Journal of Biomaterials
2021; 5(2): 16-22
http://www.sciencepublishinggroup.com/j/jb
doi: 10.11648/j.jb.20210502.11
ISSN: 2640-2602 (Print); ISSN: 2640-2629 (Online)

Light Weight Clay Bricks in Combination of Sludge Blended with Agro/Wastes

Hassan Hassanien Mohamed Darweesh

Refractories, Ceramics and Building Materials Department, National Research Centre, Cairo, Egypt

Email address:
hassandarweesh2000@yahoo.com

To cite this article:
Hassan Hassanien Mohamed Darweesh. Light Weight Clay Bricks in Combination of Sludge Blended with Agro/Wastes. *Journal of Biomaterials*. Vol. 5, No. 2, 2021, pp. 16-22. doi: 10.11648/j.jb.20210502.11

Received: September 2, 2021; **Accepted**: September 22, 2021; **Published**: September 30, 2021

Abstract: The objective of the study is to produce light weight bricks to use as an isolating layer. So, porous or light weight bricks were prepared from clay, sludge, agro/ashes as Saw dust ash (DSA), sugarcane bagasse ash (SCBA) and corn stalk ash (CSA) fired up to 900°C. Physical and mechanical properties were investigated. The chemical composition of the starting raw materials was carried out by XRF analysis. Results proved that the water absorption (25.51, 25.74 and 25.86%) and apparent porosity (29.31, 29.51 and 29. 68%) were slightly lowered up to 6 wt. % of these waste ashes, and then increased with further increase. The bulk density (1.9989, 1.9987 and 1.9985 g/cm^3) and compressive strength (48.54, 48.45 and 48.26 MPa) improved and enhanced with the replacement up to 6 wt. %, and then diminished. So, the optimum ash content was not more than 6 wt. % because the substitution of more than that bad or adverse effect was exhibited. Results also proved that the physical and compressive strength was better in case of SDA > SCBA > CSA. The prepared fired bricks could be successfully used and preferred as isolating bricks against heat.

Keywords: Clay, Sludge, Bricks, Water Absorption, Density, Porosity, Strength

1. Introduction

1.1. Scope of the Problem

The worldwide use of the natural clay for the brick industry has created a huge lacking of clay. It made the scientists to look for new materials and/or to utilize and exploit the byproducts from different environmental activities [1, 2]. The quality of bricks is significantly influenced with the properties of the used raw materials as well as the used methods and techniques. Ingredients, e.g. SiO_2, Al_2O_3, CaO and iron oxide, present in clay in various amounts, influencing the properties of bricks [3]. The agro/wastes include rice husk ash (RHA), sugarcane bagasse ash (SCBA), water sludge (WS), high pulverized fly ash (HPFA), saw dust ash (SDA), sun flower ash (SFA), wheat stalk ash (WSA), corn straw ash (CSA), Physalis pith ash (PPA), Coir pith ash (CPA), and many others could be used as pozzolanic materials [4-13]. Many scientific researches in USA, China, Brazil and Egypt have been discussed the utilization of water treatment sludge or alum sludge that contains a high clay percent in many industrials. Some studies could be utilized sludge in the manufacturing of bricks [14, 15]. Inorganic products of alum sludge are like to those of clay which facilitated the addition of alum sludge to bricks [16]. Unfavorable glass sludge improves and enhances the compressive strength nearly by 20-24%. It can lower the total porosity and even the costs [17]. Few studies [14, 15] could be utilized the alum sludge as a replacement or full substitution for clay in the brick-making industry. In some cases, various ratios of sludge in combination to clay have been studied. Results revealed that the optimum content of sludge to produce bricks from sludge–clay mixes was 50% [15]. It was recommended that more substitutions could be directed towards the incorporation of sludge of water treatment plants with other high-silica-content waste materials, such as rice-husk ash, in brick-making [18, 19]. A huge quantity of dredged sludge could be obtained from the dredging of rivers, seas and reservoirs. The dredged sludge is similar to other sludge from various plants. Many types of wastes can be used in the production of red clay bricks [20–22]. The production of clay bricks incorporating waste by-products certainly diminishes the environmental pollution particularly air pollution that is coming from the disposal of agro/wastes in the open landfills. Also, it often offers the chance to produce a high quality brick performance. Consequently, the addition of agro/wastes of some plants as sugarcane bagasse and rice husk ashes improves the brick making [23]. The production of rice all over the world is about 800–1000 million ton yearly [24]. In Egypt, it could be produced about 7-9 million tons of rice in 2018 [25]. Moreover, nearly about 3.5 million tons of rice husk and/or stalk are disposed through burning in open fields, causing air pollution, i.e. the disposal of agro/wastes by burning increased the green-house gas in the air [26, 27]. The fibrous residue from sugarcane after the extraction of sugar juice is known as bagasse [27].

1.2. Objectives of the Study

An environment-friendly method is needed to simplify the disposal of the CO_2 emissions from burning saw dust (SD), sugarcane bagasse (SCB) and corn stalk (CS) wastes which are available in Egypt [27-29]. In the present study, SD, SCB, and CS are burnt in a suitable muffle furnace at 700°C for 2 hours soaking time to create what is known as ash [1]. The present article studied the properties of 50% clay and 50% sludge waste brick mixture as a control mixture. The sludge portion was substituted by 5, 10, 15 and 20 wt. % of saw dust ash (SDA), sugarcane bagasse ash (SCBA) and corn straw ash (CSA)) in clay bricks. The physical properties of the prepared brick batches in terms of bulk density, apparent porosity and water absorption as well as the mechanical properties in terms of compressive and flexural strengths of the fired clay bricks are investigated.

2. Experimental

2.1. Raw Materials

The clay (CL), sludge (SG), saw dust (SD), sugarcane bagasse (SCB), and corn stalk (CS) were brought from local plants in Assuit, Egypt. The SD, SCB, and CS were first subjected to firing up to 800°C to convert them to ashes. The chemical oxide compositions, the particle size distribution and the physical properties of these raw materials are shown in Tables 1-3, respectively. The clay sample was composed of five major crystalline phases as kaolinite ($Al_2O_3.2SiO_2.2H_2O$), montmorillonite ($Al_2H_2O_{12}Si_4$), illite (K0.65Al2.0(OH)2), Quartz (SiO_2) and calcite (Ca CO_3), while the sludge sample was composed of only four phases as montmorillonite ($Al_2H_2O_{12}Si_4$), quartz (SiO_2), calcite (Ca CO_3) and albite (Na Al Si_3 O_8) [30]. The SDA and CSA samples were comined of only three phases as Quartz (SiO_2), halite (NaCl) and sylvite (K Cl), while SCBA sample of four phases as Quartz (SiO_2), albite (Na Al Si_3 O_8), sylvite (K Cl) and halite (NaCl) were identified.

Table 1. *Chemical analysis of the raw materials, wt. %*

Materials Oxides	Clay	Sludge	SDA	SCBA	CSA
SiO_2	51.47	64.48	65.17	70.83	66.47
Al_2O_3	28.78	16.50	4.35	9.21	8.29
Fe_2O_3	3.99	3.43	2.36	1.95	3.13
CaO	0.61	2.81	10.06	8.16	3.13
MgO	1.38	3.15	4.41	1.32	5.46
MnO	0.04	0.05	2.19	-----	4.16
Na_2O	1.15	2.04	0.08	0.12	2.52
K_2O	1.19	0.69	0.12	1.65	2.06
SO_3	--	0.49	0.30	1.47	0.51
TiO_2	1.14	0.82		-----	-----
P_2O_5	0.53	0.38	0.46	-----	-----
Cl^-	--	0.29	-----	-----	-----
LOI	9.72	4.85	0.84	6.91	1.02
Total	100	100	100	100	100

Table 2. *Particle size distribution of the starting raw materials, wt. %.*

Particle size, %	Starting raw materials				
	Clay	Sludge	SDA	SCBA	CSA
>63	1.39	0.12	0.09	0.09	0.15
63-16	1.72	0.18	0.19	0.18	0.28
16-8	2.91	0.81	0.08	0.21	0.16
8-2	9.11	10.48	4.59	1.16	6.38
<2	84.87	88.41	96.15	98.36	93.03
Total	100	100	100	100	100

Table 3. *Physical properties of the starting raw materials.*

Property Materials	Specific gravity	Color
Clay	2.71	Grayish
Sludge	2.36	Grayish
SDA	2.07	Dark gray
SCBA	1.96	Dark gray
CSA	1.98	Dark gray

2.2. Preparation of Brick Specimens

The constitution of the various prepared clay brick batches is shown in Table 2. One mixture was composed of 50 wt. % clay and 50 wt. % sludge which was considered as a blank to which all results were compared. Then, there are three groups; each group was containing only one type of the available agro/ashes namely, SDA, SCBA and CSA as clearly shown in Table 2. Each group was containing four brick batches as 0, 3, 6, 9, 12 and 15 wt. % [30]. The clay content was kept constant by the ratio 50 wt. %, while all other ingredients were variable. The addition of the agro/ashes was at the expense of the sludge. Thereafter, the mixing process was first carried out manually and then mechanically by a suitable mixer using 5 balls to ensure the complete homogeneity of all brick batches. The brick batches were let to dry in the open air for three days, and then in a suitable dryer at 105°C for another three days to illuminate the free and evaporable water [31]. Then, the drayed clay and sludge were crushed, ground and quartered to have a representative sample which was fine ground to pass a 200 mesh sieve using a suitable agate mortar.

Table 4. *Batch ratios of the prepared bricks, wt. %.*

Materials Gp. mixes	Clay	Sludge	SDA	SCBA	CSA
Blank	50	50	-----	-----	-----
	50	47	3	-----	-----
	50	44	6	-----	-----
I	50	41	9	-----	-----
	50	38	12	-----	-----
	50	35	15		
	50	47	-----	3	-----
	50	44	-----	6	-----
II	50	41	-----	9	-----
	50	38	-----	12	-----
	50	35	-----	15	-----
	50	47	-----	-----	3
	50	44	-----	-----	6
III	50	41	-----	-----	9
	50	38	-----	-----	12
	50	35	-----	-----	15

The water was then added to the prepared powder brick batches inside a suitable blender and stirred well. Thereafter, the pastes of the brick composites were inserted into 2.5 x 2.5 x 2.5cm^3 stainless steel lab. cube moulds for physical properties [30, 32], or inserted into a cylindrical samples of 3 cm height and 1 cm diameter for compressive strength [33, 34]. The green bricks were then air dried in sunlight for another 4 days to avoid cracks during firing [33-36]. Thereafter, the dried bricks were inserted into the furnace up to 600°C for 30 minutes, and up to 800°C for another 30 minutes and finally up to 900°C for 2 hours soaking time. After complete the firing process, the furnace was let to gradually cool to the room temperature. The produced fired bricks were then subjected to determine the physical properties [35, 37] in terms of water absorption (WA), bulk density (BD) and apparent porosity (AP) using the following equations:

$$WA, \%=W1/(W-W2) \times 100 \quad (1)$$

$$BD, g/cm^3=W3/(W1-W2) \quad (2)$$

$$AP, \%=(W1-W3)/(W1-W2) \times 100 \quad (3)$$

Where, W1: Saturated weight in air, W2: Suspended weight in water, W3: Dried weight. The crushing or compressive strength of the fired cube samples [33, 38] could be measured by the following relation:

$$CS=(D)/(L) \times (w)=kg/cm^2/10.2\ MPa \quad (4)$$

Where, CS is the crushing or compressive strength kg/cm^2, D is the load kg, L and W are the length and width of the samples, respectively.

3. Results and Discussion

3.1. Physical Properties

3.1.1. Water Absorption

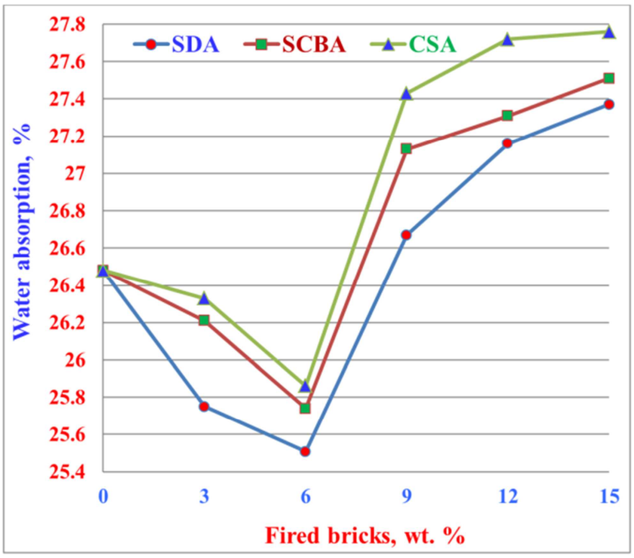

Figure 1. *Water absorption of the various fired bricks containing different ratios of agro/ashes.*

The water absorption of the prepared fired brick samples containing SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. % at the expense of sludge (SD) are graphically plotted in Figure 1, respectively. The values of water absorption of brick samples containing SDA or SCBA or CSA were slightly higher than that of the blank only up to 6 wt. %, i.e. a positive response was existed. The decrease of water absiorption is mainly contributed to the thermal reactions that happened among the particles of the clay and/or sludge with the active nano-silica of the agro/ashes [33, 34]. With any further increase of these waste ashes, the water absorption started to increase. This may be due to the spongy nature of SDA, SCBA and CSA which made the bricks to absorb more water due to the open pore structure [39, 40]. In addition, the large content of nano-silica enhances the total porosity. As a result, the pore structure of the fired samples could be increased.

3.1.2. Bulk Density

The bulk density of the prepared fired brick samples incorporating SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. % at the expense of sludge (SD) are graphically represented in Figure 2, respectively. The bulk density of the brick samples of the blank slightly improved and enhanced with the increase of these waste ashes only up to 6 wt. %, but decreased with any further increase of its contents. This is mainly attributed to that the used ashes are too light to decrease the bulk density compared with of sludge [40, 41]. Moreover, the increment in the total porosity due to the fact that the addition of these ashes played an important role to decrease the weight of the brick specimens on account of the lower specific gravity of SDA, SCBA and CSA compared with that of clay and/or sludge. Therefore, the higher quantities of SDA, SCBA, and CSA in the bricks, the weight of the brick will be lighter. As the contents of SDA, SCBA, and CSA increased in the bricks, the bricks became much lighter. Accordingly, the hhigher amounts of the agro/ashes must be avoided. However, the lighter clay bricks would be required in building construction due to its beneficial reduction in the weight of building [42].

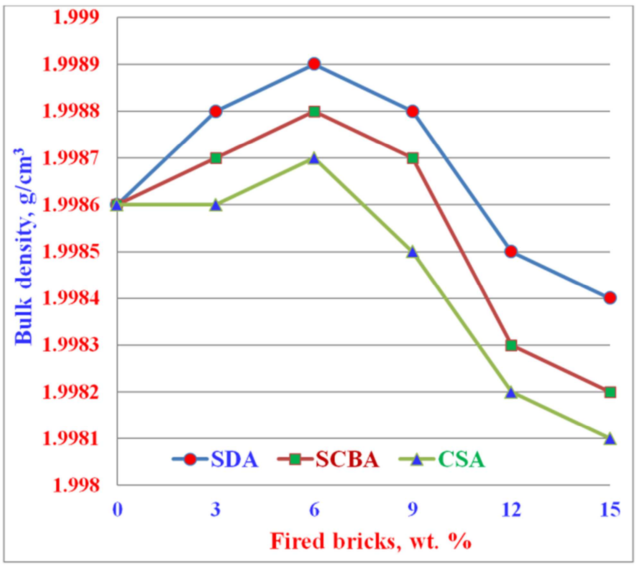

Figure 2. *Bulk density of the various fired bricks containing different ratios of agro/ashes.*

3.1.3. Apparent Porosity

The apparent porosity of the prepared fired brick samples incorporating SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. % at the expense of sludge (SD) are graphically represented in Figure 3, respectively. The apparent porosity of the brick of the blank batch decreased slighly with the replacement of SDA, SCBA and CSA at the expense of sludge (SD). This could be attributed to the thermal reaction among the constituents of the agro/ashes with those of the clay and/or sludge. With any further increase of these agro/ashes, the apparent porosity increased too. This could be led to produce porous bricks. The obtained data are similar to some of previous studies [29, 43, 44]. Porous bricks are generally preferred owing to its insulating properties, and it could be used to resist the high heat of the atmosphere [45].

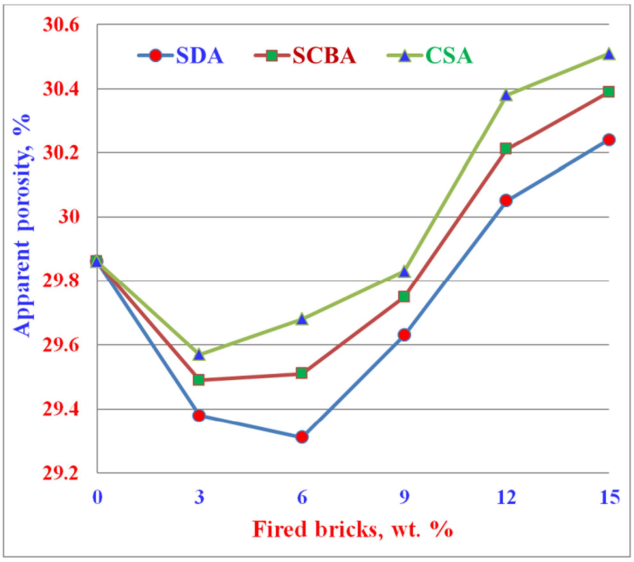

Figure 3. *Apparent porosity of the various fired bricks containing different ratios of agro/ashes.*

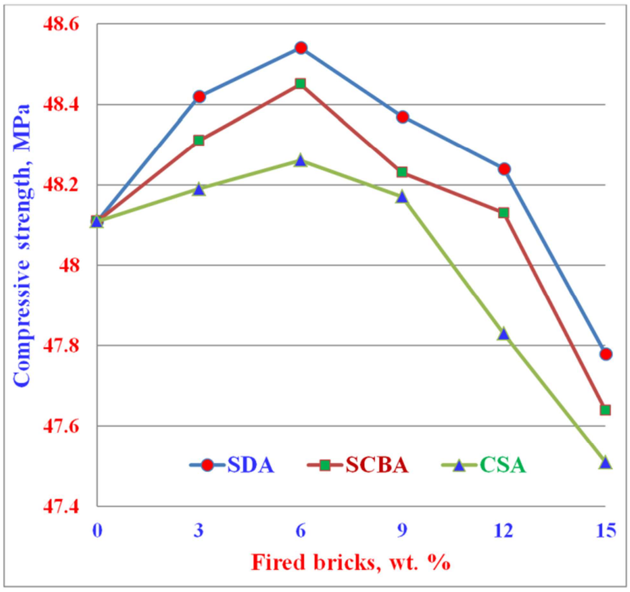

Figure 4. *Compressive strength of the various fired bricks containing different ratios of agro/ashes.*

3.2. Compressive Strength

The compressive strength of the prepared fired brick samples containing SDA, SCBA and CSA by 0, 3, 6, 9, 12 and 15 wt. %, respectively, at the expense of sludge (SD) are graphically plotted in Figure 4. The compressive strength of the fired blank bricks increased with the incorporation of SDA, SCBA and CSA only up to 6 wt. %, and then decreased. The brick batch containing SDA achieved the highest values of compressive strength at all contents up to 15 wt. %, while that containing CSA exhibited the lowest, noticing that the same trend was displayed by all brick batches. The increase of compressive strength is mainly due to the thermal reactions that happened between the ingredients of the clay and the active nano-silica of the agro/ashes [33, 34]. The decrease of the compressive strength is essentially attributed to the fact that the larger amounts of these ashes decreased the bulk density of the bricks, which in turn reflected negatively on the mechanical properties in general [30, 34]. Moreover, the resulting volatile gases during firing, and the higher contents of silica could be led to the increase of the porosity. So, the larger quantity of silica is unwelcome in brick-making [30, 44, 45]. Therefore, the production of porous or light weight bricks could be successfully achieved by using SDA > SBA > CSA.

4. General Discussion

To throw light on the behavior of samples during firing, the firing cycle for the green samples started with the evaporation of any moisture content left in the samples after drying and also any hygroscopic moisture that picked up from the atmosphere were also driven off at 300°C. At the temperature range 500–600°C, the kaolinite ($Al_2O_3{\cdot}2SiO_2.H_2O$) was converted to metakaolin ($Al_2O_3{\cdot}2SiO_2$) as shown in Eq. 5. At 800°C, the organic matter existed in the raw materials were burned off. At 980°C, the formed metakaolin was converted to mullite phase ($3Al_2O_3{\cdot}2SiO_2$) as shown in Eq. 6.

$$Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O \rightarrow Al_2O_3{\cdot}2SiO_2 \quad (5)$$

$$Al_2O_3{\cdot}2SiO_2 \rightarrow 3Al_2O_3{\cdot}2SiO_2 \quad (6)$$

In presence of mullite, the thermal reactions could be enhanced and some calcium-rich phases were formed [24, 35, 46]. The thermal reactions increased in presence of CaO, SiO_2, Al_2O_3 and alkali oxides (Na_2O and K_2O) that were available in the agro/ashes. Mullite could be reacted with the available CaO and MgO to form cordierite ($2MgO{\cdot}2Al_2O_3{\cdot}5SiO_2$) as shown in Eq. 7.

$$3Al_2O_3{\cdot}2SiO_2 + 2MgO \rightarrow 2MgO{\cdot}2Al_2O_3{\cdot}5SiO_2 \quad (7)$$

The formation of these new phases could be combined to those already existing in the fired samples, is an advantage for sintering of the clay composite since this could be reflected positively on the mechanical strength. Moreover, the collapse or the partial decomposition of other crystalline phases, would favor the abundant viscous flow phase formation, which fill the pore volume, involving a decrease in the apparent porosity and water absorption [46-48]. So, the bulk density and compressive strength were improved. The excess of the agro/waste ashes increased the silica content in the brick body, which in turn reflected negatively on both physical and mechanical properties of the fired bricks. Therefore, the large replacement of the agro/ashes is undesirable [4, 5, 7, 10, 49].

5. Conclusions

This paper presents an approach for the safely disposal of agro/wastes, and its recycling in the brick-making. Clay bricks containing agro/wastes like saw dust ash (SDA), sugarcane bagasse ash (SCBA) and corn straw ash (CSA) could be used as a combustible replacement in the clay-making bricks. The SDA, SCBA and CSA have high nano-silica content which could be incorporated with clay and sludge in clay-brick making. Apparent porosity and water absorption decreased with the replacement of SDA, SCBA and CSA only up to 6 wt. %, and then re-increased with further addition. The bulk density and compressive strength improved and enhanced with the increase of agro/wastes content but only up to 6 wt. %, and then decreased, the same trend was displayed by all brick samples, Accordingly, the best ratio of replacement of waste materials to get the best performance of the bricks is 6 wt. % of the SDA, SCBA and CSA. This could be created a sustainable source of new and alternative raw materials in the brick-making. The recycling of agro/wastes as SDA, SCBA, and CSA in clay-making bricks showed positive responses in terms of environmental protection, waste management, alternative raw materials and moreover, the raw material saving.

Fund

The fund of this study paper was carried out by the author.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Acknowledgements

Author wishes to express this deep thanks for National Research Centre for helping to obtain materials, processing, preparing, molding and measuring all of the obtained data of the study.

References

[1] Agwa IS; Omar OM; Tayeh BA; Abdelsalam BA (2020) Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete, Journal of Construction and Building Materials, 235, 117541. doi: http://dx.doi.org/10.1016/j.conbuildmat.2019.117541.

[2] Kazmi MS; Abbas S; Saleem MA; Munir MJ; Khitab A (2016) Manufacturing of sustainable clay bricks: utilization of waste sugarcane bagasse and rice husk ashes, Journal of Construction and Building Materials, 120, 29–41, doi: http://dx.doi.org/10.1016/j.conbuildmat.2016.05.084.

[3] Riaz MH; Khitab A; Ahmed S (2019) Evaluation of sustainable clay bricks incorporating brick kiln dust, Journal of Building Engineering, 24, 100725. doi: http://dx.doi.org/10.1016/j.jobe.2019.02.017.

[4] De Silva GS; Surangi MLC (2017) Effect of waste rice husk ash on structural, thermal and run-off properties of clay roof tiles, Journal of Construction and Building Materials, 154, 251–257. doi: http://dx.doi.org/10.1016/j.conbuildmat.2017.07.169.

[5] Eliche-Quesada D; Felipe-Sesé MA; López-Pérez JA; Infantes-Molina A (2017) Characterization and evaluation of rice husk ash and wood ash in sustainable clay matrix bricks, Ceramics International, 43, 1, 463–475, doi: http://dx.doi.org/10.1016/j.ceramint.2016.09.181.

[6] Darweesh HHM; Abo El-Suoud MR (2019) Palm Ash as a Pozzolanic Material for Portland Cement Pastes, To Chemistry Journal, 14, 72-85. http://purkh.com/index.php/tochem.

[7] Darweesh HHM; Abo El-Suoud MR (2019) Influence of sugarcane bagasse ash substitution on Portland cement characteristics, Indian Journal of Engineering, 16, 252-266. www.discoveryjournals.org.

[8] Li1Q; Zhao Y; Chen1 H; Hou P; Cheng X (2019) Effect of cornstalk ash on the microstructure of cement-based material under sulfate attack, IOP Conf. Series: Earth and Environmental Science, 358, 052010. doi: 10.1088/1755-1315/358/5/052010.

[9] Darweesh HHM (2020), Specific characteristics and microstructure of Portland cement pastes containing wheat straw ash (WSA), *Journal of Engineering*, 2020, 17, 48, 569-583. www.discoveryjournals.org.

[10] Darweesh, HHM (2020) Saw dust ash substitution for Portland cement pastes-Part II: Chemical resistance against sulfate attack, Indian Journal of Engineering, 17, 48, 396-407. www.discoveryjournals.org.

[11] Darweesh HHM (2020) Influence of sun flower stalk ash (SFSA) on the behavior of Portland Cement, Results in Engineering, 8, 100171. https://doi.org/10.1016/j.rineng.2020.100171.

[12] Darweesh HHM (2021) Utilization of Physalis Pith ash as a pozzolanic material in Portland cement pastes, Jounal of Biomaterials. 5, 1, 1-9. http://www.sciencepublishinggroup.com/j/jb.

[13] Darweesh HHM (2021) Characterization of Coir Pith Ash Blended Cement Pastes, Research & Development in Material science, RDMS.000851. 15, 1, 1630-1630. DOI: 10.31031/RDMS.2021.15.000851.

[14] Hegazy BE; Fouad HA; Hassanain AM (2012) Brick manufacturing from water treatment sludge and rice husk ash, Aus. J. Bas. Appl. Sci. 6 (3) 453–461. https://sswm.info/node/4027.

[15] Ramadan MO; Fouad HA; Hassanain MA (2008) Reuse of water treatment plant sludge in brick manufacturing, J. Appl. Sci. Res. 4, 10, 1223-1229. https://www.researchgate.net/publication/295548404.

[16] Darweesh HHM; El-Meligy MG (2014) Non-Conventional Light-Weight Clay Bricks from Homra and Kraft Pulp Wastes, Journal of Chemistry and Materials Research, 1, 4, 123–129. www.oricpub.com.

[17] Kazmi SM; Abbas S; Nehdi ML; Saleem MA; Munir MJ (2017) Feasibility of using waste glass sludge in production of ecofriendly clay bricks, J. Mater. Civ. Eng. 29, 8, 04017056. doi: http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0001928.

[18] Esmeray E; Atis M (2019) Utilization of sewage sludge, oven slag and fly ash in clay brick, Construct. Build. Mater. 194, 110–121. https://doi.org/10.1016/j.conbuildmat.2018.10.231.

[19] Hegazy BE; Fouad HA; Hassanain AM (2012) Incorporation of water sludge, silica fume, and rice husk ash in brick making, Adv. Environ. Res. 1, 1, 83–96. doi: http://dx.doi.org/10.12989/aer.2012.1.1.083.

[20] Lang L; Song C; Xue L; Chen B (2020) Effectiveness of waste steel slag powder on the strength development and associated micro-mechanisms of cement-stabilized dredged sludge, Constr. Build. Mater. 240, 117975. doi: http://dx.doi.org/10.1016/j.conbuildmat.2019.117975.

[21] Lang L; Liu N; Chen B (2020) Strength development of solidified dredged sludge containing humic acid with cement, lime and nano-SiO2, Constr. Build. Mater. 230, 116971. doi: http://dx.doi.org/10.1016/j.conbuildmat.2019.116971.

[22] Lang L; Chen B; Li N (2020) Utilization of lime/carbide slag-activated ground granulated blast-furnace slag for dredged sludge stabilization, Mar. Georesources Geotechnol., 1–11. doi: http://dx.doi.org/10.1080/1064119X.2020.1741050.

[23] Kazmi MS; Abbas S; Munir MJ; Khitab A (2016) Exploratory study on the effect of waste rice husk and sugarcane bagasse ashes in burnt clay bricks, J. Build. Eng. 7, 372–378, doi: http://dx.doi.org/10.1016/j.ceramint.2014.10.102.

[24] IRRI International Rice Research Institute. (Accessed 28.7.16). https://www.irri.org/rice-straw-management.

[25] Abdelhady S; Borello D; Shaban A; Rispoli F (2014) Viability study of biomass power plant fired with rice straw in Egypt, Energy Procedia 61, 211–215. doi: http://dx.doi.org/10.1016/j.egypro.2014.11.1072.

[26] Yuan Q; Pump J; Conrad R (2014) Straw application in paddy soil enhances methane production also from other carbon sources, Biogeosciences 11, 237–246.https://pdfs.semanticscholar.org/1dea/910420d45de6c0f1e1c43821fedcca72e947.pdf.

[27] Rehman MSU; Umer MA; Rashid N; Kima I; Han J (2013) Sono-assisted sulfuric acid process for economical recovery of fermentable sugars and mesoporous pure silica from rice straw, Ind. Crops Prod. 49, 705–711, doi: http://dx.doi.org/10.1016/j.indcrop.2013.06.034.

[28] Darweesh HHM (2021) Extraction of lignin from wastes of sugarcane bagasse and its utilization as an admixture for Portland cement, NanoNext, 2, 1, 13-27. DOI: https://doi.org/10.34256/nnxt2113.

[29] Darweesh HHM (2021) Low Heat Blended Cements Containing Nanosized Particles of Natural Pumice Alone or in Combination with Granulated Blast Furnace Slag, Nano Progress, 3, 5, 38-46. DOI: 10.36686/Ariviyal.NP.2021.03.05.025.

[30] Velasco PM; Ortíz MM; Giró MM; Velasco LM (2014) Fired clay bricks manufactured by adding wastes as sustainable construction material–a review, Constr. Build. Mater. 63, 97–107. doi: http://dx.doi.org/10.1016/j.conbuildmat.2014.03.045.

[31] Szymkiewicz F; Barrett AG; Marino JP; Le Kouby A; Reiffsteck P (2015) Assessment of Strength and Other Mechanical Properties of the Deep Mixing Material June, (2015). https://hal.archives-ouvertes.fr/hal-01597675/document.

[32] Allam M; Garas G (2010) Recycled chopped rice straw–cement bricks: an analytical and economical study, WIT Trans. Ecol. Environ. 140, 79–86. https://www.witpress.com/Secure/elibrary/papers/WM10/WM10008FU1.pdf.

[33] Darweesh HHM; Awad HM; Tawfik A (2011) Red bricks from Dakhla formation clay –Tushka area- incorporated with some industrial waste by-products, Ce Ca, 41, 2, 125-131.

[34] Darweesh HHM; Kenawy SH (2020) Light-weight highly porous building bricks from Sawdust, Indian Journal of Engineering, 17, 47, 193-202. www.discoveryjournals.org.

[35] Darweesh HHM (2019) Recycling of glass waste in ceramics—part I: physical, mechanical and thermal properties, SN Applied Sciences, 1: 1274. https://doi.org/10.1007/s42452-019-1304-8.

[36] Darweesh HHM; El-Meligy MG (2014) Non-conventional light-weight clay bricks from homra and kraft pulp wastes", J. Chemistry and materials research Vol. 1, No. 4, November 5, 2014, 1-7. ORIC publications ISSN: 2381-3628.

[37] ASTM C.20 (2010) Standard test methods for apparent porosity, water absorption, apparent specific gravity and bulk Modulus of burned refractory brick and shapes. doi: http://dx.doi.org/10.1520/C0020-00R10.

[38] ASTM- Designation, C133-97 (1997) Standard test method for cold crushing strength and modulus of rupture of refractories, 1-6.

[39] Sutcu M (2015) Influence of expanded vermiculite on physical properties and thermal conductivity of clay bricks, Ceram. Int., 41, 2, 2819–2827. doi: http://dx.doi.org/10.1016/j.ceramint.2014.10.102.

[40] Ukwatta A; Mohajerani A; Eshtiaghi N; Setunge S (2016) Variation in physical and mechanical properties of fired-clay bricks incorporating ETP biosolids, Journal of Cleaner Production, 119, 76–85, doi: http://dx.doi.org/10.1016/j.jclepro.2016.01.094.

[41] Darweesh HHM; El-Meligy MG (2014) Pulp White Liquor Waste as a Cement Admixture-Part I, American Journal of Mining and Metallurgy, 2, 4, 88-93. DOI: 10.12691/ajmm-2-4-5.

[42] Garcia-Ubaque CA; Liliana G; Juan CM (2013) Quality study of ceramic bricks manufacture with clay and ashes from the incineration of municipal solid wastes, Afinidad LXX 561, 61–66. https://www.raco.cat/index.php/afinidad/article/view/268541/356130.

[43] Eliche-Quesada D; Leite-Costa J (2016) Use of bottom ash from olive pomace combustion in the production of eco-friendly fired clay bricks, Waste Manag. 48, 323–333. doi: http://dx.doi.org/10.1016/j.wasman.2015.11.042.

[44] Faria K; Gurgel R; Holanda J (2012) Recycling of sugarcane bagasse ash waste in the production of clay bricks, J. Environ. Manage.101, 7–12, doi: http://dx.doi.org/10.1016/j.jenvman.2012.01.032.

[45] ASTM C. 67 (2003) Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile, American Society for Testing and Materials, Philadelphia, PA. doi: http://dx.doi.org/10.1520/C0067-03.

[46] Darweesh HHM, Wahsh MMS, Negim EM (2012) Densification and thermo mechanical properties of conventional ceramic composites containing two different industrial byproducts. Am Eurasian J Sci Res 7: 123–130. https://doi.org/10.5829/idosi.aejsr.2012.7.3.1104.

[47] Kale SA (2019) Mechanical design, materials and manufacturing, chapter 7 by Darweesh HHM (2019) Nanomaterials, ceramic bulk and bioceramics: synthesis, properties and applications, 1st edn. Nova Science, New York, pp 175–262.

[48] Zanelli C, Raimondo M, Guarini G, Dondi M (2011) The vitreous phase of porcelain stoneware: Composition, evolution during sintering and physical properties. J Non-Cryst Solids 357: 3251–3260. https://doi.org/10.1016/j.jnoncrysol.2011.05.020.

[49] Darweesh HHM (2020) Characteristics of Portland cement pastes blended with silica nanoparticles, Chem. J. 5, 1–14. http://purkh.com/index.php/tochem.