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Durability characteristics of millet husk ash: A study on self-compacting concrete

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ABSTRACT

Durability is one of the major concerns in concrete industries. Several attempts have been made to investigate the suitability of various supplementary materials from agricultural waste to increase the durability properties such as acid resistance, sulfate attack, alkaline attack, sorptivity, chloride permeability, elevated temperature, and water absorption self-compacting concrete mixes. However, this paper studied the durability properties of self-compacting concrete modified with millet husk ash (MHA) subjected to different environmental conditions such as sulfate attack from sulphuric acid and magnesium sulfate salt, elevated temperature, and water absorption. Grade 40 (control) SCC obtained from serries of trial mixes using 0.35 water-cement ratio was used for this study. Other mixes were derived from the control mix by replacing cement with 5, 10, 15, 20, 25, and 30 % by weight of MHA, respectively. The effects of sulfate elevated temperature and water absorption was evaluated for all mixes. The experimental results of this work showed that the MHA is a pozzolanic material and can reduce the ingress of water and sulfate attack on concrete. However, the addition of MHA reduces the heat-resisting capacity of concrete.

ABSTRAK

Daya tahan adalah salah satu perhatian utama dalam industri beton. Beberapa upaya telah dilakukan untuk mengetahui kesesuaian berbagai bahan pelengkap dari limbah pertanian untuk meningkatkan sifat daya tahan seperti ketahanan asam, serangan sulfat, serangan basa, daya serap, daya tembus klorida, suhu tinggi, dan penyerapan air campuran beton *self-compacting*. Namun, makalah ini mempelajari daya tahan beton *self-compacting* yang dimodifikasi dengan abu sekam millet (MHA) yang mengalami kondisi lingkungan yang berbeda seperti serangan sulfat dari asam sulfat dan garam magnesium sulfat, suhu tinggi, dan penyerapan air. Grade 40 (kontrol) SCC yang diperoleh dari serangkaian campuran percobaan menggunakan rasio air-semen 0,35 digunakan untuk penelitian ini. Campuran lain berasal dari campuran kontrol dengan mengganti semen dengan 5, 10, 15, 20, 25, dan 30% berat MHA, masing-masing. Efek dari peningkatan suhu dan penyerapan air sulfat dievaluasi untuk semua campuran. Hasil percobaan penelitian ini menunjukkan bahwa MHA merupakan material pozzolan dan dapat mengurangi serangan air dan sulfat pada beton. Namun, penambahan MHA mengurangi kapasitas beton menahan panas.

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1. Introduction

Self-compacting concrete is defined as a homogeneous material that can flow and fill the formwork, even in the presence of congested reinforcement, without requiring vibration [1-2]. Okamura first developed it in 1988 [3]. Despite the lower coarse aggregate content compared with CC, SCC has better mechanical properties and resistance to the ingress of aggressive agents [4]. The introduction of SCC has caused a revolution in the concrete construction process among construction industries [5]. The improved construction practice and performance, combined with the health and safety benefits, make SCC a desirable solution for precast concrete and civil engineering construction [6].

Concrete consumption is the most consumed material globally after water and was estimated in 2006 as 21 to 31 billion tonnes [7]. It is produced from aggregates (coarse and fine), water, cement, and admixtures [8]. Concrete could either be conventional or self-compacting. However, self-compacting concrete (SCC) has greater compressive strength, bond strength, and durability when compared to conventional concrete (CC) of similar properties [9]. In addition, a large number of voids in CC compared to SCC can be eliminated/reduced by adequate compaction by mechanical vibrator; hence, this makes concrete more expensive and delays its production. The elimination of SCC vibration has reduced the construction time and labor cost with improved productivity [6, 8]. Thus, to overcome the challenges mentioned above associated with the placement of CC, SCC was introduced for easier placement and associated benefits [10].

Cement is an important construction ingredient, constitutes a major source of carbon dioxide (CO^2), with approximately 2.4% of worldwide emissions from industrial and energy sources [11]. In addition, SCC required more cement (400 – 600 kg/m^3) [6]. This implies, the more the production SCC, the more the emission of CO_2. However, this emission can be reduced using incorporating mineral additives in SCC [2, 12]. There have been extensive studies carried out on the use of the more common mineral additives such as RHA [3, 13-14], fine limestone powder [15-17], pulverized-fuel ash [18-20], silica fume [21-23]. However, lesser interests are shown to other types of mineral additives due to various factors: their availability, transportation, and handling problems, and heterogeneity of the additives' chemical components [3].

Out of the approximate 29.87 million tons of millet is produced yearly globally, Nigeria is the second-largest producer of millet, account for about 16.74% [24]. In addition, about 40% of the weight of the harvested millet is removed as husk from the stalk harvested [25]. The use of millet husk has no long history in construction industries. However, some researches show that millet husk ash (MHA) is a pozzolanic material [26-28] and can serve in partial replacement of cement in NC [26, 29]. The findings of [30] show that 10% or less of MHA can be used as a replacement in NC. The finding of [28] also shows that up to 10% MHA can improve NC blended with lateritic soil. Pozzolanas are known to increase durability [31], increase the resistance to sulfate attack [32] and reduce the energy cost per cement unit [33]. However, limited or no information is available on the effects of MHA on the durability of SCC. It is based on this background that this study seeks to investigate the effects of MHA on the durability properties of SCC.

2. Research Methodology

2.1. Materials Characteristics

a. Cement: Ordinary portland cement (CEM II/A-L, 42.5N) was used in this study. The cement has a specific gravity of 3.16, bulk density of 1446kg/m^3, and Fineness (% retained on 45μm sieve) of 13%. The oxide composition is presented in Table 1.
b. Millet husk ash (MHA): the millet husk was collected from a dumpsite around farmland in Kano State, Nigeria, and Burned to ash at a controlled temperature of 700˚C for 4 hours. The ash was then cooled and sieved through 75μm for use in the SCC. The MHA has a specific gravity of 2.21, bulk density of 1101kg/m^3, and fineness (% retained on 45μm sieve) of 29%. The oxide composition and the grading of MHA are presented in Table 1 and Figure 1, respectively.
c. Aggregates: clean river sand with fineness modulus of 2.57, the specific gravity of 2.61, and bulk density of 1569kg/m^3 were used for the study as fine aggregate. The fine aggregate, as presented in Figure 1, is zone II. While on the other hand, crushed granite rock collected from the Rimin Gado Crushing plant in Kano, Nigeria was used as the coarse aggregate. The coarse aggregate has a maximum size of 14mm, as shown in Figure 1, fineness modulus of 6.53, specific gravity of 2.74, and bulk density of 1661 kg/m^3.

Table 1. Oxide composition of cement and MHA

Oxides	Cement	MHA	Oxides	Cement	MHA
SiO_2	12.01	64.22	P_2O_5	-	4.06
Al_2O_3	3.03	3.71	Cl	0.1	1.05
Fe_2O_3	4.14	3.49	TiO_2	0.33	0.71
CaO	74.06	6.55	Cr_2O_3	-	-
MgO	1.4	2.81	Mn_2O_3	-	0.09
SO_3	2.05	1.56	ZnO	-	0.09
Na_2O	-	0.86	SrO	0.49	0.06
K_2O	1.27	6.01	LoI	1.04	4.54

d. Water: Potable water available in the storage tank within The Laboratory of Civil Engineering, Bayero University, Kano, Nigeria, was used for mixing and curing the SCC.
e. Superplasticizer: to improve new properties of the SCC, a chloride-free, super plasticizing, and water-reducing admixture produced based on selected sulfonated naphthalene polymers is used. Its specific gravity was 1.20 and 0.5 – 2.0 Litres/100 kg of cement dosage limit. This type of superplasticizer reduces permeability SCC without loss of its workability [34].

2.2. Methods

a. Mix design of self-compacting concrete*:* The principles for selecting and proportioning SCC constituents were based on guidelines laid out in [44]. Grade 40 SCC (control mix) was prepared by trial mixes using a 0.35 water-cement ratio. As presented in Table 2, other mixes were derived from the control mix by replacing cement with 5, 10, 15, 20, 25, and 30 % by weight of MHA, respectively.

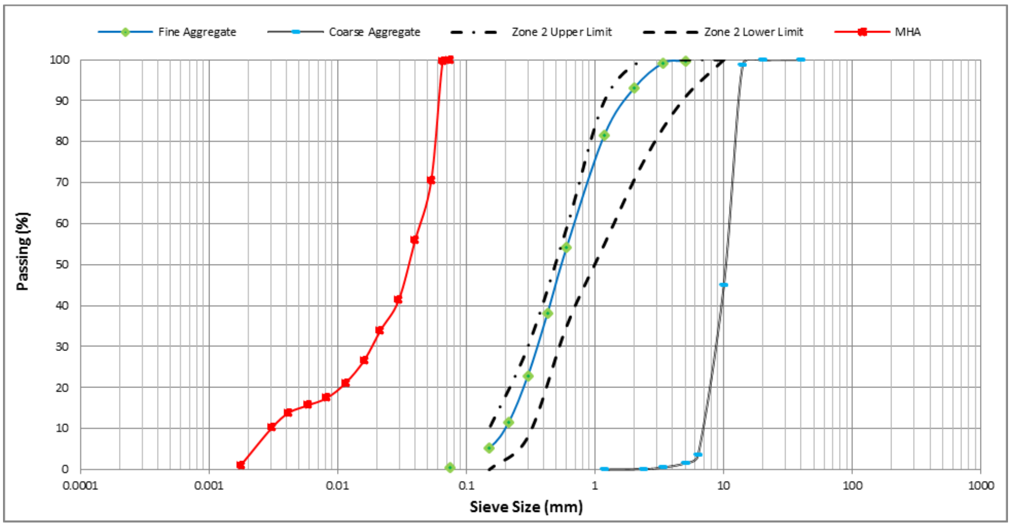

Figure 1: Grading of aggregates and millet husk ash

Table 2. Material batching for SCC with MHA

Mix No	% MHA	Cement (kg/m³)	Sand (kg/m³)	Granite (kg/m³)	MHA (kg/m³)	Water (kg/m³)	Super Plasticiser (l/m³)
M0	0	520	860	900	0	182	5.46
M1	5	494	860	900	24.7	182	5.46
M2	10	468	860	900	46.8	182	5.46
M3	15	442	860	900	66.3	182	5.46
M4	20	416	860	900	83.2	182	5.46
M5	25	390	860	900	97.5	182	5.46
M6	30	364	860	900	109.2	182	5.46

b. Specimen preparation: The SCC was achieved by first mixing the fine and coarse aggregates with 10% of the required water. Then, the cement and MHA were added and mixed homogeneously. About 60% of the water was added and mixed uniformly. The plasticizer was added to the remaining water and mixed with the concrete until a homogenous and uniform mixture of millet husk ash self-compacting concrete (MHA-SCC) was achieved. The MHA-SCC was cast in 100mm diameter and 200mm height cylinder and 100 x 100 x 100 mm cube molds. The specimens were cured in clean water for 28 days before testing for durability.

c. Testing methods: The durability test was carried out on the specimens to examine their characteristics under the influence of different environmental conditions.

1. Concrete immersion in diluted sulfate: MHA-SCC cylinders of 100mm diameter and 200mm height after curing for 28 days were immersed into a 5% concentrated solution of hydrogen tetraoxosulphate (VI) acid (H_2SO_4). The specimens were immersed in the acid solution for further 3, 7, and 28 days, respectively. At the lapse of the immersion periods, the specimens' surface was washed with clean water, air-dried, and reweighed to evaluate the effect of the acid on the weight loss. Evaluation of weight loss was carried out using Equation 1. This test was repeated using a 5% concentrated magnesium tetraoxosulphate (V) salt ($MgSO_4$).

$$\text{Percentage weight loss} = \frac{\text{Loss in weight}}{\text{original weight}} \times 100\% \,. \tag{1}$$

2. Concrete subjected to elevated temperature*:* MHA-SCC specimens of 100 x 100 x 100 mm cubes were used for this test. After cured for 28 days in water, the specimens were air-dried, weighed, and then subjected to heat at elevated temperature 100, 200, 300, 400, and 500 0C respectively for one hour using CARBOLITE CWF1100 model furnace and after that reweighed after cooling. The effect of elevated temperature on the concrete was evaluated in terms of percentage weight loss and percentage loss in strength as given in Equation 1 and 2, respectively, while other visual defects were noted, such as cracks or spalling.

$$\text{Percentage strength loss} = \frac{f_{c1} - f_{c2}}{f_{c1}} \times 100\%. \tag{2}$$

Where, f_{c1} = Strength before heating, and f_{c2} = Strength after heating.

3. Water absorption test*:* the water absorption test was conducted following [45] using the complete immersion test method. MHA-SCC specimens 100 x 100 x 100 mm cubes, cured for 28 days, were used for this test. The specimens were dried in the D81L201 multipurpose oven at 60°C, then cooled for 24 hours, and then completely immersed in the water for 30 min. The water absorption was evaluated in percentage as given in Equation 3.

$$\text{Water absorption} = \frac{w_2 - w_1}{w_1} \times 100\% \,. \tag{3}$$

where, w_1 = weight of dried cube, and w_2 = weight after removal from water.

3. Results and Discussion

3.1. The Effect of MHA on the Durability of MHA-SCC in Sulphate Media

The effect of 5% concentration of H_2SO_4 solution on MHA-SCC is presented in Figure 2. The figure shows how MHA-SCC is affected as a result of its immersion in the H_2SO_4 solution. The figure shows that the weight of MHA-SCC reduces with an increase in the immersion period in the H_2SO_4. This condition is a result of continuous attack by the sulfate with time. The decrease in weight (%) can be attributed to the large amount of CaO in the Portland cement and its hydration products $Ca(OH)_2$, which is primarily responsible for the poor resistance of SCC exposed to acidic attack [35]. However, the attack by sulfate reduces with an increase in MHA content. The reason for the improvement could be attributed to the pozzolanic reactivity of MHA in the MHA-SCC. The reason for the improvement could be attributed to the pozzolanic reactivity of MHA in MHA-SCC.

The reason for the improvement could be attributed to the pozzolanic reactivity of MHA in MHA-SCC. MHA incorporated in SCC has a small amount of CaO and no $Ca(OH)_2$ in the hydration product, thus increasing the durability of SCC. In addition, the better finishing surface and the minimum empty voids on the concrete surface of the specimens containing MHA led to lower penetration of the acid solution into the interior of concrete and improved its resistance against acid attack [36-38]. The behavior MHA-SCC in the $MgSO_4$ solution is similar to that within the H_2SO_4 solution. However, the effects are less and slower, as shown in Figure 3, which shows how MHA resists the aggression of sulfate in $MgSO_4$ solution.

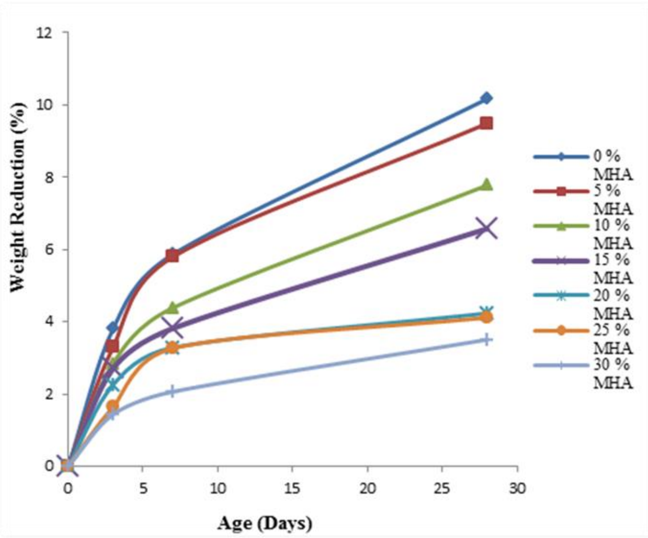

Figure 2: Effects of immersion period in H_2SO_4 on weight loss of MHA-SCC

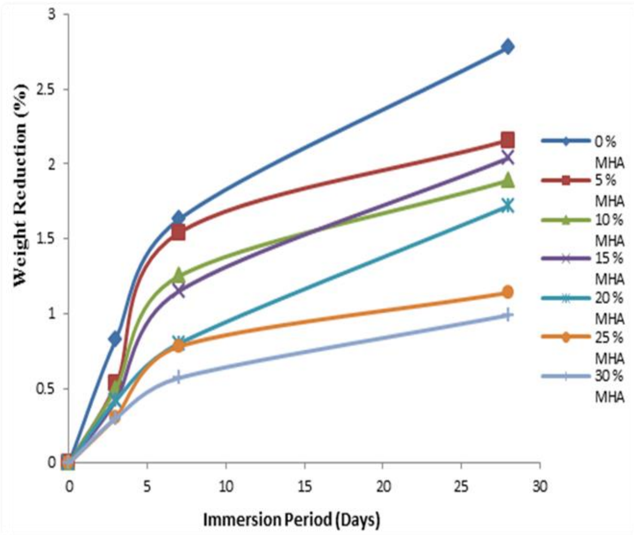

Figure 3: Effects of immersion Period in $MgSO_4$ on weight loss of MHA-SCC

3.2. The Effect of MHA on the Durability of MHA-SCC in Elevated Temperature

The effects of elevated temperature on MHA–SCC are presented in Figures 4 and 5. Figure 4 display the effects of heat on the weight of MHA-SCC, while Figure 5 shows how the compressive strength of MHA-SCC is affected as temperature rises. The figures show that when MHA-SCC is subjected to heat between the ambient temperature and 500ºC, MHA-SCC loses more weight as MHA content is increased. The loss in weight could be a result of spalling caused by internal water pressure [39]. The loss in weight could also result from the expulsion of the excess pore water in the MHA–SCC [40-41]. In addition, the color of MHA-SCC changes with increases in temperature from 400ºC to 500ºC. At this range of temperature, MHA-SCC changes slightly yellowish-grey. Certain colors indicate a specific temperature range, which is critical for determining the maximum temperature to which the concrete can be exposed. At temperatures below 400ºC, the concrete color does not change noticeably. The compressive strength of MHA-SCC decreases with an increase in temperature and reduces with an increase in MHA content. At temperatures above 300ºC, concrete losses a significant amount of its strength. This condition could result from dehydration of hydrated calcium silicate hydrate, increasing internal stresses, and inducing micro-cracks [39].

3.3. Water Absorption Capacity of MHA-SCC

Figure 6 presents the water absorption of MHA-SCC. The figure shows that water absorption of SCC decreases with an increase in MHA content. The reduction in water absorption is due to the beneficial effect of the void filled by MHA and its pozzolanic reaction [42]. This observation is similar to the findings of [43].

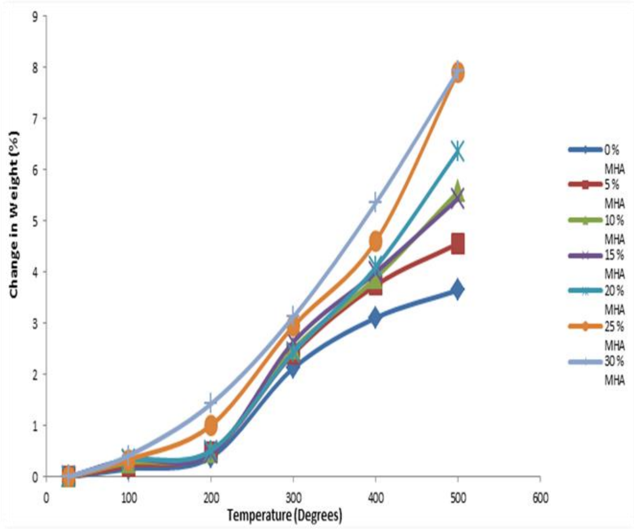

Figure 4. Effect of elevated temperature on weight loss of MHA-SCC

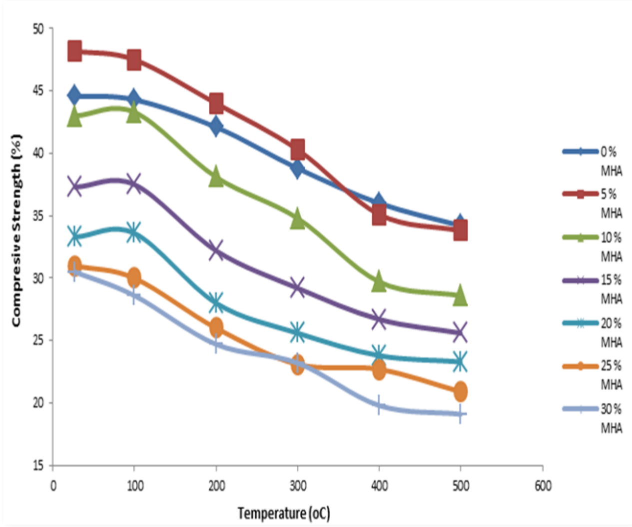

Figure 5. Effect of elevated temperature on the compressive strength of MHA-SCC

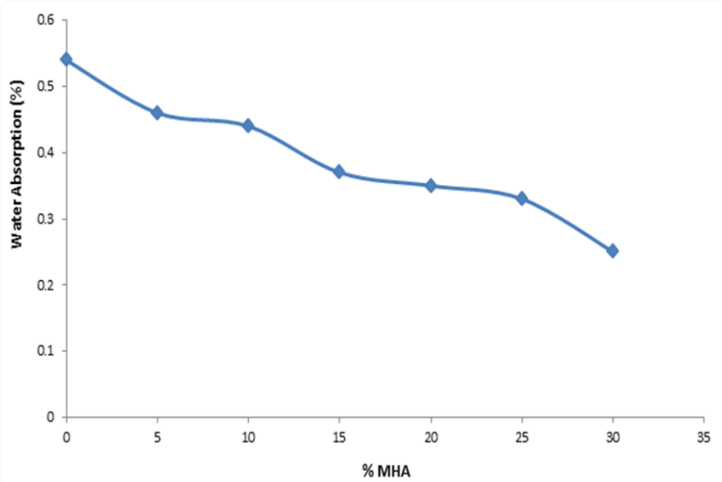

Figure 6. Water absorption of MHA-SCC

4. Conclusions

Based on the study conducted, the following conclusions are drawn. MHA satisfies the requirement for the minimum content of SiO_2, Al_2O_3 and Fe_2O_3 recommended by ASTM C618 and hence is considered a good pozzolana. MHA improved the resistance of SCC against H_2SO_4 and $MgSO_4$ aggression. The resistance increase with an increase in MHA content. The resistance of MHA-SCC to heat is reduced with an increase in MHA content and increased temperature. The water absorption of SCC decreases with an increase in MHA content.

REFERENCES

[1] Mohamed Y. (2013). Development of carbon fiber reinforced self-consolidating concrete patch for repair applications. *Master Theses*. Ontario: University of Waterloo.

[2] Awang, H., Atan, M. N., Abidin, N. Z., & Yusof, N. (2016). Cost-reduction of self-compacting concrete incorporating raw rice husk ash. *Journal of Engineering Science and Technology*, vol. 11, no. 1, pp. 96-108.

[3] Atan M. N., & Awang H. (2011). The compressive and flexural strengths of self compacting concrete using raw rice husk ash. *Journal of Engineering, Science and Technology*, vol. 6, no. 6, pp. 720 – 732.

[4] Nunes, S., Figueiras, H., Sousa, C., & Figueiras, J. (2009). SCC and conventional concrete on site: Property assessment. *Structures and Materials Journal*, vol. 2, No. 1, pp. 25 – 36.

[5] Zhu W., Quinn, J., & Bartos, P. J. M. (2002). Aspects of durability of self compacting concrete. *Advanced Concrete and Masonry Centre*, paper 249, pp. 1–7.

[6] European Federation of National Associations Representing for Concrete. (2002). *Guidelines for Self-Compacting Concrete, European Federation for Specialist Construction Chemicals and Concrete Systems*. Surrey: EFNARC Association House.

[7] European Concrete. (2009). *Sustainable Benefits of Concrete Structures*. Brussel: European Concrete Platform ASBL.

[8] Bradu, A., Cazacu, N., Florea, N., & Mihai, P. (2016). Modulus of elasticity of self compacting concrete with diferents levels of limestone powder. *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura*, vol. 62, no. 3, pp. 43-52.

[9] Kapoor, Y. P., Munn, C., & Charif, K. (2003). Self-compacting concrete-an economic approach. *Proceeding of 7th International Conference on Concrete in Hot & Aggressive Environments, Manama, Kingdom of Bahrain*, pp. 509-520.

[10] Ouchi, M. (2000). State-of-the-art report on self-compactability evaluation. *Japan Society of Civil Engineers*, no. 30, pp. 80-83.

[11] Marland, G., Boden, T. A., Griffin, R. C., Huang, S. F., Kanciruk, P., & Nelson, T. R. (1989). *Estimates of CO_2 Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on the United Nationals Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data*. Report No. #ORNL/CDIAC-25. Tennessee: Carbon Dioxide Information Analysis Centre.

[12] Malhotra, V. M., & Mehta, P. K. (2002). *High-performance, high-volume fly ash concrete: materials, mixture proportioning, properties, construction practice, and case histories*. Ottawa: Suplementary Cementing Materials for Sustainable Development Inc.

[13] Habeeb, G. A., & Fayyadh, M. M. (2009). Rice husk ash concrete: The effect of RHA average particle size on mechanical properties and drying shrinkage. *Australian Journal of Basic and Applied Sciences*, vol. 3, no. 3, pp. 1616-1622.

[14] Aboshio , A., Shuaibu, H. G., & Abdulwahab, M. T. (2018). Properties of rice husk ash concrete with periwinkle shell as coarse aggregates. *Nigerian Journal of Technological Development*, vol. 15, no. 2, pp. 33 – 38.

[15] Felekoglu, B. (2007). Utilisation of high volumes of limestone quarry wastes in concrete industry (self-compacting concrete case). *Resources, Conservation and Recycling*, vol. 51, no. 4, pp. 770-791.

[16] Ye, G., Liu, X., De Schutter, G., Poppe, A. M., & Taerwe, L. (2007). Influence of limestone powder used as filler in SCC on hydration and microstructure of cement pastes. *Cement and Concrete Composites*, vol. 29, no. 2, pp. 94-102.

[17] Esping, O. (2008). Effect of limestone filler BET (H_2O)-area on the fresh and hardened properties of self compacting concrete. *Cement and Concrete Research*, vol. 38, no. 7, pp. 938-944.

[18] Sukumar, B., Nagamani, K., & Raghavan, R. S. (2008). Evaluation of strength at early ages of self-compacting concrete with high volume fly ash. *Construction and Building Materials*, vol. 22, no. 7, pp. 1394–1401.

[19] Liu, M. (2010). Self-compacting concrete with different levels of pulverized fuel ash. *Construction and Building Materials*, vol. 24, no. 7, pp. 1245-1252.

[20] Siddique, R. (2011). Properties of self-compacting concrete containing class F fly ash. *Materials and Design*, vol. 32, no. 3, pp. 1502-1507.

[21] Yazici, H. (2008). The effect of silica fume and high-volume class C fly ash on mechanical properties, chloride penetration and freeze–thaw resistance of self-compacting concrete, *Construction and Building Materials*, vol. 22, no. 4, pp. 456-462.

[22] Gesoglu, M., Guneyisi, E. & Ozbay, E. (2009). Properties of self compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. *Construction and Building Materials*, vol. 23, no. 5, pp. 1847-1854.

[23] Turkel, S., & Altuntas, Y. (2009). The effect of limestone powder, fly ash and silica fume on the properties of self-compacting repair mortars. *Sadhana*, vol. 34, no. 2, pp. 331-343.

[24] Worldatlas, (2017). *The Leading Millet Producing Countries in the World*. Accessed on www.worldatlas.com/articles/the-leading-millet-producing-countries-in-the-world.html. Accessed at 28th December, 2018.

[25] Akande A. B. (2002). Economic analysis of the relationship between drought and millet production in the arid zone of nigeria: A case study of Borno and Yobe State. *Journal of Agriculture and Social Science*, vol. 2, no. 3, pp. 112- 121.

[26] Narain, D. B., Fareed, A, M., Shanker, L. M., Abdul Wahab, A., & Irfan, A. S. (2018). Millet husk ash as environmental friendly material in cement concrete. *Proceeding of 5th International Conference on Energy, Environment and Sustainable Development* 2018, *Mehran University of Engineering and Technology, Jamshoro, Pakistan*, pp. 153 – 158.

[27] Abdulwahab, M. T., Uche, O. A. U., & Suleiman, G. (2017). Mechanical properties of millet husk ash bitumen stabilized soil block. *Nigerian Journal of Technological Development*, vol. 14, no.1, pp. 34 – 38.

[28] Jimoh. R. A., Banuso. O. R., & Oyeleke. F. M. (2013). Exploratory assessment of strength characteristics of millet husk ash (MHA) blended cement laterized concrete. *Advances in Applied Science Research*, vol. 4, no. 1, pp. 452-457.

[29] Uche O. A. U., Adamu M., & Bahuddeen M. A. (2011). Influence of millet husk ash (MHA) on the propertiesof plain concrete. *Epistemics in Science, Engineering and Technology*, vol. 2, no. 2, pp. 68-73.

[30] Auta, S. M., Shiwua, A. J., & Tsodo, T. Y. (2015). Compressive strength of concrete with millet husk ash (MHA) as partial replacement of cement. *Magazine of Civil Engineering*, no. 7, pp. 74 – 79.

[31] Rojas, M. F., & Cabrera, J. (2002). The effect of temperature on the hydration rate and stability of the hydration phases of metakaolin-lime-water systems. *Cement and Concrete Research*, vol. 32, pp. 133–138.

[32] Janotka, I., & Krajci, L. (2003). Utilization of natural zeolite in portland cement of increased sulphate resistance. *ACI Special Publications*, vol. 192, pp. 223–229.

[33] Shi, C. (1998). Pozzolanic reaction and microstructure of chemical activated lime-fly ash pastes. *ACI Materials Journal*, vol. 95, no. 5, pp. 537–545.

[34] Fosroc Limited. (2014). *Fosroc Conplast SP430*. Staffordshire: Fosroc Limited.

[35] Chatveera, B., & Lertwattanaruk, P. (2011). Durability of conventional concretes containing black rice husk ash. *J. Environ. Manage.*, vol. 92 no. 1, pp. 59-66.

[36] Budiea, A., Hussin, M. W., Muthusamy, K., & Ismail, M. E. (2010). Performance of high strength POFA concrete in acidic environment. *Concrete research letters*, vol. 1, no. 1, pp. 14-18.

[37] Ramesh B. T. S., & Neeraja, D. (2016). Rice husk ash as supplementary material in concrete – A review. *International Journal of ChemTech Research*, vol. 9, no. 5, pp. 332-337.

[38] Dharani, D., & Arivu T. S. V. (2017). Durability studies on concrete by using groundnut shell ash as mineral admixture. *International Journal for Innovative Research in Science and Technology*, vol. 3, no. 10, pp. 168 – 172.

[39] Mydin, M. A. O., & Wang, Y. C. (2012). Thermal and mechanical properties of lightweight foamed concrete at elevated temperatures. *Magazine of Concrete Research*, vol. *64, no.* 3, pp. 213-224.

[40] Arabi, N. S. Q., & Sleiman, M. Z. (2014). Effect of fibre content and specimen shape on residual strength of polypropylene fibre self-compacting concrete exposed to elevated temperatures. *Journal of King Saud University – Engineering Sciences*, vol. 26, no. 1, pp. 33–39.

[41] Ogork, E. N., & Auwal, A. M. (2016). Mechanical properties of self compacting concrete (SCC) made with corn cob ash (CCA). *Book of Proceedings of the 15th Annual International Conference/ Nigerian Materials Congress (NIMACON 2016), Ahmadu Bello University, Zaria, Nigeria*, pp. 379-

383.

[42] Hafez, E. E., Elmoaty, A. M. A. E., & Mohamed, B. (2014). Effect of filler types on physical, mechanical and microstructure of self compacting concrete and flow-able concrete. *Alexandria Engineering Journal*, vol. 53, no. 2, pp. 295-307.

[43] Wazumtu, M., & Ogork, E. N. (2015). Assessment of groundnut shell ash (GSA) as admixture in cement paste and concrete. *IJISET - International Journal of Innovative Science, Engineering and Technology*, vol. 2, no. 2, pp. 77 – 87.

[44] European Committee for Standardization. (2013). *Concrete - specification, performance, production and conformity* (*BS EN* 206:2013+*A*1:2016). London: British Standards Institution.

[45] European Committee for Standardization. (2011). *Testing concrete: Method for determination of water absorption* (*BS* 1881-122). London: British Standards Institution.