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STRENGTH PREDICTION MODEL OF MILLET HUSK ASH (MHA) SELF-COMPACTING CONCRETE

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Abstract

Cement is the most useful and diverse construction material globally next water. Its demand to address housing deficit is on the rise daily due to increasing population. Cement production are economically expensive and contribute about 7 to 10 per cent (%) of the total global emissions, with potentially adverse environmental implications. Compressive strength of concrete is the important parameter that determines the performance of the material during service condition. It plays a key role in offering high-quality modified concrete. This paper presents the findings of an investigation on the strengths of self-compacting concrete (SCC) containing Millet Husk Ash (MHA) and development of strength prediction models of the concrete. The MHA used was obtained by controlled burning of millet husk to a temperature of 650 ^oC and sieved through 75 μm sieve after allowing cooling. The compressive, splitting tensile and flexural strengths of (MHA)-SCC grade 40 were investigated at replacement levels of 0, 5, 10, 15, 20, 25 and 30 %, respectively, at curing ages of 3, 7, 28, 56 and 90 days in accordance with standard procedures. The strengths of MHA-SCC were modeled using Response Surface Methodology. The result of the investigations showed that the strength properties of SCC decreased with increase in MHA content. However 10% MHA replacement was considered as optimum for structural concrete. The models of MHA-SCC for compressive, splitting tensile and flexural strengths were developed with R^2 values of 0.9937, 0.9959 and 0.9952, respectively and are considered to be good for prediction of concrete strengths.

Keywords: *Response Surface Methodology, Hardened Properties MHA-SCC,*

Introduction

Concrete has been used in the construction industry for a time immemorial. Over 20 billion tonnes of concrete is produced annually worldwide (Mehta, 2004). The need of concrete to address the requirements of construction industries and human activities is on the increase globally. Besides water, concrete is the most utilized material around the globe (Olafusi, and Olutoge, 2012). Concrete production involves processes such as; mixing, transporting, placing, compaction and curing. Compaction is one of the key processes whereby the fluid concrete mass is compressed so as to remove the entrapped air and have more aggregate packing to achieve a more dense mass of concrete (Neville and Brooks, 2010). Compaction depends on shape and gradation of the aggregates and is achieved by the process of vibration. During the mixing process, air is entrapped in the concrete which reduces the strength by some certain amount, thus, compaction is necessary in order to achieve maximum ultimate strength, durability and bond between the concrete and reinforcements. Lack of uniformity and complete compaction are the main challenges which lead to poor performance of normal concrete structure since full compaction within heavy reinforcement and completely fill form work is not guarantee (Okamura and Ouchi, 2003). In addition, there is gradual decrease in the availability of skilled workers in construction industries which make production of durable concrete impossible (Nevelli, 2003) Poor compaction leads to many problems in the concrete which affect the overall performance of the structure, (Anwar, 2014).

Previously, attaining a full compaction of concrete on construction site was a challenge as a result; several efforts to achieve concrete with full compaction and without the use of vibrator lead to the development of modern SCC (Okamura and Ouchi, 2003). Self-compacting concrete (SCC) as special concrete was developed to tackle the key factors responsible for poor performance of normal concrete structures due to lack of uniform and complete compaction.

Portland cement is one of the crucial materials used in the production of conventional concrete. Ordinary Portland Cement (OPC) is conventionally used as the main binder to produce Portland cement concrete. Nevertheless, the use of cement as a binding agent in a concrete mix has often been denounced by environmental protection circles (Lie et al., 2020; Dunuweera, and Raja, 2018). The irreplaceable and massive use of cement in construction has generated a lot of environmental concerns (Uche *et al.*, 2012; Hardjito and Rangan, 2005). Nearly, most of the CO_2 emitted was due to decarbonation of limestone during cement production (Huntzinger and Eatmon, 2009). There is a need to find a substitute binding material that can mitigate the use of cement. It is, therefore, essential to replace Portland cement with low CO_2 emission materials for the production of environmentally friendly concrete.

In addition, high inflation in the country economy has led to the increase in the prices of traditional building materials. To lessen material and construction cost to affordable rate, the effective utilization of these waste materials will extensively boost the production of cheaper construction materials (Vora and Dave, 2013; Ogork and Ayuba, 2014).

In order to promote green construction technologies and reducing the problems of shelter, alternative indispensable material that is cost effective and at the same time recycling agricultural and industrial waste materials as cement replacement in concreting are few among many causes of trends in research globally (Ogork and Ayuba, 2014). In the present time, scholars are conducting research by using agriculture and industrial waste products as a primary source of raw materials for the construction industry. These waste products are economical and useful in reducing environmental pollution there by creating a sustainable environment (Bheel *et al.,* 2019), the substitutes to the orthodox materials involve use of pozzolanas as alternatives to cement. Previous literature revealed that Supplementary cementitious materials are essential in strengthening low cost construction materials purposely to protect our nonrenewable natural resources and energy at the same time enabling environmental sustainbility through the use of the available mineral admixtures (Bheel *et al.,* 2020; Elinwa, and Mahmood; Jimoh 2013).

In construction engineering, strength is the basic standard commonly used to decide on a concrete for a certain purpose. The strength of concrete is influence by the pozzolanic activity of the material during hydration reaction depending on the pozzolana content and the type of supplementary cementitious materials. The strength development of concrete used for construction requires a long period of time after casting, for this reason, reliable prediction for the strength gain of concrete would provide information on the concrete and to make adjustment where needed on the mix proportion used to overcome any challenges that would make concrete structure not reach the expected design strength or for more economic use of raw materials and fewer construction failures, hence reducing construction cost (Kheder, 2003). Previous and a substantial number of researches such as (Ogork and Ayuba, 2014; Kheder, 2003; Popovics, and Ujhelyi, 2008; Zain, 2009; Deepa *et al.,* 2010; Ramadoss, 2012), among many that have conducted a research on prediction of strength of concrete at different eras with high level of accuracy. Previous studies conducted by (Hardjito and Rangan, 2005; Ogrok *et al.,* 2014; Zain, 2009), revealed that regressional models are more advantageous than some modeling techniques with high mathematical performance used to execute predictions speedily at the same time provide comprehensive idea on the main factors influencing strength. The Response surface methodology (RSM) is one of the powerful mathematical and statistical method of prediction that allows us to evaluate the influence of the independent variables on the responses with a minimal number of experiments (Hammoudi *et al.,* 2019; Dahmoune *et al.* ,2015). RSM is a collection of mathematical and statistical methods to that evaluate relationships between a group of independent variables (in-put parameters) and one or more responses (out-put parameters) Dahmoune *et al.* ,2015. This technique is generally used when there are several input parameters affecting the output (response). In recent times, (RSM) methods have been largely used in the field of concrete materials in order to predict or to model their properties (Hammoudi *et al.,* 2019; Behnood and Golafshani, 2018). However, studies to predict the strength properties of MHA-SCC using RSM have not been conducted Hammoudi *et al.,* 2019. Therefore, this research aimed at modelling the strength properties of MHA-SCC using response surface methodology.

Materials and Methods

Materials

The particles size distribution and physical properties of the materials is shown in Figure 1 and Table 2 respectively. Ordinary Portland cement (Dangote brand), with a specific gravity of 3.14 was used. The chemical composition analysis of the cement is shown in Table 2. The fine aggregate has a specific gravity of 2.61; bulk density of 1560 kg/m^3 moisture content of 2.35 % was used and classified as zone -2 based on BS 882 (1992) grading limits for fine aggregates. The coarse aggregate is crushed granite with dominant size between 10mm-14mm with a specific gravity of 2.71, moisture content of 1.18 percent and bulk density of 1661.0 kg/m^3. A super plasticizer of 7.49kg/m^3 as an additive in compliance with ASTM C494 and BS EN 5075 blended with optimum percentage of MHA-SCC was used.

Millet husk ash was sourced from villages in Jigawa and Kano State, Nigeria. The Millet Husk Ash (MHA) was obtained by a control burning method at temperature of about 650℃ in a kiln using control burning system for about two hours and the ash was allowed to cool before sieving through 75 μm sieves. The MHA has specific gravity of 2.22, bulk density of 694 Kg/m^3; moisture content of 2.25 % and grain size distribution is shown in Figure 1. A chemical composition analysis of the MHA was conducted using X-Ray Flouresence (XRF) analytical method and shown in Table 1.

Table 1 Oxides composition of ash and binder

Oxides	Dangote Cement (%)	BSEN197-1(2000) ASTM C618(2005)	MHA (%)	BS EN 197-1(2000) ASTM C 618 (2005)
SiO_2	16.42	$CaO + SiO_2 \geq 50\%$	65.01	$CaO + SiO_2 + Fe_2O_3 \geq 70\%$
AL_2O_3	3.23		5.12	
Fe_2O_3	4.42	$CaO/SiO_2 \geq 2\%$	3.03	
CaO	69.93		6.03	$LoI \leq 12\%$
MgO	1.36	$SO_3 \leq 3.5\%$	2.81	
SO_3	1.98		1.21	
Na_2O	0.32	$MgO \leq 5.0\%$	1.06	
K_2O	0.66		5.13	
P_2O_5	0.103	$Cl \leq 0.1\%$	3.11	
Cl	0.1		0.16	
TiO_2	0.31	$LoI \leq 5\%$	0.15	
Cr_2O_3	-		0.01	
BaO	0.18		0.02	
LOI	1.03		6.01	

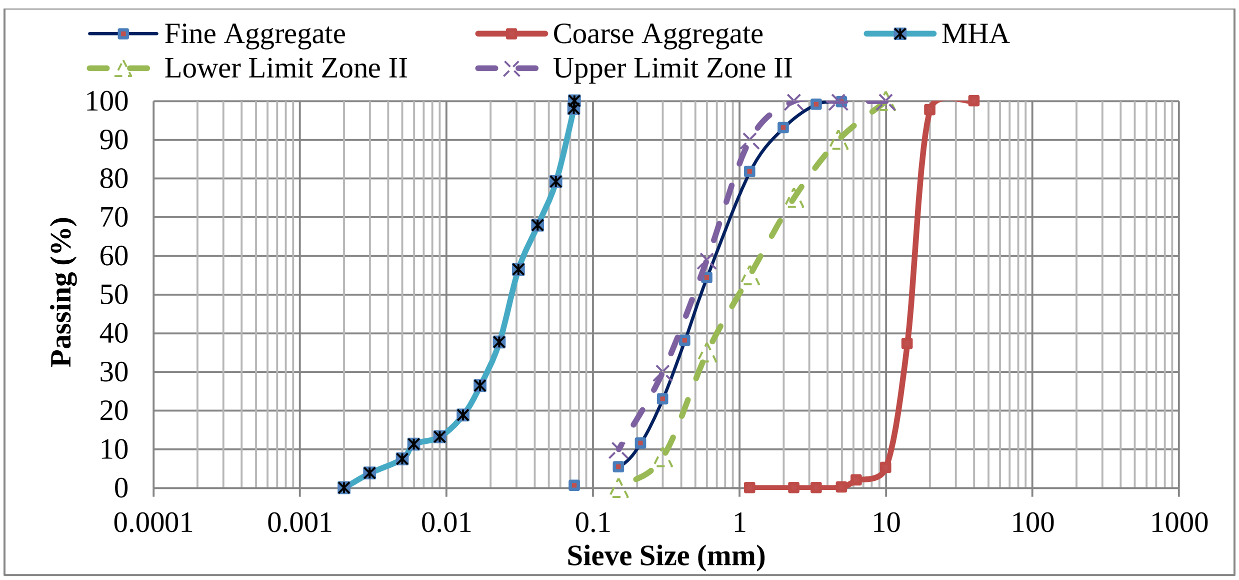

Figure 1 Particle Size Distribution of Aggregate and MHA

Table 2 Physical Properties of Binders and Aggregates

Properties	Value			
	Cement	MHA	Sand	Gravel
Moisture content (%)	0.68	2.25	2.35	1.18
Specific gravity	3.14	2.22	2.61	2.69
Density (kg/m^3)	1440	694	1560	1665
Loss on ignition (%)	1.30	6.01	-	-
Fineness(%)	14	25	-	-
Colour	Dark grey	Grey	-	-

Trial Mix design of grade 40 self-compacting concrete

Mix design of the self-compacting concrete was based on guidelines laid out in BS EN 206 (2013) which involved the selection and proportioning of SCC constituents materials. The mix design for the control TM-00 (SCC without MHA) was obtained via trial mixes using TM-00 as the control mix and TM-1, - TM-10, as shown in Table 3. Trial mix TM7 was selected having met the requirement for the design strength of grade 40 concrete. The requirement for fresh properties of SCC are slump flow 550mm-850mm, passing ability of 0.8-1.0, and segregation not greater than 15% as shown in Table 3.

Table 3 Summary of Mix Design Proportion of Grade 40 SCC by Trial

Trial	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	water(kg/m^3)	Passing Ability	Slump Flow (mm)	Segregation Resistance	Compressive strength (N/mm^2)	Super-plasticizer (kg/m^3)
TM1	520	840	890	182	0.73	531	5.9	38.4	7.49
TM2	520	860	870	182	0.78	544	7.4	40.39	7.49
TM3	520	880	850	182	0.81	651	9.4	41.36	7.49
TM4	520	900	830	182	0.84	658	11.7	43.87	7.49
TM5	520	920	810	182	0.85	682	17.6	42.81	7.49
TM6	520	840	890	192.4	0.78	584	6.6	40.22	7.49
TM7	**520**	**860**	**870**	**192.4**	**0.81**	**657**	**9.2**	**44.42**	7.49
TM8	520	880	850	192.4	0.83	672	12.6	42.68	7.49
TM9	520	900	830	192.4	0.84	689	15.1	44.89	7.49
TM10	520	920	810	192.4	0.87	722	18.6	45.52	7.49

Development of Strength Predictive Model of MHA Self-Compacting Concrete

Millet husk ash has been used as partial replacement of cement in normal vibrated concrete with the aim of reducing cement production; minimize the emission of CO_2 to the atmosphere and the way of waste disposal. This research studies the effect of partial replacement of cement with MHA in SCC using a statistical tool response surface methodology for the design and analysis of the strength development of hardened SCC properties. To evaluate the relationship and interactive effects of the individual parameters on the dependent variables (responses) response surface methodology was employed for designing the experiments based on one factors (MHA). Each parameter was varied in seven levels, MHA (0%, 5% 10%, 15%, 20%, 25% and 30%) by weight of the total binder. The responses were compressive strength, flexural strength and splitting tensile strength. The design expert software generates model equations and graphs that would best fit the experimental data. A comparison is then made between the actual value or observed value and the predicted value experimental data and data generated by the models and the residual evaluated.

Table 4 Material Batching for Self -Compacting – Millet Husk Ash

Mix No	MHA (%)	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	MHA (kg/m^3)	Water (kg/m^3)	Super Plasticiser (kg/m^3)
MC0	0	520	870	890	0	185	7.49
MC1	5	494	870	890	24.7	185	7.49
MC2	10	468	870	890	46.8	185	7.49
MC3	15	442	870	890	66.3	185	7.49
MC4	20	416	870	890	83.2	185	7.49
MC5	25	390	870	890	97.5	185	7.49
MC6	30	364	870	890	109.2	185	7.49

Hardened properties assessment of self-compacting – Millet Husk ash concrete

Reference to the design mix generated using RSM the test on the hardened properties self-compacting concrete – Millet husk ash was carried out on following tests; compressive, flexural and splitting tensile strengths in conducted in accordance to BS EN 12390-3,5,6, (2000)

Results and Discussion

Result of Compressive Strength of MHA-SCC

Figure 2 shows the results of compressive strength of MHA-SCC and revealed that compressive strength increased with curing age but decreased with increase in MHA content at all curing ages. The 28 days compressive strength developed from 43.7 N/mm^2 – 26.7 N/mm^2 at (0% – 30 %) MHA with minimum compressive strength at 30 % MHA content as shown in Table 5. It was however observed that the 28 days compressive strength of SCC increase with up to 10 % MHA content meeting the design characteristic strength of 40 N/mm^2. The boost in strength was due to high content of silica in MHA and its fineness when combine with calcium hydroxide in the presence of water form a stable calcium silicate compound possessing cementitious properties and improves the properties that results in optimum crushing strength up to 10% of MHA. After it, strength begins declined with rise in proportion of MHA owing to less hydration of cement as the MHA possesses a lesser amount of cementitious property than OPC, (Banthia *et-al.,* 2003 and Naraindas *et-al.*, (2020). Therefore, the use of 10% MHA as cementitious ingredient in concrete provides slightly less strength compared to the control. Hence, it is recommended that beyond 10% MHA replacement with cement could not positively affect the strength of concrete. Similar results were observed by Jimoh *et-al.*, (2013); Ajayi *et-al.* (2013) and Bheel *et-al.* (2020) who revealed that the use of up to 10%MHA as OPC replacement gives better strength compared to control sample after 28 and 90 days respectively

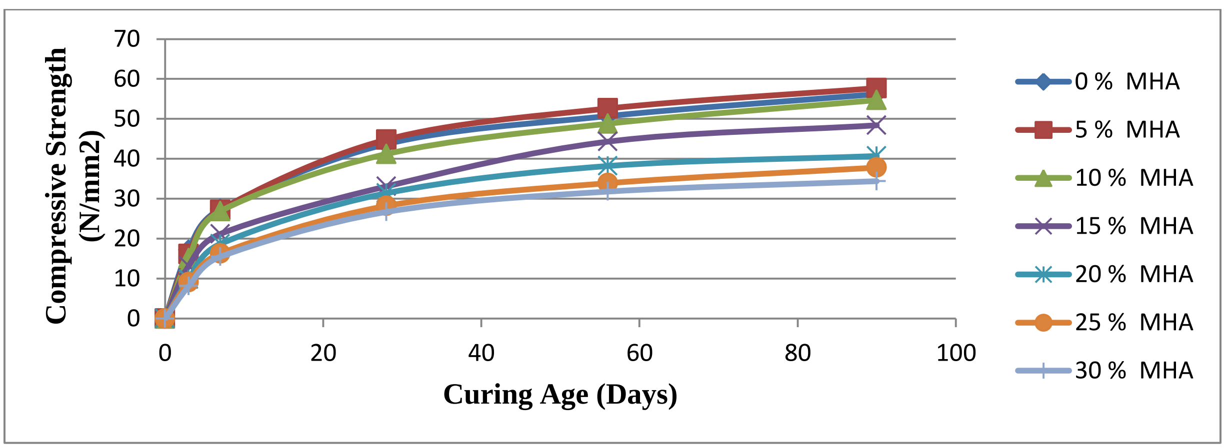

Figure 2 Effect of Curing Age on Compressive Strength MHA- SCC

Result of Splitting Tensile Strength of MHA-SCC

Figure 3 shows split tensile strength results of MHA-SCC samples after 28 days. The result reveals maximum tensile strength of 4.80N/mm^2 at 5% MHA greater than the control and minimum strength equals to 2.07N/mm^2 for 30% MHA replacement, at early curing age the splitting tensile strength decreases with increase in MHA content as shown this may be due to delay in strength development caused by the delay in setting time. While, the increase in strength on addition of MHA at 10% and above could be due to high specific surface area of MHA when compared to OPC as observed by Bheel *et-al.*, (2021) when OPC is replaced by MHA improves the strength up to 10% compared to ordinary concrete at 28 days. This is in line with the work of Pai *et- al.*, (2014); Foong *et-al.*, (2015) and Bheel *et-al.*, (2019).

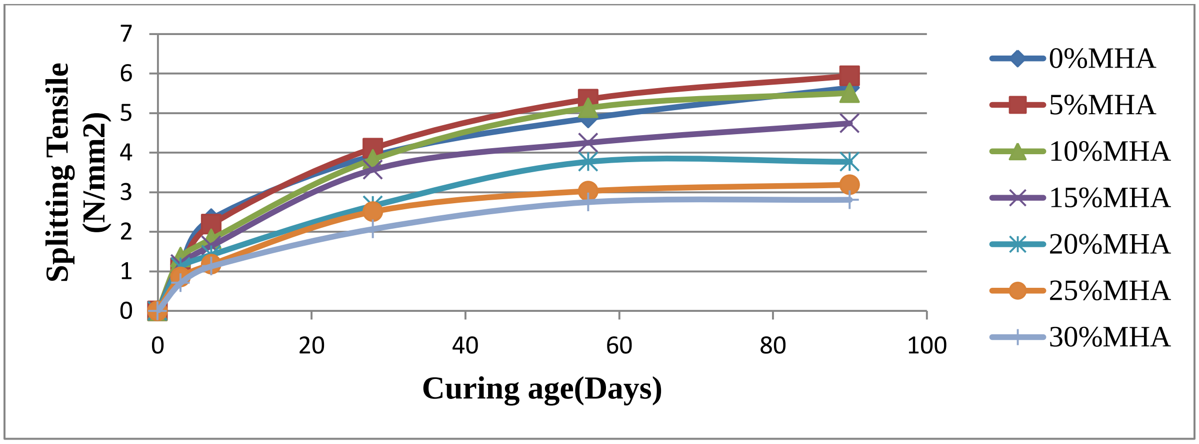

Figure 3 Effect of curing age on Splitting Tensile Strength of MHA-SCC

Statistical interpretation of the Test Results

The statistical models developed have been completely analysed statistically and validated. The analysis has been conducted at a 5 percent significance level to examine the importance of experimental factors. The compressive strength, flexural strength and splitting tensile strength were the dependent variables in the analysis, whereas, the independent variable factors was millet husk ash (MHA). The discussions of variance analysis of each response model are presented in the following subsection belo

Table 5 Experimental design parameters and their responses

Runs	Variables	Responses		
	MHA-SCC (%)	Compressive Strength(N/mm^2)	Flexural Strength(N/mm^2)	Splitting Tensile strength(Nmm^2)
1	25	27.6	3.61	2.33
2	0	43.7	5.88	4.63
3	0	44.1	5.74	4.5
4	15	34.2	4.91	3.16
5	10	40.1	5.61	3.83
6	30	26.7	3.47	2.07
7	10	41	5.7	3.85
8	15	33.2	4.8	3.05
9	30	27.2	3.4	2
10	20	31	4.06	2.66
11	5	44.8	5.92	4.8

ANOVA Analysis for Compressive Strength of MHA-SCC

Compressive strength of concrete is one of most essential properties of hardened concrete to be considered in high strength concrete since other structural properties depend on the compressive strength of the concrete. After carrying out the regression analysis, a fitted quartic model was developed for the prediction of compressive strength of MHA-SCC. The model was chosen based on the highest order polynomial in which the additional terms were significant and not aliased by the software (design expert). The summary of the analysis of variance for the response surface quadratic model for compressive strength are presented in Table 6

Table 6 ANOVA for MHA-SCC Compressive Strength Quartic model

Source	Sum of squares	Degree of freedom	Mean square	F-value	Prob>F	Remarks
Model	510.95	4	127.74	235.75	< 0.0001	significant
A-MHA	132.31	1	132.31	244.20	< 0.0001	
A^2	5.09	1	5.09	9.40	0.0221	
A^3	23.83	1	23.83	43.99	0.0006	
A^4	4.46	1	4.46	8.24	0.0284	
Residual	3.25	6	0.54			
Lack of Fit	2.14	2	1.07	3.86	0.1166	not significant

Table 6, shows the result of the Anova for the compressive strength model, the model F-value of 235.75 implied that the model is statistically significant and there is only a 0.01% chance that an F-value of that large could occur due to noise. The significance of the model and all the model terms were evaluated at 5 % significance level ($P<0.05$). As shown in Table 6, model terms A, A^2, A^2, and A^4 (where, A= MHA) have Prob>F of less than 0.05,

which implies that the terms are statistically significant, which implies that MHA has substantial effect on the compressive strength of SCC.

Additionally, the "Lack of Fit F-value" of 3.86 implies the Lack of Fit is not significant relative to the pure error; its p-value was greater than 0.05 which is 0.1166. There is a 11.66% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good thus the model has good fitness. The final model equation in terms of the actual factors for the compressive strength of MHA with all the model terms is given in Eqn. 1.

$$\begin{aligned} &Compressive\ Strength\ F_{C(mha)} \\ &= +43.88560 + 1.25834MHA - 0.25623MHA^2 + 0.010765MHA^3 - 1.41694 \\ &- 004MHA^4 \end{aligned} \tag{1}$$

Table 7 MHA-Compressive Strength Model Validation

Response	S. D	μ	R^2	Adj. R^2	Pred. R^2	AP
Compressive strength (N/mm^2)	0.74	35.78	0.9937	0.9895	0.9787	36.514

Where S.D: Standard deviation, μ: mean, R^2: correlation coefficient, Adj.R^2: adjusted correlation Coefficient, Pred. R^2: predicted R^2, AP: adequate precision.

Table 7 shows the fit statistic values for the compressive strength model. The R^2 value of 0.9937, which is almost 1 indicates that 99.37% of the experimental results can be correlated by the models. For a good model, a high R^2 value close to 1. The adjusted R^2 is a corrected form of R^2, modified for the number of predictors in the model. The predicted $R^2$is the measure of the dissimilarity of the data for the estimated model (Muhammed *et-al.*, 2018; Haruna *et-al.*, 2019). Standard deviations (SD) can be used to assess the variation of the model based on the test data. When the SD has small value in relation to the mean of the model is an indication that the experimental results have a higher degree of correlation between the existing models. "Adequate Precision" (AP) is used to relate the range of the predicted data at the design points to the average prediction error. It can also be used to measures the signal to noise ratio. A ratio greater than 4 is desirable. AP value of 35.78 indicates that the model has an adequate signal and can be used to navigate the design space since is greater than 4. Similarly, Figure 4 shows the predicted versus actual plots, the graph is used to check the level of accuracy and fitness of the model developed. Also; the data were analyzed to check the correlation between the experimental and predicted values as shown in Figure 4. The points are fitted smoothly on a straight line indicating a good relationship in the developed models between experimental and predicted outcomes. The distribution of the points indicates a satisfactory fitting precision of the models, and there is a mutual agreement between the predicted and actual results of the response (Haruna *et-al.,* 2019). The adequacy of the model was further checked from the normal residual plots as shown in Figure 3. It shows the normal probability plot which revealed that the residuals follow the normal distribution and the assumption of normality is valid (Haruna *et-al.*, 2019; Montgomery, 2006). Similarly, Figure 6 is the studentized residuals plotted against the observed number of run. The studentized residual are very effective in detecting outliers and accessing the equal variance assumption. The test is conducted essentially to check if the outlier is extreme relative to other values. A result from Figure 6 does not have outlier the values are well fitted within the range. While figure 7 shows the result of compressive versus %MHA and reveals that compressive strength reduces with increase in MHA content similar to the experimental result from the laboratory.

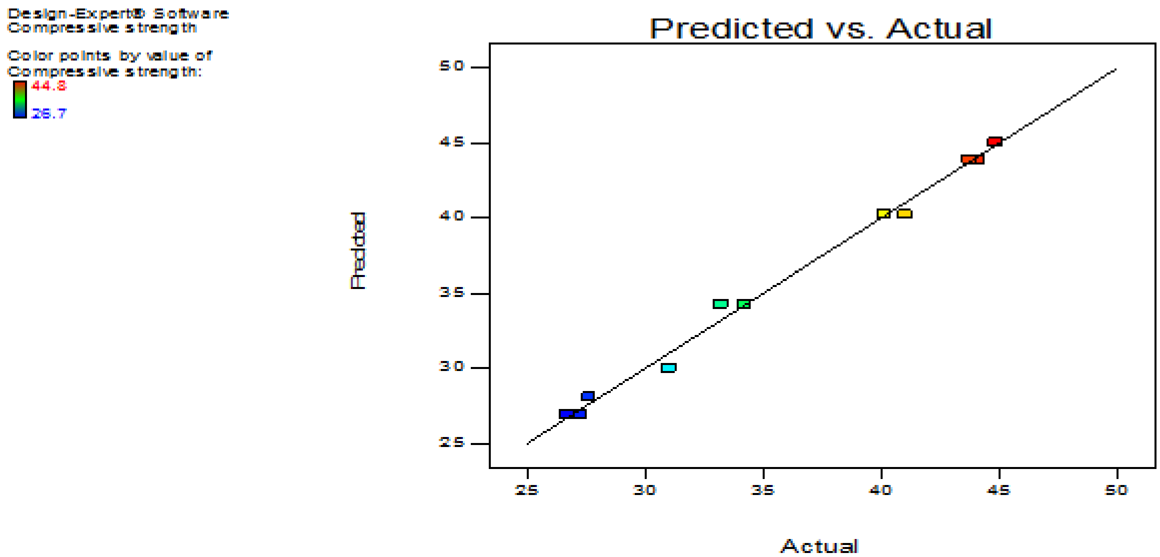

Figure 4 the predicted versus actual plots

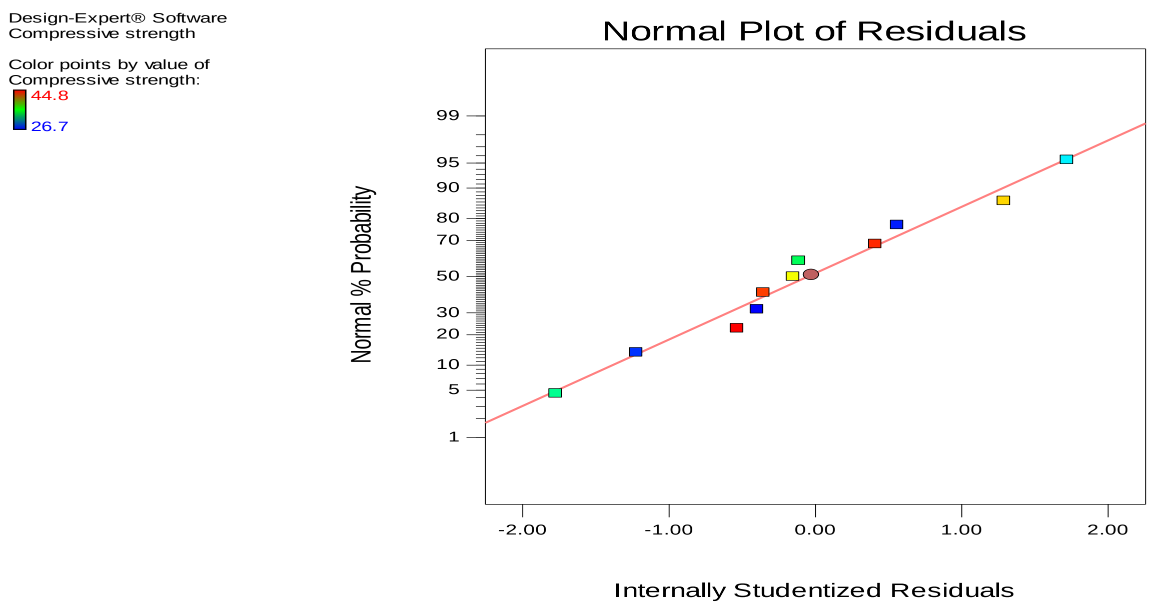

Figure 5 Normal plot of residual versus internally studentized residual.

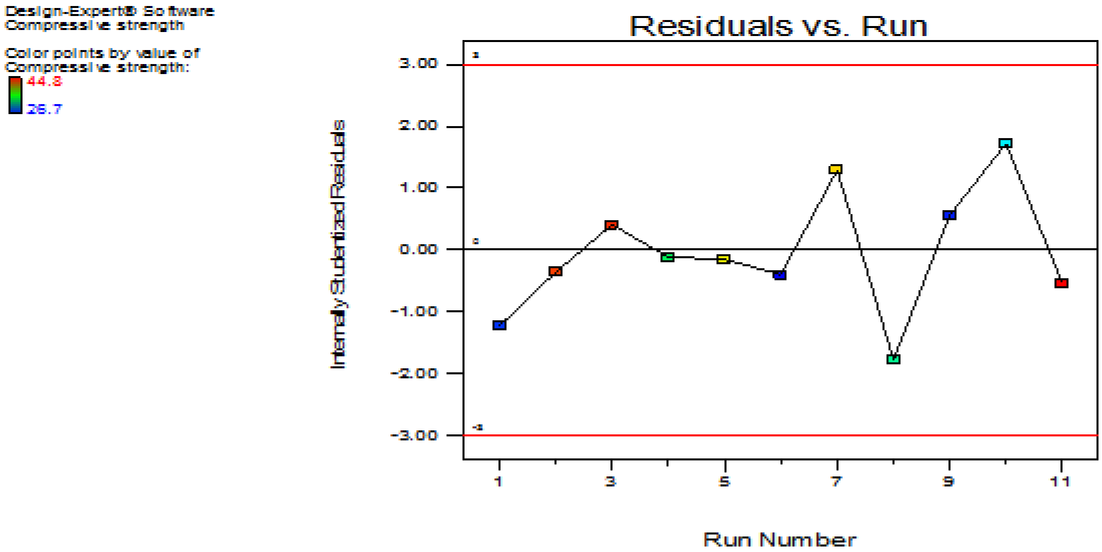

Figure 6 the Studentized Residual versus Run number

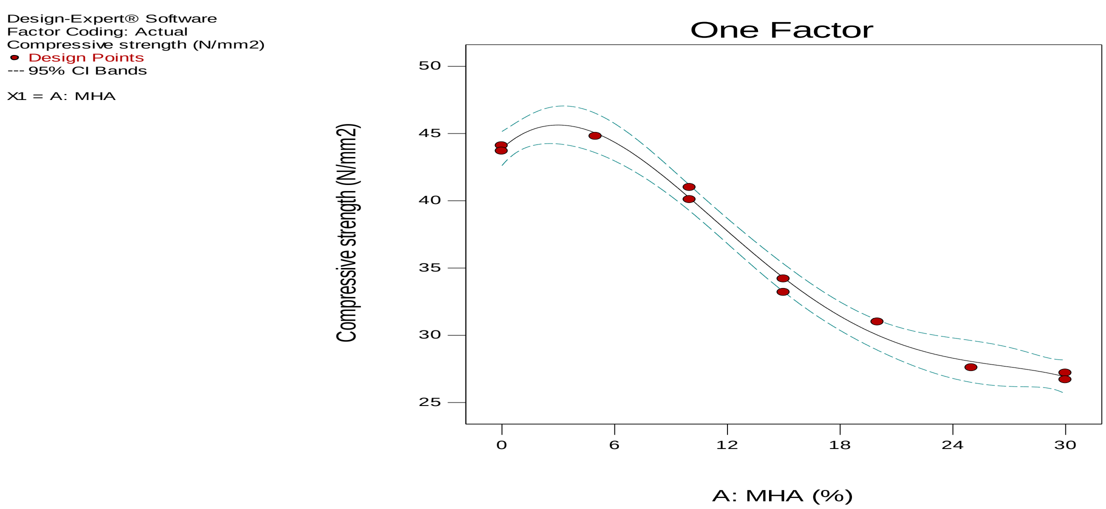

Figure 7 compressive Strength versus MHA

Table 8 ANOVA for MHA-SCC Flexural Strength Cubic model

Source	Sum of squares	Degree of freedom	Mean square	F-value	Prob>F	Remarks
Model	10.42	3	3.47	566.79	< 0.0001	significant
A-MHA	2.83	1	2.83	461.39	< 0.0001	
A^2	0.13	1	0.13	21.13	0.0025	
A^3	0.57	1	0.57	92.61	< 0.0001	
Residual	0.043	7	6.130E-003			
Lack of Fit	0.021	3	6.854E-003	1.23	0.4092	not significant

The effects MHA on the flexural strength of SCC is shown in Table 8. After carrying out the regression analysis, a fitted cubic model was developed for the prediction of flexural strength of MHA-SCC It revealed that the model has a high F-value of 566.79 and a very small p-value of less than 0.0001. This implies that the model selected is statistically significant with a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. The level of significance of 5% was adopted to assess the importance of the model. In this case A, A^2, A^3 are significant model terms having P-values greater than 0.05. However, the fitness or goodness of the model can also be checked using the lack of fit term. For the model to be statistically fit, the P-value for the lack of fit must be greater than 0.05. The "Lack of Fit F-value" of 1.23 implies the Lack of Fit is not significant relative to the pure error. There is a 40.92% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good.

$$Flexural\ strength\ F_{C(mha)} = +5.80278 + 0.11311MHA - 0.016869MHA^2 + 3.49290E - 004MHA^3 \quad (2)$$

Table 9 ANOVA for MHA-SCC Flexural Strength Model Validation

Response	**S. D**	**µ**	**R^2**	**Adj. R^2**	**Pred. R^2**	**AP**
Flexural strength (N/mm^2)	0.078	4.83	0.9959	0.9941	0.9896	53.916

Where S.D: Standard deviation, µ: mean, R^2: correlation coefficient, Adj.R^2: adjusted correlation coefficient, Pred. R^2: predicted R^2, AP: adequate precision

Table 9, shows that the flexural strength response model has a very high correlation coefficient R^2 of 0.9959 is approximated to 1 which indicates the acceptability and quality of the developed model. Also, it is worthy to know that the predicted R^2 of 0.9896 values is in good agreement with the adjusted R^2 of 0.9941; as the difference between them is less than 0.2. The lower standard deviation of the model developed relative to its mean clearly demonstrates its variance with respect to the test data. Experimental data therefore provided less uncertainty for the models developed. The signal to noise ratio of the model is estimated based on adequate precision (AP). For a model to be adequate, an AP value greater than 4 is generally desirable for a good model (Montgomery, 2006; Haruna *et-al.,* 2019). In this study the adequate precision (AP) value for the flexural strength model was found to be 53.915, indicating that the model is adequate and can be used to navigate the design space.

Figure 8 shows the relationship between the predicted and experimental results. It can be observed that the predicted data provide by the model is well fitted with the experimental results as the data points are evenly distributed along the straight line. Figure 9 is a plot of normal residual to check the distribution of the results which lie almost on the line of equality having a shape similar to S-shaped distribution. A linear trend showed normality in the error term and the experimental results did not show any signs of problems. This confirmed that the results are normally distributed. Figure 9 is the plot of studentized residuals is plotted against the observed number of run. The studentized residual are very effective in detecting outliers and accessing the equal variance assumption. The test is conducted essentially to check if the outlier is extreme relative to other values. A result from Figure 10 does not have outlier the values are well fitted within the range. While figure 11 shows the result of flexural strength versus %MHA which shows that the strength reduces with increase in MHA content similar to the experimental result from the laboratory.

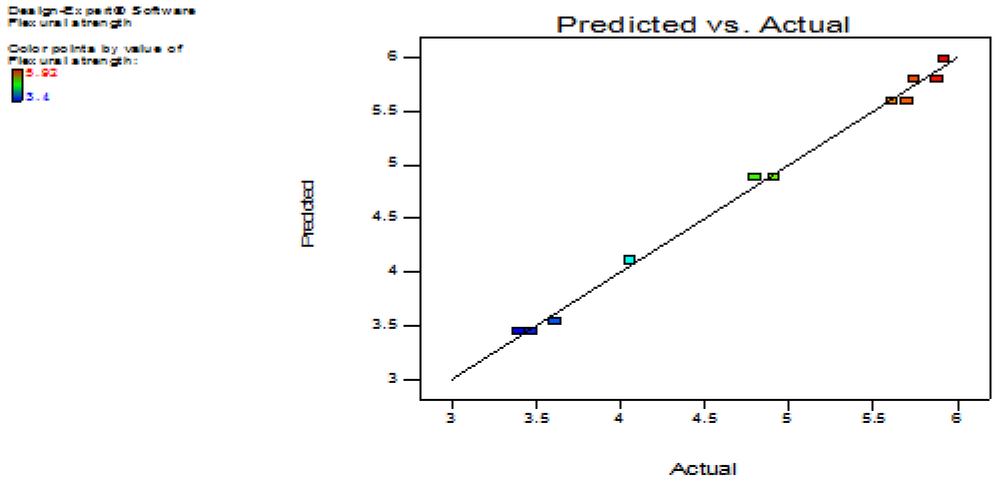

Figure 8 the predicted versus Actual

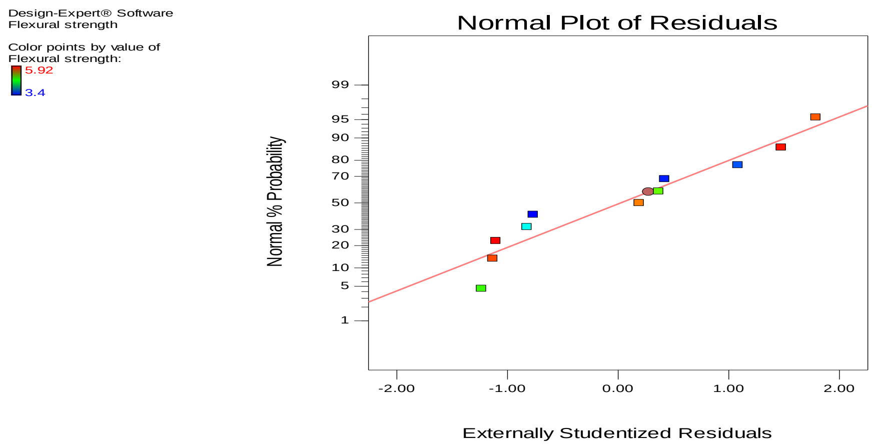

Figure 9 Normal plot of residual versus studentized residual

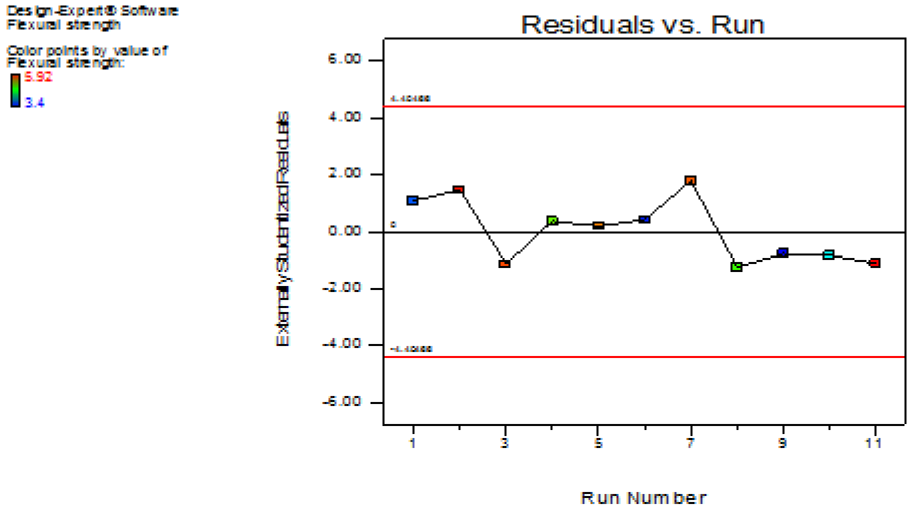

Figure 10 the Studentized Residual versus Run number

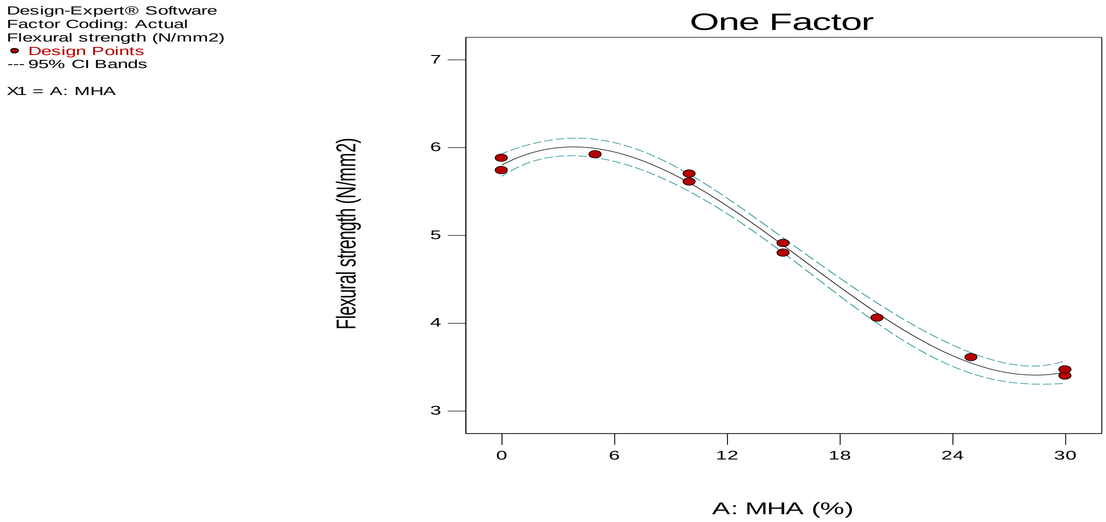

Figure 11 flexural strength vs % MHA

Table 10 ANOVA for MHA-SCC Splitting Tensile Strength Quartic Model

Source	Sum of squares	Degree of freedom	Mean square	F-value	Prob>F	Remarks
Model	10.60	4	2.65	311.36	< 0.0001	significant
A-MHA	2.19	1	2.19	257.83	< 0.0001	
A^2	0.22	1	0.22	25.91	0.0022	
A^3	0.26	1	0.26	30.77	0.0014	
A^4	0.20	1	0.20	23.09	0.0030	
Residual	0.051	6	8.508E-003			
Lack of Fit	0.034	2	0.017	3.95	0.1129	not significant

Table 10 shows a fitted quartic model was developed for the prediction of splitting tensile strength of MHA-SCC, the splitting tensile strength response of MHA-SCC has a high F-value of 311.36 and a very small p-value of less than 0.0001. This indicates that the model selected is statistically significant with 0.01% chance that a model F-value that large could happen due to noise. Fitted quartic model was developed for the prediction of splitting tensile strength of MHA-SCC. The model was chosen based on the highest order polynomial in which the additional terms were significant. The summary of the analysis of variance for response surface quartic model for splitting tensile strength is shown in Table 11. The significance of the model and all the terms of the model were tested at 5% significance level ($P<0.05$). The model terms A, A^2, A^3 and A^4 have Prob>F values of less than 0.05 which implies that the terms are significant for splitting tensile strength model. The "Lack of Fit F-value" of 3.95 implies the Lack of Fit is not significant relative to the pure error. There is 11.29% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good for the model. The splitting tensile strength can be predicted from Anova model given in Eqn. 4.8.

$$Splitting\ Strength\ F_{S(mha)} = +4.57730 + 0.19265 \times MHA - 0.043127 \times MHA^2 + 2.02078E - 0.003 \times MHA^3 - 2.97266E - 005 \times MHA^4 \quad (3)$$

Table 11 MHA-Splitting strength model validation

Response	S. D	μ	R^2	Adj. R^2	Pred. R^2	AP
Compressive strength (N/mm^2)	0.092	3.5	0.9952	0.9920	0.9745	42.942

Where S.D: Standard deviation, μ: mean, R^2: correlation coefficient, Adj.R^2: adjusted correlation coefficient, Pred. R^2: predicted R^2, AP: adequate precision.

The models were further validated using the R^2 value to ascertain the quality. As shown in Table 11, a high R^2 value of 0.9952 approximately close to 1 which indicates the acceptability and quality of the developed model. The difference between the adjusted and the predicted R^2 is less than 0.2. This indicates that the adjusted and predicted R^2 are in good agreement with each other. The "Lack of Fit F-value" of 3.95 implies the Lack of Fit is not significant relative to the pure error. There is a 11.29% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good for the model fitness. The adequate precision of 42.952, which is greater than the threshold value of 4 confirmed that the developed model is desirable and can be used to traverse the design space. From the above analysis, it can be assumed that these models can be perfect for forecasting the splitting tensile strength of the MHA-SCC.

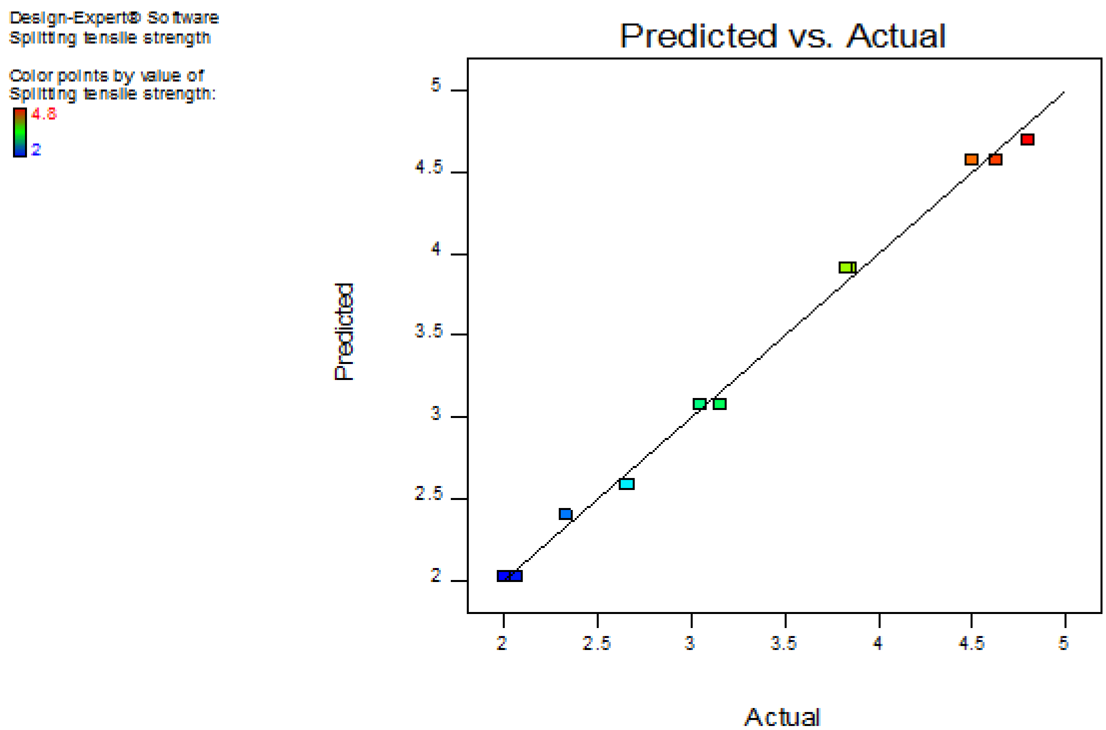

Figure 12 shows the predicted versus Actual

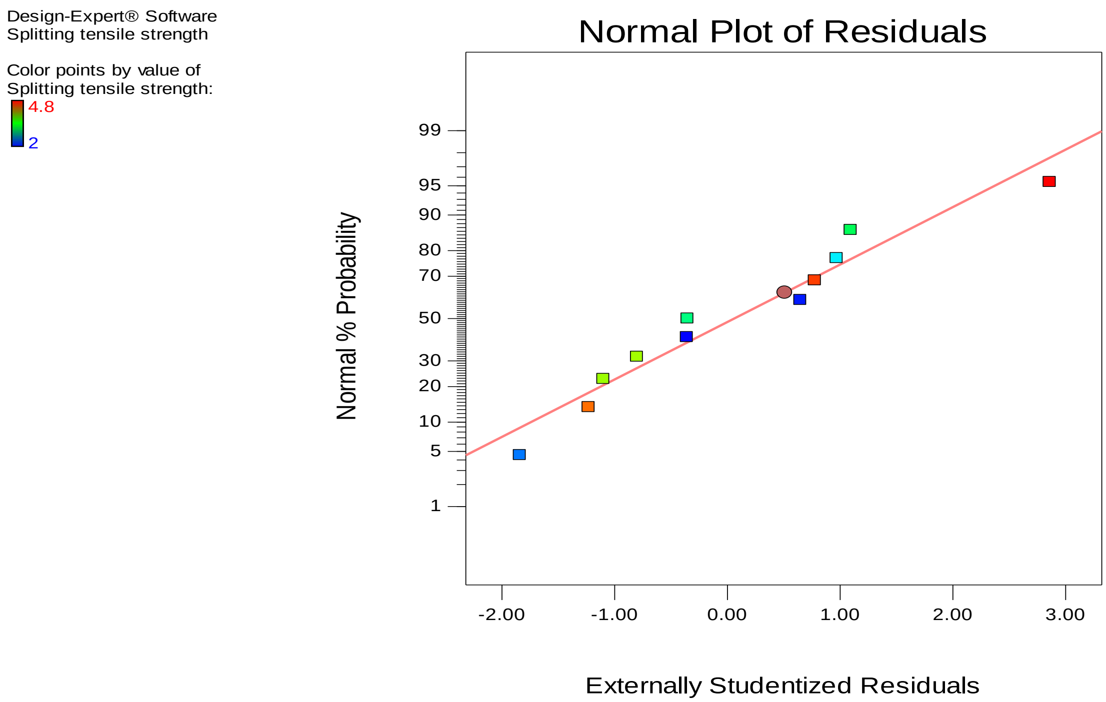

Figure 13 shows the plot of normal versus studentized Residuals

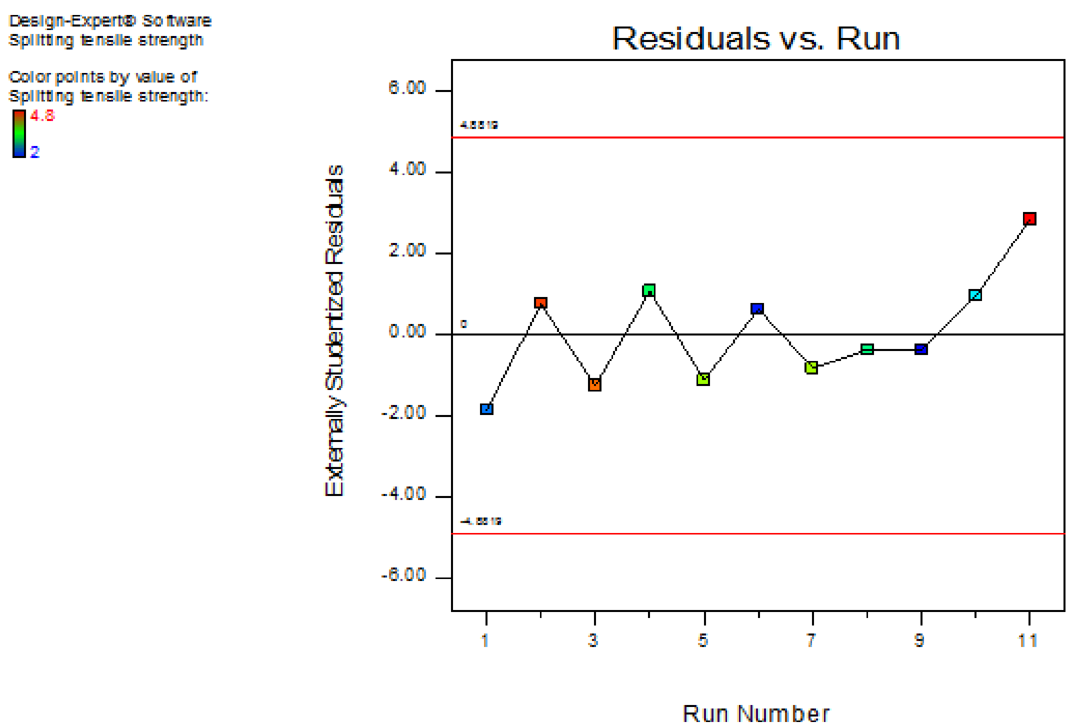

Figure 14 shows the Residual versus Run

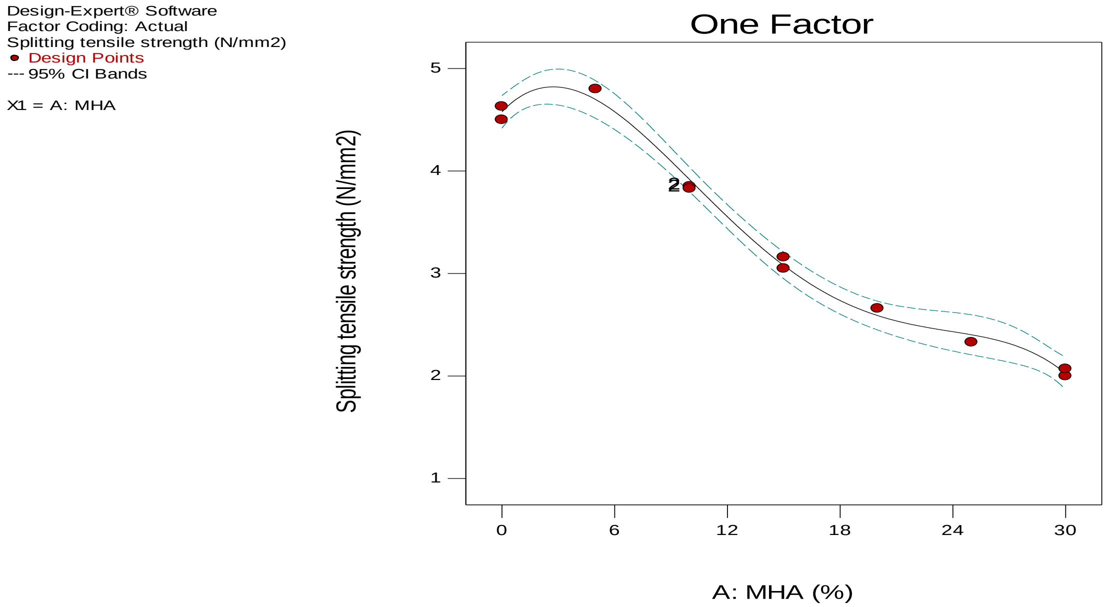

Figure 15 shows one factor splitting tensile strength versus MHA (%)

Conclusions

From the research conducted the following conclusions were made;

1. The chemical properties of MHA showed that is a good pozzolana has satisfied the requirement for BS EN 197-1 (2000) and ASTM C 618 (2005) for (SiO_2, Al_2O_3 and Fe_2O_3).
2. The compressive strength, flexural strength and splitting tensile strength reduce as % replacement of MHA increases, the compressive strength of MHA increase up to 10 replacements at 28 days and 15% and 20% at 56 and 90 days respectively. MHA improves the compressive strength of SDA up to 5%. The flexural strength and splitting strength of MHA increase up to 5%.
3. Statistical model equations for MHA-SCC was effectively developed the models developed using RSM for predicting the compressive, flexural strength and splitting tensile strengths of MHA-SCC shows a high degree of correlation and predictability with percentage error less than 10%.

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