Journal of
Engineering Sciences
Faculty of Engineering
Assiut University
مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط
journal homepage: http://jesaun.journals.ekb.eg

Recycling Agricultural Wastes in Concrete Maize and Sorghum as examples

Received 5 October 2023; Revised 3 February 2024; Accepted 3 February 2024

Ahmed Faisal Oan[1]

Keywords
Agricultural wastes, Corn Cob ash, Sorghum Stalks ash, Supplementary cementitious materials.

Abstract: Agricultural crops produce large number of agricultural wastes. Some of this waste is reused as fertilizers for the agricultural areas, but the remaining amount which represents the majority of the wastes is incinerated in uncontrolled and random ways and has a negative impact on the environment. One of these methods is to burn the maize and sorghum wastes to get rid of the stalks s and corn cob after use. The process of burning results in excessive production of carbon dioxide that pollutes the environment significantly. This study aims to investigate the use of Corn Cob Ash (CCA) as well as Sorghum Stalks Ash (SSA) as a partial replacement of cement in concrete. XRF chemical analysis was carried out on both SSA and CCA, and the results showed that both materials contained high percentages of silica oxide which indicates that these ashes can exhibit pozzolanic activity. The aim of this study is to investigate the effect of using the ashes of corn cobs and sorghum stalks as supplementary cementitious materials on the mechanical properties of concrete. In this study, the ashes of sorghum stalks and corn cobs were used to partially replace the cement in mortar and concrete mixtures. For mortar mixtures the replacement ratios were 5%,10%,20% and 40% while in concrete mixtures the replacement ratios were 5%,10% and 20%. Different concrete and mortar mixtures were tested in compression at different ages and the results showed that CCA and SSA can be used as a partial replacement of cement in both mortar and concrete as there was a significant improvement in the compressive strength, as for mortar mixtures the maximum increase in strength was 22% while the maximum increase in strength of concrete mixtures was 30%.

1. **Introduction**

Agricultural waste can represent national wealth for any country. Many developed countries have taken serious actions to make benefits out of the agricultural wastes [1,2]. The United

[1] Assist. Professor. Dept. of Construction Eng., Egyptian Russian University, Cairo, Egypt. afoan@eru.edu.eg

https://doi.org/10.21608/JESAUN.2024.2430887.1268

States, China and India represent the countries with the highest number of studies in this field. Most of the research carried out was focused upon wheat and corn because they are the main producers of these types of crops [3].

The United States, China and India represent the countries with the highest number of studies in this field. Most of the research carried out was focused upon wheat and corn because they are the main producers of these types of crops [3]. In Egypt, the agricultural wastes vary between 30-35 million tons annually, only about 30% of these wastes are being used either as animal feed or as organic manure [4]. This waste can be converted to real wealth if properly recycled. Most of these wastes are burned in open fields which harms the environment, whereas if there are goods waste management systems, these agricultural wastes can be used in beneficial applications such as organic fertilizers, biochar, composts…etc.

One of the crops that is widely cultivated in Egypt is the Rice, which leaves behind lots of wastes that are usually burnt in the field to get rid of its husk, Although the Rice Husk Ash (RHA) proved to be beneficial when used as a supplementary cementitious material [5-10] as it contains a very high percentage of amorphous silica that possess the pozzolanic activity. A 15% RHA replacement ratio (of cement by weight) seemed to be a common optimum percentage obtained by many researchers e.g. [5,9] that leads to superior behavior of concrete. Not only the rice husk ash was investigated, but also the Rice Straw Ash (RSA) have been studied and proved to be beneficial in reducing the water absorption of concrete and increasing the compressive strength [11-13]. Also, Sugar cane is widely cultivated in Upper Egypt as a main source for the sugar production results in lots of bagasse wastes; these wastes can be recycled in different ways. For example, some studies showed that bagasse ash can increase the compressive strength significantly when used to replace cement in concrete [14-16]. Also, the sugarcane was used as a retarding admixture in concrete [17], While the bagasse fibers were used to increase the tensile strength and ductility of the concrete [18, 19]. The wastes of maize and sorghum – which are the main points of investigation in this paper- were also used in concrete and showed a promising result. For example, the corncob was used to replace the coarse aggregate to produce light weight concrete for non-structural applications [20, 21], whereas most of the research carried out investigated the possibility of using the corncob and sorghum stalks ashes as supplementary cementing materials [22-27].

According to the latest statistics carried out in Egypt [28], the total cultivated area of maize is 1741 thousand feddans which produces around 5.5 million tons. The maize stalks are used as feed for the cattle while the corncob is useless and is thrown away. For the sorghum, the total area of cultivated land is 355 thousand feddans which produces 914 thousand tons of sorghum [28], the sorghum stalks are subjected to uncontrolled incineration processes to clear it from the lands which lead to polluting the environment.

2. Experimental Program

An experimental program was designed to study the effect of using Corn Cob Ash (CCA) and Sorghum stalks Ash (SSA) as a possible partial replacement of cement. A total number of 138 specimens were examined in the experimental work, where the experimental program was divided into two phases; the first phase was to study the effect using the two types of ashes as partial replacement of cement in mortar mixtures, while the second phase was to study the effect of such replacement on the compressive strength of concrete mixtures.In phase one, the percentages of replacement were 5%, 10%, 20% and 40% of cement by weight for the mortar cubes. While for the concrete cubes in phase 2, the replacement ratios were 5%, 10 and 20% of cement by weight.

2.1. Materials

Cement: ordinary Portland cement (OPC) CEMI 42.5N was used. The chemical composition of cement is shown in table (1) as percentages of the total mass of the sample.

Table 1: Chemical composition of OPC, SSA and CCA

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	TiO_2	MnO	ZnO	SrO	CuO	ZrO_2	Cl^-	LOI*
OPC	21.20	4.67	5.05	64.73	1.50	2.05	0.30	0.22	-	-	-	-	-	-	-	-	0.20
SSA	38.92	4.24	3.81	9.95	7.21	3.86	3.18	11.60	3.48	0.61	0.17	0.03	0.03	0.02	-	7.13	5.70
CCA	23.00	5.17	6.39	9.45	6.93	4.90	0.80	20.80	5.15	0.64	0.15	0.07	0.03	-	0.02	3.55	12.9

*LOI: Loss on ignition

2.1.1. Corn cob ash (CCA)

Corn cob from the maize locally available in Egypt was obtained and burned in air at temperature up to 600°C until it was converted totally to ash; then the ash was placed in oven at temperature 250°C for 4 hours to get rid of organic matters (carbon). The resultants were then grinded to produce fine ash that can pass through sieve #170. To obtain reactive amorphous silica in the ashes, the temperature should be lower than 700^{o}C [6,8,29] and that was the reason to burn the wastes at a temperature around 600°C. The chemical composition of CCA is shown in table (1).

2.1.2. Sorghum stalks s Ash (SSA)

Sorghum stalks were converted into ash by the same sequence which used in (CCA), then the ash was ground in grinder to be with fineness as cement. The chemical composition of SSA is shown in table (1).

2.1.3. Aggregates

Crushed dolomites obtained from Ataka Mountain were used in this experimental program as coarse aggregate with maximum nominal size 12.5mm and specific gravity 2.57. The fine aggregate used in this experimental program was medium sand with specific gravity of 2.6 and the percentage of clay and soft materials by weight was 1%.

2.2. Mix proportions of specimens

In phase one, the mortar used in this program was mixed by using 3:1 proportion, where three parts of sand were mixed with one part of cement for the control mix. For the other mixes, the ashes of CCA and SSA were used to replace the cement (by weight) partially with ratios 5%, 10%, 20% and 40% and the overall mixing proportion of sand and modified cement was maintained 3:1.

In phase 2, the concrete mix used in the experimental program was designed using the British method for design. For the other mixes, the ashes of CCA and SSA were used to replace the cement (by weight) partially with ratios 5%, 10 and 20% and the overall mixing proportion of concrete was maintained as designed. For all specimens, content of course and fine aggregate and water / binder ratio was kept constant. Table (2) shows the concrete mixing proportions of all specimens in phase two.

Table 2: Concrete Mix Proportions

Mix no.	Dolomite Kg m^{-3}	Sand Kg m^{-3}	Cement Kg m^{-3}	SSA Kg m^{-3}	CCA Kg m^{-3}	Water L m^{-3}
M1	1302	701	300	-	-	150
M2	1302	701	285	15	-	150
M3	1302	701	270	30	-	150
M4	1302	701	240	60	-	150
M5	1302	701	285	-	15	150
M6	1302	701	270	-	30	150
M7	1302	701	240	-	60	150

M1: Control Mix.
M2: Mix with 5% of the cement replaced by SSA
M3: Mix with 10% of the cement replaced by SSA
M4: Mix with 20% of the cement replaced by SSA
M5: Mix with 5% of the cement replaced by CCA
M6: Mix with 10% of the cement replaced by CCA
M7: Mix with 20% of the cement replaced by CCA

3. Results and Discussion

3.1. Fresh Concrete properties

All mixes with different ratios of SSA and CCA were tested for Slump to determine the workability of concrete. The results are given in table (3).

Table 3: Slump test values

Replacement Percentage	Control (0%)	5%	10%	20%
SSA	29 mm	27mm	25mm	24mm
CCA	31mm	29mm	32mm	28mm

There was a slight variation in the slump when CCA was used in different percentages, but when SSA was used the slump reduced and the reduction in slump increased by increasing the percentage of replacement.

3.2. Hardened properties

3.2.1. Compressive strength of mortar

Standard mortar cubes (50 × 50 × 50 mm) were used in the testing, and the replacement ratios were 5%, 10%, 20%, and 40%replacement. The specimens were placed in curing sink using tape water for curing. The compression tests were carried out on the mortar cubes at 3-day, 7-day and 28-day ages.

3.2.2. Sorghum stalks Ash (SSA)

The results showed that the maximum compressive strength was obtained at 20% replacement for all tested ages. When SSA was used in different ratios, the 5% and 20% replacement ratios showed an improvement in compressive strength by 20% increase, while 10% and 40% replacement showed a reduction in strength by 28 % and 14% respectively at age 28 day. This increase is due to the pozzolanic reaction between C-H from hydration process of cement and silica which exists in SSA resulting in forming more C-S-H. The results of compressive strength at different ages are given in table (4) and figure (1).

Table 4: Compressive strength of Mortar with different percentages of SSA

Replacement	**Compressive strength at age 3-days (MPa)**	**Compressive strength at age 7-days (MPa)**	**Compressive strength at age 28-days (MPa)**
Control	14.63	16.15	27
5%	15.46	18.85	31.19
10%	11.93	14.15	19.46
20%	15.91	23.61	32.94
40%	11.22	13.38	23.34

3.2.3. Corn Cob Ash (CCA)

The results showed that optimum compressive strength was obtained at 5% replacement after that the specimens exhibited strength degradation. At age 28-day, the 5% replacement ratio showed an increase in compressive strength by 20%, while10%, 20% and 40% replacement showed a reduction in strength by 3 %,14% and 48% respectively. The results of compressive strength at different ages are given in table (5) and figure (2).

Table 5: Compressive strength of Mortar with different percentages of CCA

Replacement	**Compressive strength at age 3-days (MPa)**	**Compressive strength at age 7-days (MPa)**	**Compressive strength at age 28-days (MPa)**
Control	14.63	16.15	27
5%	21.85	24.36	33.03
10%	15.22	20.26	26.3
20%	12.66	14.96	21.56
40%	10.1	9.74	14.11

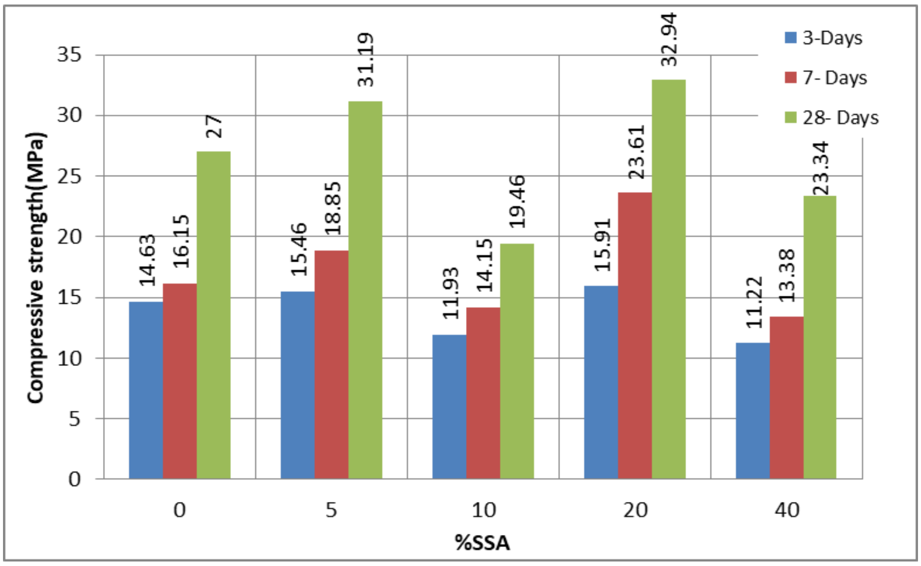

Fig. 1: The results of compressive strength of mortar using SSA at different ages

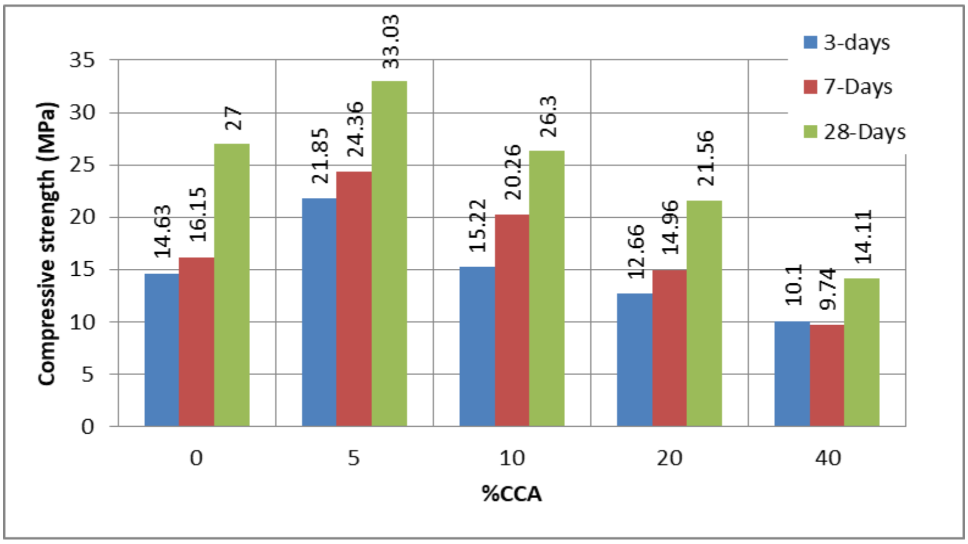

Fig. 2: The results of compressive strength of mortar using CCA at different ages

Compressive strength of concrete cubes

In phase two, standard concrete cubes of dimensions 150*150*150 mm were tested at the ages of 7-day and 28-day ages. The percentages of replacements were 5%, 10% and 20% of cement by weight.

3.2.4. Sorghum stalks Ash (SSA)

The results showed that 5% replacement gave optimum compressive strength at 28-day age, which corresponds to 30% increase in the compressive strength. Similar results were obtained by researchers that showed the optimum percentage of SSA to replace the cement in pervious concrete was5%, which resulted in increasing the compressive strength of concrete by 16%.[32]. The strength at 7-day age was almost the same for the 5% replacement ratio but showed gradual decrease in strength when the replacement ratio increased to 10% and 20% but at 28- day age all the results showed significant increase in compressive strength which varied from 12% to 30%. This can be attributed to the effect of high percentage of silica (39%) in the SSA which could have pozzolanic effect that appears on the late ages of concrete (i.e. 28-day and afterwards). As the excess silica will require the formation of calcium hydroxide (C-H) first to react with it to form the calcium silicate hydrate (C-S-H) which increases the strength significantly. This opinion is supported by the results obtained by researchers who showed that using corn straw ashes as binder supplement in concrete showed low strength values at early ages and over long periods there was a significant increase in strength [30].

Table 6: Compressive strength of Concrete with different percentages of SSA

Title	Compressive strength at age 7-days (MPa)	Compressive strength at age 28-days (MPa)
Control	20.1	23.7
5%	20.27	30.77
10%	18.99	27.17
20%	18.62	26.65

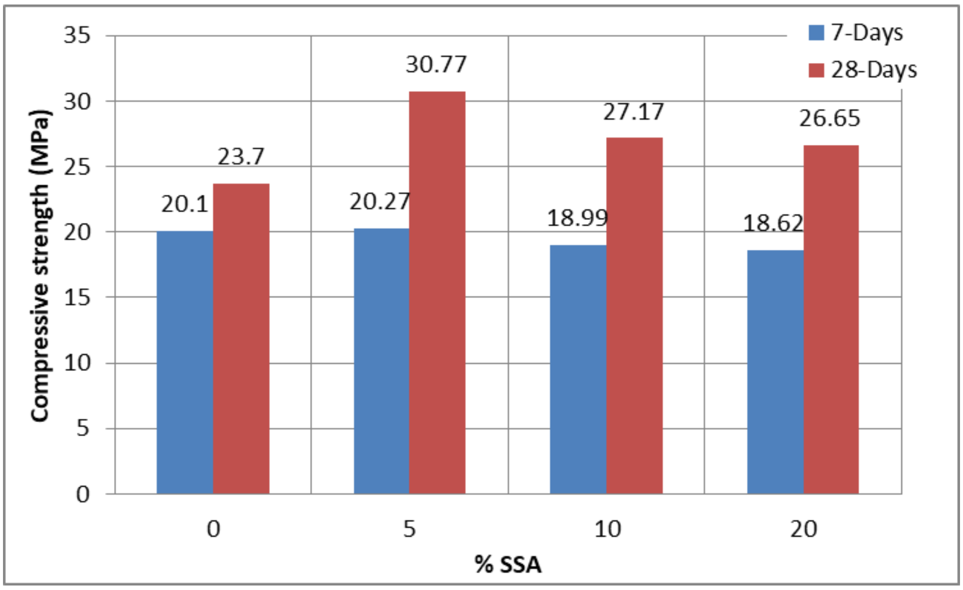

Fig. 3: Compressive strength of Concrete with different percentages of SSA

3.2.5. Corn Cob Ash (CCA)

The results of compressive strength test showed that at age 7 days there was slight difference in compressive strength at 5% and 10% replacement ratios but for 20% there was a drop in the compressive strength. An explanation for that might be the effect of CCA which contains considerable amount of silica that could delay OPC's early hydration which in turn slows down concrete's ability to acquire strength [31]. For 28-day age, - similar to SSA - all the replacement ratios showed an increase in the compressive strength which was maximum at 10% replacement with 28% increase. Similar results showed that the compressive strength of concrete at 7-day age was not affected when CCA was added to concrete whereas at 28-day age the strength increased significantly [29]. The results are shown in table (7) and figure (4).

Table 7: Compressive strength of Concrete with different percentages of CCA

Replacement	Compressive strength at age 7-days (MPa)	Compressive strength at age 28-days (MPa)
Control	20.1	23.7
5%	20.84	28.34
10%	20.24	30.29
20%	17.91	25.26

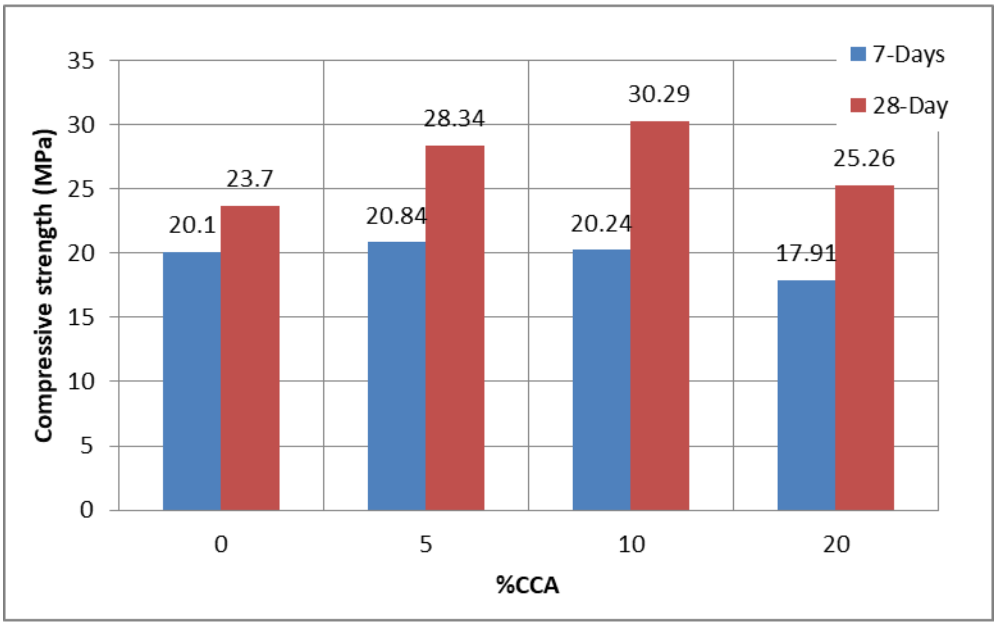

Fig. 4: Compressive strength of Concrete with different percentages of CCA

4. Conclusions

The poor waste management of agricultural wastes can lead to major problems from the environmental and economical perspectives. Many researchers were motivated to investigate the possibility of recycling agricultural waste in concrete production.

The current study focused on the evaluation of pozzolanic reactivity of Sorghum stalks and corn cob ashes ash supplementary cementitious materials in mortar and concrete mixtures. The following conclusions were drawn from the study:

• XRF chemical analysis showed that Sorghum stalks ashes and corn cob ashes contains considerable amounts of silicon oxide that proved to have a pozzolanic reactivity and can be used as a binder supplement.

• The use of Sorghum Stalk Ash and Corn Cob Ash showed lower initial strength at early ages (i.e. 7-day age) when compared to control mixtures, while over longer periods of time the strength increases.

• Corn Cob Ash proved to be used as a binder supplement in mortar and concrete mixtures. The optimum percentage of replacement in mortar mixtures was found to be 5% of cement weight, while the optimum percentage was increased to 10% of the cement weight when the coarse aggregate was introduced to the mixture to for concrete.

• For the Sorghum Stalk Ash, the optimum percentage or replacement was found to be 5% of the cement weight which resulted in increase of almost 30% of the concrete compressive strength.

References

[1] Shaik Muntasir Shovon, Faysal Ahamed Akash, Wahida Rahman, Md Abdur Rahman, Prosenjeet Chakraborty, H.M. Zakir Hossain, Minhaj Uddin Monir (2024), “Strategies of managing solid waste and energy recovery for a developing country – A review”, Heliyon Journal, January 2024, e24736.

[2] Agnieszka Komor and Barbara Bujanowicz-Haraś (2019), “Waste from the agricultural sector in the European Union countries in the context of the bioeconomy development”, Agronomy Science, Volume 4, p.p 47-59.

[3] Monica Duque-Acevedo, Luis J. Belmonte-Urena, Francisco Joaquín Cortes García, Francisco Camacho-Ferre (2020), “Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses”, Global Ecology and Conservation Journal, Volume 22.

[4] Shaban D. Abou Hussein and Omaima M. Sawan (2010), “The Utilization of Agricultural Waste as One of the Environmental Issues in Egypt (A Case Study)”, Journal of Applied Sciences Research, Volume 6, Issue 8, p.p 1116-1124.

[5] Smita Sahoo, Pravat Kumar Parhi and Bikash Chandra Panda (2021), “Durability properties of concrete with silica fume and rice husk ash”, Cleaner Engineering and Technology Journal, Volume 2, June 2021, Article 100067.

[6] Ayesha Siddika, Md. Abdullah Al Mamun, Rayed Alyousef, and Hossein Mohammad Hosseini (2021), “State-of-the-art-review on rice husk ash: A supplementary cementitious material in concrete”, Journal of King Saud University - Engineering Sciences, Volume 33, Issue 5, July 2021, Pages 294-307.

[7] Natt Makul (2019), “Combined use of untreated-waste rice husk ash and foundry sand waste in high-performance self-consolidating concrete”, Results in Materials Journal, Volume 1, August 2019, Article 100014.

[8] Fapohunda Christopher, Akinbile Bolatito and Shittu Ahmed (2017), “Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement – A review”, International Journal of Sustainable Built Environment, Volume 6, Issue 2, December 2017, Pages 675-692.

[9] Mohaiminul Haque, Sourav Ray, Ayesha Ferdous Mita, Shayan Bhattacharjee and Md. Jami bin Shams (2021), “Prediction and optimization of the fresh and hardened properties of concrete containing rice husk ash and glass fiber using response surface methodology”, Case Studies in Construction Materials Journal, Volume 14, June 2021, Article e00505.

[10] Ezio Marchetti (2020), “Use of Agricultural Wastes as Supplementary Cementitious Materials”, M.Sc. thesis, KTH Royal Institute of Technology, School of Architecture and the Built Environment, Stockholm, Sweden.

[11] Arunabh Pandey and Brind Kumar (2017), “Evaluation of water absorption and chloride ion penetration of rice straw ash and microsilica admixed pavement quality concrete”, Heliyon Journal, volume 5, Issue 8, August 01, 2019, Article e02256,

[12] Samantha Hidalgo, Lourdes Soriano, José Monzó, Jordi Payá, Alba Font and M. Victoria Borrachero (2021), “Evaluation of Rice Straw Ash as a Pozzolanic Addition in Cementitious Mixtures”, Applied Sciences Journal, Volume 11, Article 773.

[13] S. Nour Eldin, K. Sharobim, H. Mokhtar and N. A. Hussein (2013), “Effect of Rice Straw Ash on the Behaviour of High-Performance Concrete Mixes”, Port Said Engineering Research Journal, Faculty of Engineering - Port Said University, Volume 17, Issue No. 2, September 2013 pp: 129 – 135.

[14] Nancy T. Hussien and Ahmed F. Oan (2022), “The Use of Sugarcane Wastes in Concrete”, Journal of Engineering and Applied Science, Vol. 69, Article 31, March 2022.

[15] Pritish Gupta Quedoua, Eric Wirquinb and Chandradeo Bokhoree (2021), “Sustainable concrete: Potency of sugarcane bagasse ash as a cementitious material in the construction industry”, Case Studies in Construction Materials Journal, Volume 14, June 2021, Article e00545.

[16] Travis D. Garrett, Henry E. Cardenas, and Joan G. Lynam (2020), “Sugarcane bagasse and rice husk ash pozzolans: Cement strength and corrosion effects when using saltwater”, Current Research in Green and Sustainable Chemistry Journal, Volumes 1–2, February–April 2020, Pages 7-13.

[17] Amaziah Walter Otunyo and Innocent Koate (2015), “Sugar Cane Juice as a Retarding Admixture in Concrete Production”, Global Journal of Engineering Research, Volume 14, pages 17-23.

[18] Henry A Colorado and John F Zapata (2019), “Composites of Portland cement paste and sugarcane bagasse fibers: structure-property relation and Weibull statistics”, Journal of Materials and Environmental Sciences, Volume 10, Issue 11, Pages 1162-1171.

[19] Carla Regina Ferreira, Sheron Stephany Tavares, Bruno Henrique Moreira Ferreira, Amanda Martins Fernandes, Sara Jane Gomes Fonseca,Carlos Augusto de Souza Oliveira, Ricardo Luiz Perez Teixeira and Leonardo Lúcio de Araújo Gouveia (2017), “Comparative Study About Mechanical Properties of Structural Standard Concrete and Concrete with Addition of Vegetable Fibers”, Materials Research Journal, Volume 20, Issue 2, pages 102-107.

[20] Jorge Pintoa, Barbosa Vieiraa, Hélder Pereiraa, Carlos Jacintoa, Paulo Vilelaa, Anabela Paivaa, Sandra Pereiraa, Vítor M.C.F. Cunhaa, and Humberto Varumb (2012), “CornCob Lightweight Concrete for Non-structural Applications”, Construction and Building Materials Journal, Volume 34, pages. 346–35.

[21] Naraindas Bheel, Montasir Osman Ahmed Ali, Yue Liu, T. Tafsirojjaman, Paul Awoyera, Nadhim Hamah Sor and Lenin Miguel Bendezu Romero (2021), “Utilization of Corn Cob Ash as Fine Aggregate and Ground Granulated Blast Furnace Slag as Cementitious Material in Concrete”, Buildings Journal, Volume 11, Article 422.

[22] B.G. Rolón and P. Fuentes Castañed (2021), “Mechanical resistance and corrosion of concrete added with ashes of corn, sorghum, and wheat”, Cleaner Materials Journal, Volume 2, 15 December 2021, Article 100028.

[23] E. E. Ndububa and P. I. Aburime (2021), “Flexural Strength of Concrete Made from Guınea Corn Husk Ash as Partial Replacement for Cement”, Nigerian Journal of Engineering, Volume 28, Issue 1, pages 25-31.

[24] Sunita Kumari, Dinesh Chander, and Rinku Walia (2018), “Durability and Strength analysis of Concrete by Partial Replacement of Cement with Corn Cob Ash and Rice Husk Ash”, International Journal of Research in Advent Technology, Volume.6, Issue 7, July 2018, pages 1593-1601.

[25] B.G. Rolón and P. Fuentes Castañeda (2021), “Mechanical resistance and corrosion of concrete added with ashes of corn, sorghum, and wheat”, Cleaner Materials Journal, Volume 2, 15 December 2021, Article 100028.

[26] John Kamau and Ash Ahmed (2017), “Suitability of Maize Cob Ash as a Partial Cement Replacement”, Juniper Online Journal Material Science. Volume 2, Issue 5.

[27] Charles Prado Ferreira de Lima and Guilherme Chagas Cordeiro (2021), “Evaluation of corn straw ash as supplementary cementitious material: Effect of acid leaching on its pozzolanic activity”, Cement Journal, Volume 4, June 2021, Article 100007.

[28] Statistical Yearbook 2017, Issue No. 108, Egypt.

[29] Hanifi Binici, Faruk Yucegok, Orhan Aksogan and Hasan Kaplan (2008), “Effect of Corncob, Wheat Straw, and Plane Leaf Ashes as Mineral Admixtures on Concrete Durability”, Journal of materials in civil engineering, July 2008, p.p. 478-483.

[30] Adekunle O. Aliu, Oladimeji B. Olalusi, Paul O. Awoyera and Moses Kiliswa (2023), “Evaluation of pozzolanic reactivity of maize straw ash as a binder supplement in concrete”, Case Studies in Construction Materials Journal, Volume 18. July 2023.

[31] Jawad Ahmad, Mohamed Moafak Arbili, Hisham Alabduljabbar and Ahmed Farouk Deifalla (2023), “Concrete made with partially substitution corn cob ash: A review”, Case Studies in Construction Materials Journal, Volume 18, e02100.

[32] M A Tijani, W O Ajagbe, A A Ganiyu and O A Agbede (2019), “Sustainable pervious concrete incorporating sorghum husk ash as cement replacement”, IOP Conf. Series: Materials Science and Engineering 640 (2019) 012051.