Acta Polytechnica **60**(4):359–368, 2020
DOI:10.14311/AP.2020.60.0359
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available online at https://ojs.cvut.cz/ojs/index.php/ap

EXPERIMENTAL INVESTIGATION OF THE POZZOLANIC POTENTIALS OF MILLET AND RICE HUSK ASH AS MINERAL ADDITIVE IN SELF-COMPACTING CONCRETE

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Abstract. Self-compacting concrete (SCC) is a new concept of concrete mix which flows in a formwork and consolidates itself without the need for compaction. Effectively compacting concrete can be very difficult especially in areas with a high number of reinforcement. Millet Husk Ash (MHA) and Rice Husk Ash (RHA) are agricultural waste materials obtained from farm and burnt to ashes to discard them since they are environmental waste. This research is focused on finding the pozzolanic potentials of MHA and RHA as a mineral additive in SCC to see if it will improve its properties rather than discarding them as environmental waste. Laboratory investigations were carried out on normally vibrated concrete (NVC) and SCC using MHA and RHA as an additive at a 10 % replacement with cement. Workability tests were carried out following the BS specifications. ASTM 293 C was used for the Flexural Capacity test on the beam specimen. The Results of the workability tests using MHA and RHA as mineral additive are within the specified standard values. The compressive strength test also revealed that the SCC using MHA is about 12.8 % higher than the RHA and NVC at 28 days with densities of 2487.5, 2516.5 and 2437.5 kg/m^3 respectively. The Modulus of Rupture (MoR) and Split Tensile strength for MHA is 0-19.2 % and 17.2-22.2 % higher than the RHA and NVC respectively. It was concluded that the improvement in the pozzolanic properties of MHA and RHA may be due to the content of Lime (CaO), Silica (SiO_2), Alumina (Al_2O_3), Iron oxide (Fe_2O_3) being greater than 70 % and in an accordance with BS 618 code. It is concluded that the MHA and RHA can find suitable applications in the SCC as a mineral additive rather than discarding them as environmental waste.

Keywords: Self-compacting concrete, millet husk ash, rice husk ash, compressive strength, workability.

1. Introduction

Self-Compacting Concrete (SCC) can be described as highly flowable concrete that can spread, fill and compact itself under its own weight onto every corner of a given formwork without the need of any mechanical vibration. This special concrete was first discovered in Japan in 1988 due to the dearth of skilled workers in the Japanese Construction industry. The application of SCC in the construction industry requires fewer workforces especially in the mixing, placement and compaction of concrete [1]. The Construction industries have regained confidence in terms of durability and more efficient concrete structures.

In the design, preparation and mixing of SCC, the use of water reducer cannot be overruled. Water reducers (Super plasticizer) are commonly used to enhance stability, mobility and to prevent segregation of the concrete mix. The reduction in the water content will help to increase the strength and durability of the SCC. Fillers are also employed in the SCC mix to prevent the occurrence of voids and to improve the setting time. Commonly used fillers in the SCC are fly ash, Calcium Carbonate, rice husk ash (RHA), silica fume, glass and quartzite. This research will, therefore, explore the pozzolanic properties of Rice Husk Ash (RHA) and Millet Husk Ash (MHA) in the SCC mix.

The SCC mix design will include significant amount of fine-grained inorganic materials in their constituents and thereby increasing the possibilities for the use of mineral admixtures, which are currently agricultural waste products with no practical applications and are expensive to dispose of [2].

2. Literature review

The new invention behind the SCC involves the replacement of cement (partially or wholly) with fine materials (like silica fume, fly ash) without a modification to the water content. This process alters the mechanical behaviour of the concrete [3]. In general, to achieve an effective workability of the SCC concrete mix, the fine particles must be dense enough, usually about 520 to 560 kg/m^3 [3]. The use of stabilizers or viscosity modifying agents (VMA) is common because the SCC is very susceptible to any changes in the water content.

Based on the composition of the concrete mortar, the SCC is divided into: SCC with Powder only, SCC with VMA or SCC with a combination of both powder and VMA. Elyamany et al. [4] studied the effect of

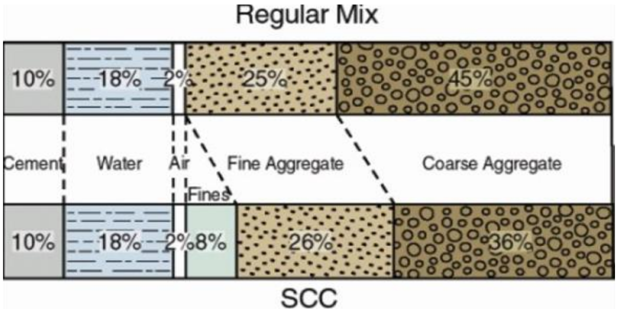

Figure 1. Materials proportion used in regular concrete and self-compacting concrete by absolute volume [6].

filler types on physical, mechanical and microstructure of self-compacting concrete and Flowable concrete. In their research, filler materials (i.e pozzolanic and non-pozzolanic fillers) in the range of 7.5 % - 15 % were used as a partial replacement for cement. Their findings revealed a significant effect of fillers on the properties of fresh and hardened concrete. The non-pozzolanic fillers have an insignificant negative effect on the properties of the SCC.

For the SCC with powder, the necessary mortar is produced by the use of a high proportion of fines while for the SCC with VMA, the proportion of fines is in the same permissible range for normally vibrated concrete (NVC). The viscosity required to inhibit the segregation will then be adjusted by using a stabilizer [5]. The combination type is created by adding a minute amount of the stabilizer to the powder type in order to balance the moisture fluctuations in the manufacturing process. This is the type adopted in this research. Mixture Proportions of the SCC by [6] as compared to normally vibrated concrete is shown in Fig. 1.

In general, the flowability of the SCC is heavily dependent on powder particle size and, in addition, on factors, such as mixing regimen and water/super plasticizer content [7, 8].

Murthi et al [9] studied the permeability properties of lightweight self-consolidating concrete made with a coconut shell aggregate. The replacement of crushed rock with a coconut shell was in the range of 0-100 % in steps of 25 %. Their experimental investigations revealed a better performance of the coconut shell as aggregates and up to a replacement of 75 %.

Millet husk has not been fully explored into as a mineral additive in the construction industry [10]. However, some researchers have shown that the MHA can be used as a partial replacement of cement in concrete mix, thereby improving its properties in fresh and hardened form [11]. Agricultural waste such as the MHA will provide a cost effective construction material when used as a partial replacement for cement. It will also provide a less expensive soil block construction with a proper strength being maintained [12]. The effectiveness of the RHA in concrete mix is attributed to the high amount of silica present in its ash. It contains about 85 % to 95 % weight percent of amorphous silica. They are found to be pozzolanic reactive material, which improves the microscopic structure of the cement paste and aggregates surface area in the SCC [13]. The RHA, as partial replacement for cement in concrete mix, is also found to perform well in fire [14].

A low-density SCC containing pumice and mineral admixtures was also studied by Arun Kumar et al [15]. They applied the principle of artificial neural network for the modelling of the mechanical properties of a lightweight SCC. Their investigation yielded the best model for the tested concrete.

3. Materials and methods

The materials used in this research work includes: Ordinary Portland Cement (OPC) obtained locally from Dangote distributor, river sand (fine aggregate) and granite (coarse aggregate) obtained from Akure quarry site, mineral additives like Rice husk ash (RHA), Millet husk ash MHA) were obtained from Maiduguri, Nigeria; and chemical admixtures (superplasticizer i.e. SP430) obtained from PURECHEM. The [16] method of design was adopted in this research. The concrete was designed using the characteristic strengths of 70 N/mm^2. Table 1 shows the mix design ratios. All measurements are kg/m^3. The maximum amount of mineral additives used in this research was obtained by carrying out a trial mix design consisting of 0 - 15 % of the MHA and RHA in the SCC that would produce an optimum strength. The trial mix design revealed an optimum strength at 10 % of the MHA and RHA as mineral additives in the SCC and this value was adopted in this research work to determine the pozzolanic potentials of both additives. The MHA and RHA was burnt in a lift out furnace at a temperature of about 650 °C for 6 hours as recommended by [17].

The Chemical properties of the MHA and RHA obtained are presented in Table 2.

Many authors have proposed a variety of test methods to assess and measure the fresh properties of the SCC. But none has proved satisfactorily well to assess all key parameters of the SCC. A brief summary of the common tests proposed by [18] in the assessment of fresh properties of the SCC and their acceptance criteria are given in Tables 3 and 4.

3.1. Test for workability

Workability tests are carried out according to the specifications of BS EN 12350-8 [19], BS EN 12350-9 [20] and BS EN 12350-10 [21] respectively. The test includes slump cone, V-Funnel and L-Box Test.

In the Slump test, the materials required are the same as those used in carrying out the slump test of the NVC. However, this test method is different from the conventional slump procedure in the sense that the concrete placed inside the slump cone is not tamped and the concrete collapses when the slump

	Cement	MHA/RHA	Fine aggregate	Coarse aggregate	SP430	Water
Quantity (Kg/m^3)	603.36	64.1	857.14	754.25	10.92	182.59
Mix ratio	1	0.106	1.41	1.24	0.02	0.302

Table 1. Design Mix Proportion for MHA and RHA.

Mineral composition	Cement (%)	RHA (%)	MHA (%)
Lime (CaO)	60 to 67	2.10	3.30
Silica (SiO_2)	17 to 25	85.7	50.9
Alumina (Al_2O_3)	3 to 8	0.58	28.16
Iron oxide (Fe_2O_3)	0.5 to 6	1.22	5.07
Magnesia (MgO)	0.1 to 4	0.39	0.98
Sulphur trioxide (SO_3)	1 to 3	0.11	-
Loss on ignition (L.O.I)	1.73	5.81	0.20
Phosphorus (P)	-	0.35	-
$CaSO_4$	-	0.06	-
Alkalies (Na_2O + K_2O)	0.5 to 1.3	3.52	1.99

Table 2. Mineral components of cement and millet husk ash.

Test method	Property
Slump flow	Filling ability
V-funnel	Filling ability
V-funnel at $T_{5\,mins}$	Segregation resistance
L-box	Passing ability

Table 3. Test methods for SCC [15].

Test	Unit	Typical range of values	
		Minimum	Maximum
Slump flow	mm	650	800
V-funnel	Sec	6	12
V-funnel at $T_{5\,mins}$	Sec	6	15
L-box	H_2/H_1	0.8	1.0

Table 4. Acceptance criteria for SCC [15].

Figure 2. Slump flow measurement of SCC.

cone is raised. Also, the diameter of the spread of the sample is measured unlike for the NVC, where the height of the concrete is measured after the removal of the slump cone. better flowability is achieved if the diameter of slump spread ranges between 650 and 800 mm. Most SCC mixes produce collapse slumps due the high flowability and self-compacting nature of the concrete as shown in Fig. 2. The water absorption of each concrete mix was estimated from equ. 1.

$$\left(\frac{(W_1 - W_0)}{W_0} \times 100\right) \tag{1}$$

3.2. Workability using V-funnel apparatus

The V-funnel test was developed in Japan and involves the use of a v-shaped funnel shown in Fig. 3. The test is used in the determination of the flowability of the SCC with a maximum coarse aggregate size of 20 mm. Although the measurement of the flowability is the major aim of the v-funnel test, the flowability results are greatly affected by other concrete properties than just the flow.

To carry out the test, the trapdoor was closed and the apparatus was filled completely with about 12 litres of concrete without tamping. The concrete is allowed to flow out under gravity with the trap door opened. The time taken for the flow was measured and recorded.

3.3. Workability using the L-box apparatus

The workability of the SCC using the L-box apparatus is used to check the extent by which the reinforcement is blocking the flow of the concrete. It is an L-shaped rectangular apparatus with a vertical and horizontal parts. The apparatus was filled with about 14 litres of concrete, after which the gate was lifted and the concrete was allowed to flow out freely into the horizontal section. When the concrete stops flowing; the height, H_1 of the concrete in the vertical section was measured and recorded. Also, the height, H_2 of the concrete in the horizontal section was also measured and recorded.

The blocking ratio, H_1/H_2 was then calculated.

If the blocking ratio $H_1/H_2 = 1$, it implies a high workability. Generally, a minimum blocking ratio of 0.8 is suggested by the EU research team. Fig. 4 shows the L-box and the execution of the test.

3.4. Strength test using compression testing machine

The load per unit area exerted on the concrete material under test and tending to shorten or reduce its size is called the compressive strength. Cubes of size 100 × 100 × 100 mm were tested following the specification of BS EN 12390-3 [22]. The results will give an idea about the kind of concrete that is being delivered at site. Many industries apply this principle in the quality control of their products. Fig. 5 shows a 2 000 kN compression testing machine in action.

By this single test, one can judge whether the process has been done properly or not. Sixteen (16) cubes were cast for each type of concrete (NVC, MHA and RHA). These specimens were cured and tested after 7 days, 14 days, 21 days and 28 days. The Load was applied at a constant rate of 140 kg/cm^2 per minute until the specimen yields. The compressive strength at failure was measured and recorded accordingly.

3.5. Split tensile test

This is an indirect test method of determining the tensile resistance of concrete. The test was performed after the 28 days of curing of the specimen. The application of the load on the specimen by the universal testing machine causes a development of tension around the plane containing the applied load. Split tensile test strength was carried out on concrete specimens based on ASTM C496-11 [23]using 75 by 150 mm cylindrical specimen for the NVC, MHA and RHA. A total of 48 specimens were prepared, 16 for each type. The samples were tested and the load causing the tensile stresses was measured and recorded accordingly.

3.6. Flexural strength test using ASTM C-2930

A total of 32 beams were cast to perform the flexural strength test (MoR) in an accordance with ASTM C293 / C293M-16 [24]using the centre-point loading system. The test was performed using a digital 100 kN Universal Testing Machine (UTM) at the ABUAD Structures laboratory. Fig. 6 shows the beam specimen being tested using the UTM. The deflection of all tested samples were measured using a dial gauge attached to the UTM with its tip at the central position of the beam. As the specimen is loaded, the value of the load and the corresponding value of deflection are displayed. See Fig. 6.

4. Results and discussion

4.1. Chemical constituents of mineral additives

Table 5 shows the comparison of the pozzolanic potentials of the MHA and RHA. following the recommendations of ASTM C618 – 78 [25], the RHA had 87.5 % of the combined mineral constituents of silicon oxide, aluminium oxide and iron oxide (SiO_2 + Al_2O_3 + Fe_2O_3) while the MHA had 84.13 % of these combinations. These values are both higher than 70 % indicating that the MHA and RHA have a high pozzolanic potentials. But the slight difference in their potentials may be due to the absence of SO_3 in the mineral constituents of the MHA.

Figure 3. V-funnel apparatus and execution of V-funnel test.

Figure 4. L-box apparatus and execution of L-box test.

Chemical pozzolan (%)	Class C	Class N	Class F	RHA	MHA
$SiO_2 + Al_2O_3 + Fe_2O_3$	> 50	> 70	> 70	87.5	84.13
SO_3	< 4	< 5	< 5	0.11	-
MgO	< 5	< 5	< 5	0.39	0.98
Na_2O	< 1.5	< 1.5	< 1.5	3.52	1.99
Loss on ignition	< 6	< 10	< 2	5.81	0.20

Table 5. Pozzolanic properties of RHA and MHA in accordance with ASTM C618-78.

Figure 5. Crushing of concrete cube specimen.

4.2. Results of the workability test

The results of workability tests using the slump cone, V-Funnel and L-Box apparatus are presented in Tables 6 and 7. These results are also validated using the specifications of EFNARC [18].

The MHA and RHA as an additive in SCC exhibited high slump spread of 748 and 738 mm respectively. Although, the flowability of the MHA being higher than in the case of the RHA may due to the high percentage of Na_2O present in the mineral constituents (i.e. 3.52 % > 1.5 % as specified by EFNARC [18]. The NVC exhibited a higher flowability than the MHA and RHA. Generally, the results of the workability tests revealed a highly workable concrete for all samples and within the acceptable criteria for SCC.

4.3. Results of compressive strength, density and absorption tests

The results of the compressive strength, density and absorption tests of the MHA, RHA and NVC are presented in Tables 8, 9 and 10 respectively. The compressive strength for the MHA, RHA and NVC increases with curing days. Their average densities are between 2 487.5 kg/m^3, 2 516.5 kg/m^3 and 2 437.5 respectively, with the RHA having the highest density. These values are within the recommendations of [26]. The MHA and RHA showed a promising pozzolanic properties in the concrete mixes.

With reference to Table 8, 9 and 10, the SCC with the MHA as an additive had about 13.2 % higher compressive strength values over the RHA and NVC at 28 days of curing. The higher compressive strength recorded with the use of the MHA as a mineral additive, and judging from the chemical composition, may be due to the higher alumina (Al_2O_3) and lime (CaO) contents present in the MHA as compared to the RHA. In terms of water absorption, the MHA has the highest absorption capacity (3.7 %) with the RHA recording the lowest (2.5 %). According to “the concrete Society” [27], water absorption should be in the range of 6-7 %. All samples tested have satisfied this requirement.

4.4. Results of the split tensile test

The Tensile strength for the NVC, RHA and MHA increases with an increase in curing days as shown in Fig. 7. The MHA shows an improvement in strength over the RHA and NVC due to the presence of pozzolanic effect of silica oxide, alumina and lime in the ash, thereby enhancing the cementitious reaction of the concrete mixes. Fig. 7 also showed that the SCC with the MHA as additive yielded higher tensile strength than the RHA and NVC at 28 days of curing. The range is about 17.2 – 22.2 % higher than the tensile strength recorded by the RHA and NVC. This results are also in an accordance with other tests carried out.

4.5. Results of flexural strength test (modulus of rupture)

The Modulus of Rupture (MoR) of the SCC with the MHA and RHA as an additive increase with curing age. Their maximum Load-Deflection curve indicates a similar trend with that of the NVC. The deflection is generally higher with the MHA and RHA as mineral additives than that of the NVC. The maximum load (F) and MoR of the MHA and RHA are 19.8 % and 19.2 % higher than that of NVC at 28 days curing respectively. The MHA and RHA have the same MoR (10.4 N/mm^2) at 28 days of curing. The deflection curve of the SCC containing the MHA and RHA seemed to be higher than that of the NVC. Although all are within the allowable value of span/effective depth ratio. Figs. 8, 9 and 10 shows the plots of the maximum load, MoR and deflection for the MHA, RHA and NVC respectively.

5. Conclusions

This research presents an experimental investigation of the pozzolanic potentials of the MHA and RHA as mineral additives in the SCC. The summary of the experimental program is summarized below:

FIGURE 6. Flexural strength test of beam specimen using 100 kN-UTM.

SCC grade	Aggregate size (mm)	Additive	D_1 (mm)	D_2 (mm)	Slump value
M70	20	MHA	755	741	748
M70	20	RHA	740	736	738
M70	20	NVC	761	757	759

TABLE 6. Slump cone test at 10 % MHA and RHA.

Type of test	MHA	NVC	RHA	Code range	
				Minimum	Maximum
V-funnel	9 secs	10 sec	9 secs	6 secs	12 secs
L-box $\left(T = \frac{H_2}{H_1}\right)$	$\frac{12.4}{13.0} = 0.954$	$\frac{13.8}{14.5} = 0.950$	$\frac{14.6}{15.7} = 0.930$	0.8	1.0

TABLE 7. Results of V-funnel and L-box tests at 10 % MHA and RHA.

No. of days	W_0 (kg)	W_1 (kg)	Absorption (%)	Force (kN)	$C.S$ (MPa)	Density (kg/m^3)
7	2.45	2.47	0.8	507.7	50.77	2450
14	2.43	2.48	2.1	664.6	65.42	2480
21	2.44	2.50	2.5	716.7	71.67	2500
28	2.43	2.52	3.7	839.0	83.9	2520

TABLE 8. Absorption, density and compressive strength of SCC at 10 % MHA.

No. of days	W_0 (kg)	W_1 (kg)	Absorption (%)	Force (kN)	$C.S$ (MPa)	Density (kg/m^3)
7	2.56	2.60	1.6	739.5	49.3	2560
14	2.44	2.46	0.8	826.5	55.1	2440
21	2.59	2.67	2.8	1042.5	69.5	2593
28	2.47	2.47	1.6	1092.0	72.8	2473

TABLE 9. Absorption, density and compressive strength of SCC at 10 % RHA.

No. of days	W_0 (kg)	W_1 (kg)	Absorption (%)	Force (kN)	$C.S$ (MPa)	Density (kg/m^3)
7	2.28	2.31	1.3	395.3	39.5	2310
14	2.41	2.45	1.7	527.4	52.7	2450
21	2.40	2.49	3.8	661.4	66.1	2490
28	2.44	2.50	2.5	731.7	72.8	2500

Table 10. Absorption, density and compressive strength of NVC (0 % additive).

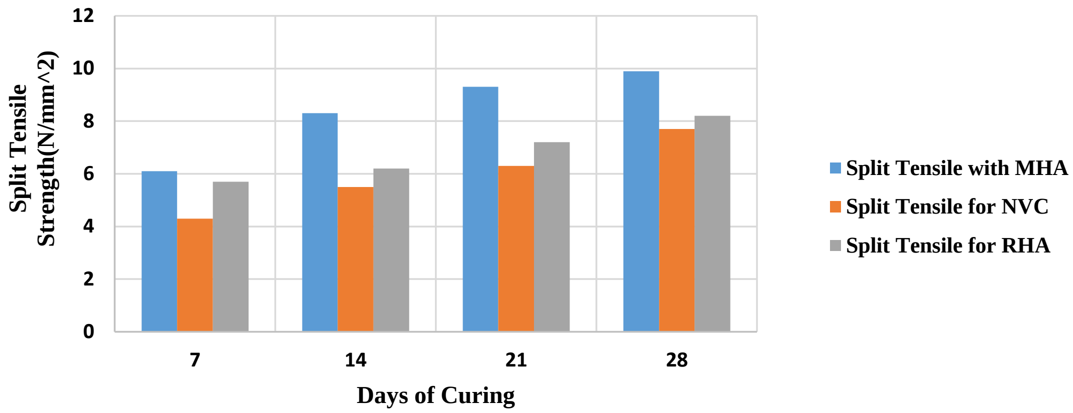

Figure 7. Variation of split tensile strength of SCC with MHA, RHA and NVC at grade M70.

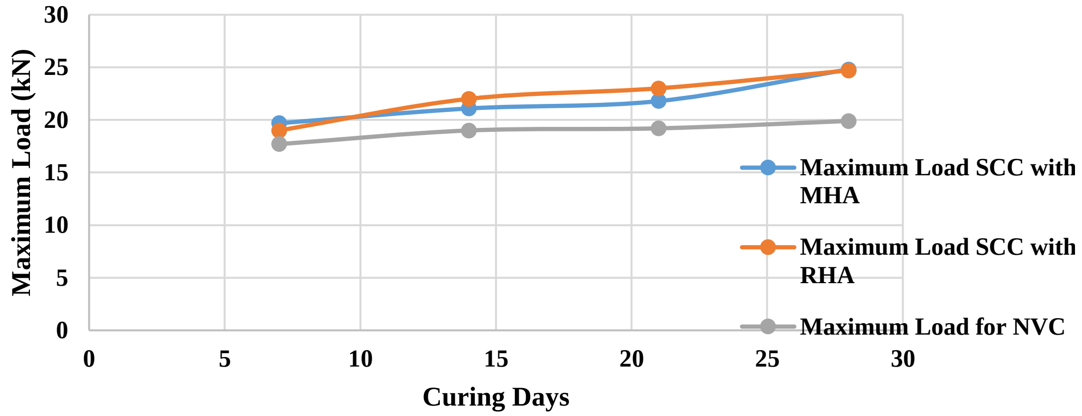

Figure 8. Plot of maximum load of SCC with MHA, RHA and NVC against curing days.

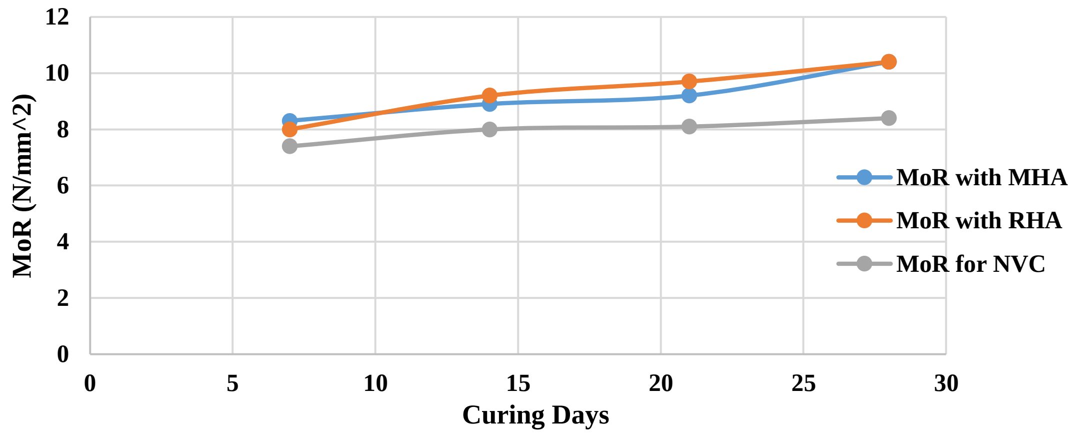

Figure 9. Plot of MoR for SCC with MHA, RHA and NVC against curing days.

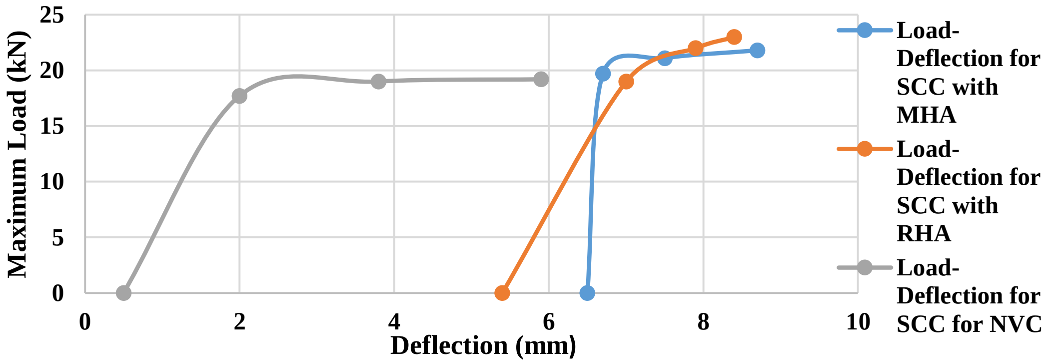

FIGURE 10. Plot of maximum load against deflection for SCC with MHA, RHA and NVC.

(1.) The mineral constituents (SiO_2 + Al_2O_3 + Fe_2O_3) of the MHA and RHA are greater than 70 % indicating their potentials as mineral additives in the SCC.

(2.) The water absorption of both the MHA and RHA are within the specified standard and as such; adequate for use as mineral additives in the SCC.

(3.) Workability tests using the L-box test, V-funnel and slump cone for the SCC for the MHA and RHA as an additive showed that they are sufficiently workable like the NVC and revealed a workable concrete within the required specification.

(4.) The addition of the MHA and RHA as mineral additives in the SCC does not reduce the density of the SCC below the average specified value of 2 400 kg/m^3. All densities are within the acceptable range.

(5.) Their compressive strengths are considerably higher than that of the NVC of the same grade M70. The tensile strength test for MHA as an additive revealed a higher resistance to tension than that of the RHA and NVC.

(6.) The MoR of MHA and RHA revealed a higher modulus of rupture than the NVC. This also indicates a better quality control than NVC.

MHA and RHA should not be discarded as a waste material since this research has proven them to be of high pozzolanic properties. Their use can help to reduce environmental waste and costs of disposal of such waste. The MHA and RHA are environmental waste that can be obtained easier than other additives used for the SCC. They can be explored as mineral materials for the SCC in the Building and Construction Industry.

ACKNOWLEDGEMENTS

Thanks to ABUAD Concrete and Structures laboratory.

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