P. Rewatkar. "Formation of insulating bricks from agricultural waste & determination of thermal properties by comparing with present bricks". IJARIIE., 3 (1) pp. 2395-4396, 2017.

[29] M. V. Madurwar, R. V. Ralegaonkar, and S.A. Mandavgane. "Application of agro-waste for sustainable construction materials: A review". Construction and Building materials, 38 pp. 872-878, 2013.

[30] M. S. Kazmi, M. J. Munir, S. Abbas, M. A. Saleem, A. Khitab, and M. Rizwan. "Development of lighter and eco-friendly burnt clay bricks incorporating sugarcane bagasse ash". Pakistan Journal of Engineering and Applied Sciences, 21 pp.1–5, 2017.

[31] L.V. Kumar, and B.J. Vignesh. "Experimental investigation on replacement of bagasse ash in bricks". International Journal of Innovative Research in Science, Engineering and Technology, 6 (5) pp. 8303-8309, 2017.

[32] ES. 4756-1. "Egyptian standard specification for cement". 2013.

[33] ASTM, C150. American Society for testing materials. "Standard Specification for Portland Cement 1". 2000.

[34] ASTM, C778. American Society for testing materials." Standard Specification for Standard Sand".2000.

[35] ASTM, C911. American Society for testing materials. "Standard Specification for Quicklime, Hydrated Lime, and Limestone for Chemical Uses". 1999.

[36] S. S. Claye, A. Idouraine, and C. W. Weber. "Extraction and fractionation of insoluble fiber from five fiber sources". Food chemistry, 57 (2) pp. 305-310, 1996.

[37] IS. 456. "Plain and Reinforced Concrete - Code of Practice [CED 2:Cement and Concrete]. 2000.

[38] ASTM, C642. American Society for testing materials. "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete".1997.

[39] ASTM, C67. American Society for testing materials. "Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile". 2001.

[40] A.M.I. Moussa. "Effects of some adhesive matter on agricultural wastes as building materials". M.Sc. Thesis, Agric, Eng., Fac. of Agric., Al-Azhar Univ. Egypt. 2008.

[41] ASTM, C1038. American Society for testing materials. "Standard Test Method for Expansion of Portland Cement Mortar Bars Stored in Water". 1995.

[42] ASTM, C1403. American Society for testing materials. "Standard Test Method for Rate of Water Absorption of Masonry Mortars". 2000.

[43] ASTM, C140a. American Society for testing materials. "Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units[1]". 2001.

[44] S.A. Tayel, M.F.A. Khairy, I.S. El-Soaly, and A.M.I. Moussa. "Using adhesive matter for agricultural wastes as building bricks". Misr J. Ag. Eng., 27 (1) pp. 347-361, 2010.

[45] M. A. Orabi. "Recycling of some agricultural residues in concrete mixes". M.Sc. Thesis, Agric. Eng., Fac. of Agric., Moshtohor, Benha Univ. Egypt.2015.

[46] Kizinievič, O., Kizinievič, V., Pundiene, I., & Molotokas, D. "Eco-friendly fired clay brick manufactured with agricultural solid waste". Archives of Civil and Mechanical Engineering, 18(4) pp. 1156-1165,2018.

[47] A. Mobili, C. Giosue, and F. Tittarelli. "Valorisation of GRP dust waste in fired clay bricks". Advances in Civil Engineering, 2018.

[48] J. P. Nayak, and J. Bera. "Effect of sintering temperature on mechanical behaviour and bioactivity of sol–gel synthesized bioglass-ceramics using rice husk ash as a silica source". Applied surface science, 257(2) pp. 458-462, 2010.

[49] S. M. S. Kazmi, M. J. Munir, I. Patnaikuni, Y. F. Wu, and U. Fawad. "Thermal performance enhancement of eco-friendly bricks incorporating agro-wastes". Energy and Buildings, 158, pp. 1117-1129, 2018.

[50] S. T. M. Carvalho, L. M. Mendes, A. A. D. S. Cesar, J. B. Flórez, F. A. Mori, and G. F. Rabelo. "Acoustic characterization of sugarcane bagasse particleboard panels (*Saccharum*

officinarum L)". Materials Research, 18 (4) pp. 821-827, 2015.

[51] Y.Y. Mohd, A.M. Kamarul, H. Sihambing, A.R. Jeefferie, M.M. Haidir, A.R. Toibah, A.H. Rahimah, and A.A. Tajul. "The potential of agriculture waste material for noise insulator application toward green design and material". International Journal of Civil & Environmental Engineering, IJCEE-IJENS., 10(5)pp.16-21,2010.

[52] F. Z. Ismail, M. N. Rahmat, and N. M. Ishak. "A study on absorption coefficient of sustainable acoustic panels from rice husks and sugarcane baggase". In Advanced Materials Research. Trans Tech Publications Ltd. 1113, pp. 198-203, 2015.

[53] F. Z. Ismail, M. N. Rahmat, and N. M. Ishak. "Sustainable absorption panels from agricultural wastes". In MATEC Web of Conferences . EDP Sciences. 15, p. 01035, 2014.

[54] A. L. Pisello, C. Fabiani, N. Makaremi, V. L. Castaldo, G. Cavalaglio, A. Nicolini, and F. Cotana. "Sustainable new brick and thermo-acoustic insulation panel from mineralization of stranded driftwood residues". Energies, 9(8) pp. 619, 2016.

[55] A. Bahurudeen, D. Kanraj, V. G. Dev, and M. Santhanam. "Performance evaluation of sugarcane bagasse ash blended cement in concrete". Cement and Concrete Composites, 59, pp. 77-88, 2015.

[56] ASTM, C55. American Society for testing materials, "Standard Specification for Concrete Brick", ASTM International, West Conshohocken, PA., 2001

[57] N. Phonphuak. "Effects of additive on the physical and thermal conductivity of fired clay brick". Journal of Chemical Science and Technology, 2(1), 95-99, 2013.

[58] H. O. Sugo, A. W. Page, and S. J. Lawrence. "The development of mortar/unit bond". In 6th Australian masonry conference. Adelaide. South Australia, pp. 367-377, 2001.

[59] Y.Z. Totoev, and M.A. James. "Development of the water absorption from fresh mortar test". Proceedings of the 13th International Brick and Block Masonry Conference . Amsterdam, Netherland. Pp. 4-7, 2004.

[60] B. E. Hegazy, H. A. Fouad, and A. M. Hassanain. "Incorporation of water sludge, silica fume, and rice husk ash in brick making". Advances in environmental research, 1(1) pp. 83-96, 2012.

[61] R. S. P. Coutts, and Y. Ni. "Autoclaved bamboo pulp fiber reinforced cement". Cement and Concrete Composites, 17 (2) pp. 99-106, 1995.

[62] T. Banu, M. M. Billah, F. Gulshan, and A. S. W. Kurny. "Experimental studies on fly ash-sand-lime bricks with gypsum addition". American Journal of Materials Engineering and Technologi, 1 (3) pp. 35-40, 2013.

[63] S. Ismail, and Z. Yaacob. "Properties of laterite brick reinforced with oil palm empty fruit bunch fibres". Pertanika Journal of Science and Technology, 19(1) pp. 33-43, 2011.

[64] ES. 1349.Egyptian standard specification. 1991.

[65] N. Hossiney, P. Das, M. K. Mohan, and J. George. "In-plant production of bricks containing waste foundry sand - A study with Belgaum foundry industry". Case Studies in Construction Materials, 9 : pp. 1-13, 2018

[66] National Engineering Services of Pakistan. "Building code of Pakistan - Seismic hazard evaluation studies", Ministry of Housing and Works, Government of Pakistan, Lahore, Pakistan. 2007.

[67] AS/NZS 4455.1:2008. "Masonry units, pavers, flags and segmental retaining wall units. Part 1: Masonry units" . Standards Australia. 2008.

[68] A. H. Abdulkareem, and S.O. Eyada. "Production of building bricks using cement kiln dust CKD waste". International Congress and Exhibition" Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology" . Springer, Cham., pp. 102-113, 2018.

[69] P. O. Modani, and M. R. Vyawahare. "Utilization of bagasse ash as a partial replacement of fine aggregate in concrete". Procedia Engineering, 51(0) pp. 25-29, 2013.

[70] P. A. Shah, J. G. Mehta, S. C. Pathariya, A. Ranajaykrushna, and A. N. Patel. "Sugarcane bagasse ash and pozzocrete as a techno-economical solution in design mix concrete". Indian Journal Applied Research, 4, pp. 243-245, 2014.

[71] F. C. Almeida, A. Sales, J. P. Moretti, and P. C. Mendes. "Sugarcane bagasse ash, sand (SBAS): Brazilian agro industrial by-product for use in mortar". Construction and Building Materials, 82, pp. 31-38, 2015.