UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 5(2), June (2025), 2511-2524
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

# Factorial model prediction for performance of sawdust ash-metakolin blended oil well cement

Silas, Ebenezar.Onyedikachi[1], Ubachukwu Obiekwe A[2], Onwuka, David O[3]

[1] Department of Civil Engineering, Federal University Technology Owerri, Imo State, Nigeria.
[2] Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, Abia State.
[3] Department of Civil Engineering, Federal University Technology Owerri, Imo State, Nigeria.
[*]Corresponding Author Email: silasebenezaronyedikachi@gmail.com

**Abstract**

Factorial methods provide an efficient statistical approach to model and optimize oil well cementing material -based on OPC blended with Metakaolin and Sawdust-Ash by systematically investigating the effects of key parameters of cementing slurry and its hardened cake including thickening time, free fluid, fluid loss, slurry density, rheology and compressive strength. The mix design of using Sawdust Ash (SDA) and Metakaolin (MK) as a blend to ordinary Portland cement (OPC) was carried out using a mathematical arrangement of a factorial DOE model allowing percentages blend of the OPC with Metakaolin for 10%,12.5% and, 15% and Sawdust ash at 0%, 5% 10% respectively. Materials for the study were characterized based on physical, chemical, and pozzolanic test parameters. the Design of the Experiment (DOE) was used for two domains three interactive factors (2x3) following the specifications of the America Institute of Petroleum (API) SPEC 10A and 10B). The results obtained showed that Metakaolin blend with OPC alone at 15% were detrimental to rheology but incorporating Sawdust-Ash up to 10% with Metakaolin at both 10% and 15% improved the both the rheology performance, free water within (0.032-1.435%), decreased fluid loss to the recommended API RP-10B range of 50 to 250ml, increased of thickening time, and modulate the control sample (OPC). The interaction effect from the yield output of the model were used to obtain several predictive mathematical models readily needed for Oil well cementing.

Key words: Factorial model, Oil Well, Cementing, Metakaolin, Sawdust Ash

## 1. Introduction

Cementing operation is the most important, expensive, and most critical process during drilling operations for wellbore completion immediately after casing is installed (Alyooda, 2017). The main purpose of cementing operation is for displacing the drilling fluid, isolating the permeable zone, supporting the axial load of the casing string, protecting the casing from corrosion, and preventing fluid migration as well as hindering the escape of oil minerals into rock formation. One of the challenges usually encountered during deep drilling, especially in a High-Pressure-High Temperature (HPHT) environment is the sustenance of wellbore integrity in terms of serviceability. The serviceability is a function of quality wellbore cementing slurry, and well cement sheaths which tends to degrade in a corrosive and high-temperature environment. This backlash leads to increased rate of chemical attacks, formation movements and mechanical failure experienced in many cases of oil wellbore drilling. This increased deterioration manifests in form of reduction in strength, formation of crack, and high rate of release of calcium hydroxide ($Ca(OH)_2$) and $CO_2$, which is structural detriment and leads to failure of cementing operation in oil exploration. (Joey and Rigoberto, 2015).

Criteria for choosing an oil-well cement slurry for individual wells is based on the physical and performance requirements of the slurry which include the thickening time; rate of fluid loss; amount of free fluid; slurry density, and rheology of the slurry. These requirements and associated risk on failure occurrence have led many oil and gas companies to research for efficient materials for oil well-cementing operations (Efstathios, 2016). Performance of Ordinary Portland Cement (OPC) or other class of oil well cement during drilling and post drilling operations is reduced regressively with increased depth and exposure to extreme conditions. Also, the use of Ordinary Portland Cement is a huge contributor to greenhouse gases with its resultant associated global warming generated during the manufacturing process in which limestone is used extensively. If the same quality of cement, especially in terms of strength, can be obtained with little limestone used, then this would mitigate the negative environmental impacts that the limestone has. On the other hand, continuous generation of wastes arising from industrial by-products and agricultural residue creates acute environmental problems both in terms of their treatment and disposal; hence necessitating a cleaner modern means of utilizing these waste materials efficiently.

Another problem is the ability of oil industries to develop and predict the behaviour of cementing material in each operation that will in real time perform optimally during its slurry stage which require the slurry to remain pumpable while maintaining low free fluid as well as fluid loss till it reaches its target depth without retrogression during its service life. Further concern, is the cost of cement especially well cement whose cost is on the rising due to increased demand and rising mining levies; and a solution to this increase in prices would be a relief to the consumers of cement in the construction industry (Waithaka, 2015). On the other hand, continuous generation of wastes arising from industrial by-products and agricultural residue like sawdust creates acute environmental problems both in terms of their treatment and disposal; hence creating the need for a cleaner modern means of utilizing these waste materials efficiently ( Ubachukwu, and Silas, 2017).

This study, therefore, looked into the viability of using Sawdust ash and Metakaolin as a partial Ordinary Portland Cement (OPC) blend to mitigate the pollution problems and also provide a cheaper and excellent oil well-cementing material. Metakaolin (MK) as well as Sawdust ash (SDA) when used as a partial replacement substance for cement in concrete is reported to increase strength and improved durability due to their reaction with $Ca(OH)_2$ one of the by-products of hydration reaction of cement and the resulting production of an additional compound of calcium silicate hydrate (C-S-H) gel (Ettu, Ezenkwa, Awodiji, Njoku, and Opara, 2016). The use of pozzolans for making oil well-cementing material is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the oil well-cemented casing. Consideration for effective oil well cement slurry design makes it necessary to use factorial design method, which has been successfully employed in various studies such as to develop a model to predict the compressive strength of oil well cement, predict the rheology of oil well-cementing material containing chemical additives. The effects of different factors; which can be the constituents or additives were usually considered individually as well as their interaction with each other during the development of the model. The model has high efficiency with a correlation coefficient of 99.8%, standard error of 0.1325, and accuracy of 99.8% (Falode, 2013). The study made use of factorial model of two domain three interactive factor $2^3$ for designing the experimentation as well as analyzing the various properties of the slurry and hardened cubes of ordinary Portland cement blend with metakaolin-Sawdust Ash cementing material. The study focuses on the performance interaction of the blending of Ordinary Portland Cement (OPC) with Metakaolin for 10%, 12.5% and 15% whereas Sawdust Ash at 0%, 5% 10% which made up for 25% maximum combined replacement. Allowing the reduction of the OPC, or imported class G and H cement consumption while improving the strength and durability properties of the oil well-cemented casing.

**2. Theoretical Background**

Oil well-cementing operation is a sensitive operation that needs prescient design information for onsite formulation. It makes use of a tested and viable model of higher accuracy of interaction and regression coefficient to predict the various desired required properties of cementing material for a successful well-cementing operation (Falode, Salam, Arinkoola, and Ajagbe, 2013). One of the important requirements before introducing wells into operation is the strengthening of the casing columns and insulation of layers by injecting grouting (Broni-bediako, Joel, and Ofori-sarpong, 2016). Furthermore, the criteria considered in choosing an oil-well cement slurry for individual wells is the physical and performance requirements of the slurry which include the thickening time, rate of fluid loss, slurry density, rheology of the slurry, and amount of free fluid; which must be kept to zero calling for reduction in the water separation of the slurry, with regards to requirements of the American Petroleum Institute (API) Specification (API 10A, 2015). A consideration for complex behavioural requirement of oil well cement slurry design demands for the use of factorial design model; which have been successfully employed in various studies such as to develop a model to predict the compressive strength of class G oil well cement, predict the rheology of oil well cementing material containing chemical additives. The model allows effects of different factors which can be the constituent or additives to be usually considered individually as well as their interaction with each other during the development. Factorial design (FD) is a model method that monitors the interactions of multiple factors as well accommodate the outcome of both main and interaction effects of the experimental factors or variables (Cheong and Gupta, 2015). The number of experimental runs performed for the model development for full factorial design is governed by the Equation (1.0).

$$N = L^K \qquad (1)$$

Where K denotes experimental variable referred to as factors

L is the number of domain levels of variables,

N is the total number of experimental runs,

While K can be represented as $X_n$, $X_{n+1}$, $X_{n+2}$…, and $X_K$ regarding various experimental factors Experimental runs based on two (2) level is attributed to 2K level domain '-'(-1) to indicate low level and ' + ' (+1) for high level which can be percentage of additive of constituent in an experimental sample or percentage of replacement of constituent in an experimental sample. The model has a high efficiency with correlation coefficient of 99.8%, standard error of 0.1325, and accuracy of 99.8% (Nguyen, Ahn, Le, Lee, 2021). The mathematical model had r repetitions per cell in a completely randomized design according to Equation (2) yielding Equation (3).

$$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{jk} + ABC_{ijk} + E_{ijkv} \qquad (2)$$

Where i,j, k = (0,1) and r = (1,2….,r) repetitions, μ = interactive intercept coefficient while E = experimental error coefficient (QMET 201,2014).

Thus for $X_1$, $X_2$, and $X_3$ factors the model becomes

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 - b_{123}X_1X_2X_3 + e \qquad (3)$$

Where b0 corresponds to μ and e corresponding the interactive errors for $b_1$,$b_2$ and $b_3$ factors.
The model pseudo effect for $2^3$ level domains.

## 3.0 Materials and Methods

**3.1 Experimental Material:** Sawdust ash were obtained from sawdust in timber market Umuahia, whereas Metakaolin were obtained from kaolin deposit in Umuariaga Oboro Ikwuano, Abia state. It were prepared by employing the standard methods within the specified temperature of calcination and heating time of 90 min for Metakaolin before being employed to the experimental module. Ordinary Portland cement for the research of grade 42.5 OPC class B according to classifications of (ASTM-C150, 2007). and American Petroleum Institute (API, (2020), 10A, ).The water for the study was clean tap water from the laboratory conforming to the standard spelt in (BS EN 196-3, 2016 and Schlumber ,2020)

**3.2 Methods:** For this study, two sets (2) of samples were prepared. One set made from factorial model experimental runs as generated in Minitab design of experiment (DOE) for slurry properties of Metakaolin –Sawdust Ash (MKSDA) blended OPC and the other set of control sample containing pure class B cement in accordance to API 10A, (2015) mix specifications.

The design followed factorial $2^3$ level domain; which have various combinations and percentages blend of the ordinary portland cement (OPC) with Metakaolin for 10%,12.5% and, 15% and sawdust ash for 0%, 5% 10% which made up for 10 to 25% pozzolan incorporation in low and high level in the experimentation at absolute volume density of the individual pozzolan material. The model design allows for slight under use as well as excess dose of the combine percentage blending with Metakaolin and sawdust ash; aligning with the factorial design by Falode, et al. (2013) For the batching process, the water cement ratio W/C was maintained at 0.46 based on API standards API SPEC 10B for all the samples as reported by Qosai and Rad (2018) for Mk dosage below 30%. The pseudo mix were formulated factorial design of three factors-two replica ($2^3$x2) factor level with two centre points randomized to take care of statistical fringes ( Falode, et al. 2013) the resultant design is as shown in the Table 1. Where N1 to N18 represents the run order for the randomised blended cementing sample from the factorial design, while the C1 and C2 run orders represent the control sample with only class B ordinary Portland cement. The samples were tested for various led down simulated test by API 10A&B for slurry required to be used in well bore; which includes thickening time, fluid loss, free water, rheology, and slurry density. The mechanical testing were mainly for cube density, water absorption and compressive strength at 8 hours, 24 hours, 7 and 28days curing periods respectively using 160 samples of $100mm^3$ cubes and testing total 360 samples for both slurry and mechanical testing.

Table 1 factorial Pseudo and Actual Mix Ratio for the Formulation Generated from Minitab DOE

| StdOrder | RunOrder | Blocks | OPC | Metakaolin (MK) | Sawdust Ash (SDA) | Equivalent OPC (%) | Equivalent MK (%) | Equivalent SDA (%) |
|---|---|---|---|---|---|---|---|---|
| **11** | 1 | 1 | -1 | 1 | -1 | 90 | 15 | - |
| **3** | 2 | 1 | -1 | 1 | -1 | 90 | 15 | - |
| **9** | 3 | 1 | -1 | -1 | -1 | 90 | 10 | - |
| **12** | 4 | 1 | 1 | 1 | -1 | 75 | 15 | - |
| **16** | 5 | 1 | 1 | 1 | 1 | 75 | 15 | 10 |
| **14** | 6 | 1 | 1 | -1 | 1 | 75 | 10 | 10 |
| **10** | 7 | 1 | 1 | -1 | -1 | 75 | 10 | - |
| **2** | 8 | 1 | 1 | -1 | -1 | 75 | 10 | - |
| **15** | 9 | 1 | -1 | 1 | 1 | 90 | 15 | 10 |
| **17** | 10 | 1 | 0 | 0 | 0 | 82.5 | 12.5 | 5 |
| **1** | 11 | 1 | -1 | -1 | -1 | 90 | 10 | - |
| **13** | 12 | 1 | -1 | -1 | 1 | 90 | 10 | 10 |
| **18** | 13 | 1 | 0 | 0 | 0 | 82.5 | 12.5 | 5 |
| **7** | 14 | 1 | -1 | 1 | 1 | 90 | 15 | 10 |
| **8** | 15 | 1 | 1 | 1 | 1 | 75 | 15 | 10 |
| **5** | 16 | 1 | -1 | -1 | 1 | 90 | 10 | 10 |
| **4** | 17 | 1 | 1 | 1 | -1 | 75 | 15 | - |
| **6** | 18 | 1 | 1 | -1 | 1 | 75 | 10 | 15 |
| **$C_1$** | | | | | | 100 | - | - |
| **$C_2$** | | | | | | 100 | - | - |

## 4.0 Result and Discussion

This research results were presented in phases of the experimental methodology regarding material characterization, formulated sample slurry test and mechanical test respectively.

**4.1 Material Characterization:** Sawdust ash was physically characterized as the most light of the three cementitious material following Table 2 the particle size of Sawdust ash and that of Metakaolin have close distribution and comparable to the distribution of fly ash, silica fume, and OPC Type I/II as in the research reported by Mehta and Monteiro. (2014)

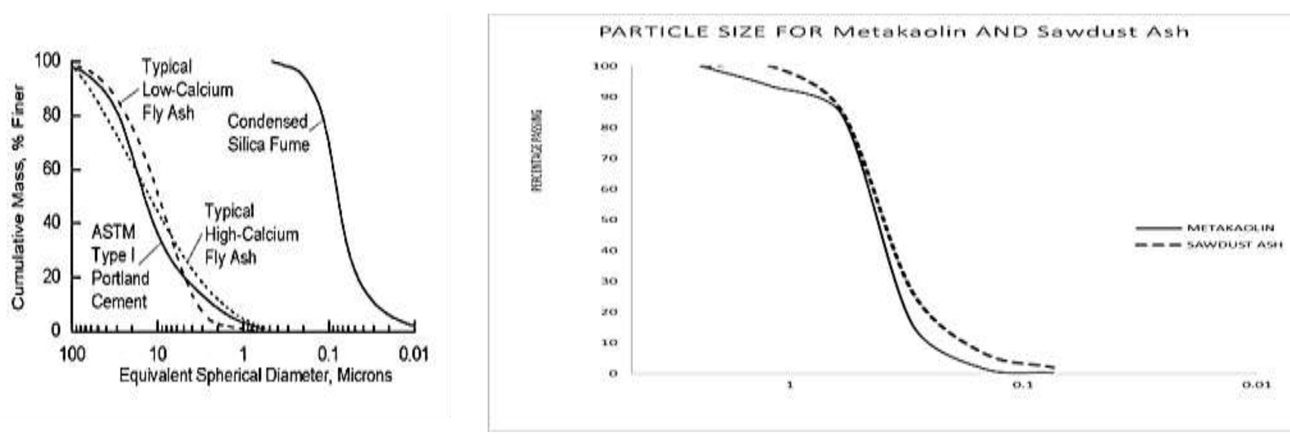


Figure 1. Particle Size Distribution of Metakaolin and Sawdust Ash as compared to other pozzolan

Table 2 Summary of Physical Characteristics of Sample Material

| Description/ Material | Sawdust Ash (SDA) | Metakaolin (MK) | Cement (OPC) |
|---|---|---|---|
| **Bulk Density (g/cm$^3$)** | 0.299 | 0.547 | 1.1164 |
| **Specific Gravity** | 1.597 | 2.064 | 3.12 |
| **Fineness Modulus (%)** | 3.6 | 3.726 | 2 |

This potentially present it as a positive constituent for tail cementing; while metakaolin (MK) makes a positive blending material in both case of lead or tail cementing. On the other hand, results from the chemical and pozzolanic test yields a combine percentage composition of the major oxides including: [Silica ($SiO_2$), Aluminium Oxide (Al2$O_3$), Iron oxide ($Fe_2O_3$) and Potassium Oxide ($K_2O$)] as shown in Table 2 for metakaolin to be 84.26% and more than 70% of (SiO2), (Al2$O_3$), ($Fe_2O_3$) which is above the stipulated minimum index of 70% as reported by Ettu et al. (2016) thus classifies it as Class N pozzolan according to ASTM C618-15. Sawdust ash for this study had slightly lower composition of about 51%, classifying it as Class C pozzolan as reported by Oladipupu,William,Emmanuel,Jacques and Julius (2018). The pozzolanic activity of metakaolin was paramount as compared to that of sawdust; attributed to the use up of detrimental $Ca(OH)_2$ by production of hydration in the cement matrix by metakaolin. Hence its potential positive blend in cementing for geothermal and deep well where $Ca(OH)_2$ by product is more.

**4.2 Slurry Experimental Result:** For the result obtain from slurry experimentation in accordance to American Petroleum Institute spec 10A&B for both the control samples as well as blended samples showed that thickening time; the time to reach 100 Bearden unit of consistency (Bc) were more than stipulated 90 minutes minimum. Nevertheless, higher values of time were recorded for run samples which had high level (15%) of metakaolin compared to control samples and those containing sawdust ash at high level (10%). Therefore, metakaolin (MK) retard the slurry more from thickening than when incorporated alongside sawdust ash (SDA). This is in agreement with the output of analysis following the factorial model fit in the Table 3 which yielded probability “P” value less than 0.05 P significant value as well as F values less than the critical value as stated reported by Falode, (2013). Thus the potential in creating more handling and pumping time of the slurry to its target depth. The following regression model coefficient in Table 3 and Figure 2 with respect to Equation (3). Corresponding to the yielded coefficient of effect in Equation (4).

Table 3 Factorial Fit: Estimated Effects and Coefficients for thickening time

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 107.913 | 0.3626 | 297.63 | 0.000 |
| cement | 4.300 | 2.150 | 0.3626 | 5.93 | 0.000 |
| metakaolin | 11.800 | 5.900 | 0.3626 | 16.27 | 0.000 |
| sawdust | -5.175 | -2.588 | 0.3626 | -7.14 | 0.000 |
| cement*metakaolin | 6.075 | 3.037 | 0.3626 | 8.38 | 0.000 |
| cement*sawdust | 7.800 | 3.900 | 0.3626 | 10.76 | 0.000 |
| metakaol*sawdust | -5.700 | -2.850 | 0.3626 | -7.86 | 0.000 |
| cement*metakaol*sawdust | -1.925 | -0.963 | 0.3626 | -2.65 | 0.026 |
| Ct Pt | | -5.913 | 1.0877 | -5.44 | 0.000 |

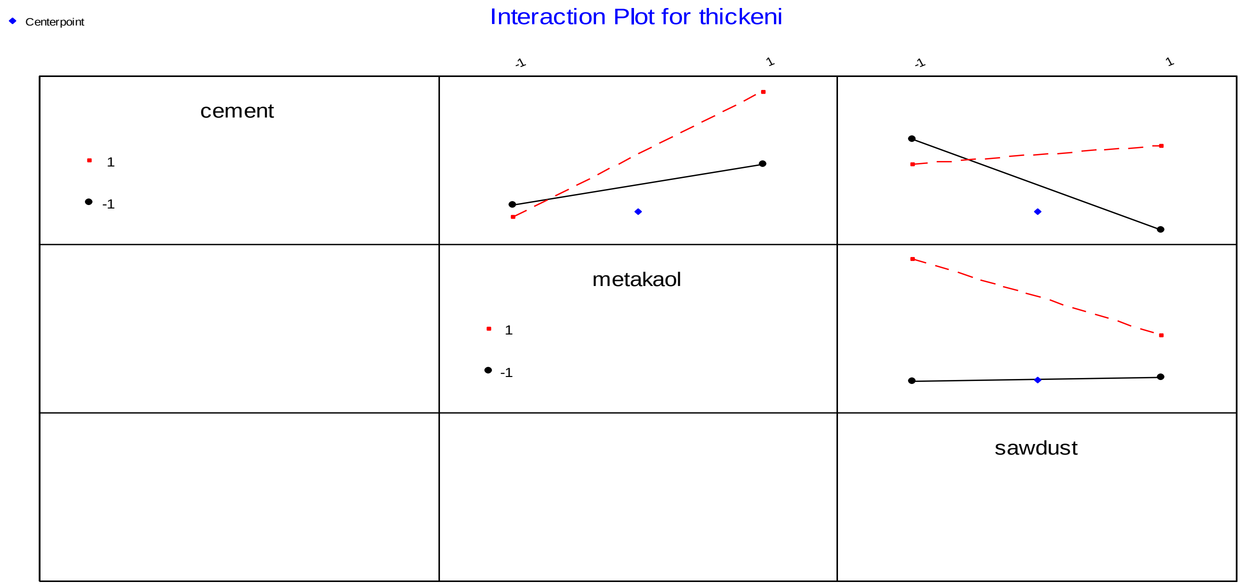


Figure 2 Interactive Effect Significant Plot for Thickening Time of Slurry

Thickening time = $107.913 + 2.15X_1 + 5.90X_2 - 2.588X_3 + 3.037X_1X_2 + 3.90X_1X_3 - 2.85X_2X_3 - 0.963X_1X_2X_3 + 0.3626$ (4)

Where: $X_1$ -Cement, $X_2$ -Metakaolin (MK), $X_3$-Sawdust Ash (SDA)

The result of slurry density shows a yield density and specific gravity within the range of 1.71-1.785. for class A and B cement as stipulated and reported by API, (2010), 10A ; also were in agreement with the range reported by Broni-bediako, Joel, and Ofori-sarpong, (2016) as within (1.45g/cm3-1.84g/cm3). Metakaolin increased the density of the slurry from the mean value of 1.75 to 1.785g/cm3 accounting for 2% increase. Nevertheless, incorporating sawdust ash reduced the sample density accounting for 2.3% decrement as compared to that of control samples. The result of free water at conditioned temperature range of 65-45°C static for 2 hours shows that sawdust ash incorporated samples at (10%) and 5% blend reduced the free water within (0.120%, 0.032%); below the 5.9% maximum free water stipulated by API, (2013) which according to Rabi, (2010) should draw up to zero (0%) to avoid water pocket formation., and this is clear indication from the interactive positive effect of sawdust ash as shown in Table 4 with its p value less than 0.05 and interactive plot in figure 3. with its p value less than 0.05 and interactive plot in figure 3. Hence, SDA is potential in reducing excess free water during slurry pumping. The following regression model with respect to Equation 3 corresponding to the yielded coefficient of effect is given in Equation 5.

Table 4 Fractional Factorial Fit: Estimated Effects and Coefficients for free water

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 0.3463 | 0.02072 | 16.71 | 0.000 |
| cement | 0.1663 | 0.0831 | 0.02072 | 4.01 | 0.003 |
| metakaol | -0.2252 | -0.1126 | 0.02072 | -5.44 | 0.000 |
| sawdust | -0.1245 | -0.0623 | 0.02072 | -3.00 | 0.015 |
| cement*metakaol | -0.0340 | -0.0170 | 0.02072 | -0.82 | 0.433 |
| cement*sawdust | -0.2528 | -0.1264 | 0.02072 | -6.10 | 0.000 |
| metakaol*sawdust | -0.0463 | -0.0231 | 0.02072 | -1.12 | 0.293 |
| cement*metakaol*sawdust | 0.2650 | 0.1325 | 0.02072 | 6.40 | 0.000 |
| Ct Pt | | 0.0138 | 0.06215 | 0.22 | 0.830 |
| | | | | | |

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Main Effects | 3 | 0.375507 | 0.375507 | 0.125169 | 18.23 | 0.000 |
| 2-Way Interactions | 3 | 0.268711 | 0.268711 | 0.089570 | 13.04 | 0.001 |
| 3-Way Interactions | 1 | 0.280900 | 0.280900 | 0.280900 | 40.91 | 0.000 |
| Curvature | 1 | 0.000336 | 0.000336 | 0.000336 | 0.05 | 0.830 |
| Residual Error | 9 | 0.061797 | 0.061797 | 0.006866 | | |
| Pure Error | 9 | 0.061797 | 0.061797 | 0.006866 | | |
| Total | 17 | 0.987251 | | | | |

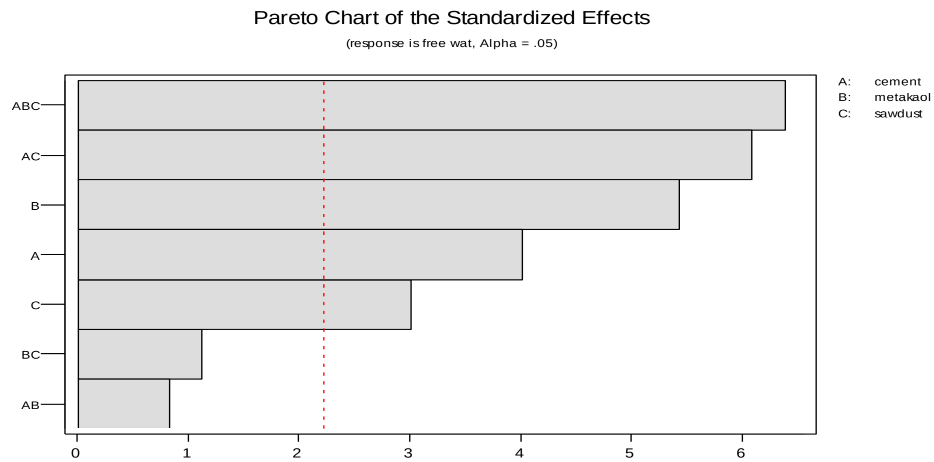


Figure 3 Interactive Effect Significant Plot for free Fluid (water) of Slurry

$$\text{Free water} = 0.3463 + 0.0831X_1 - 0.1126X_2 - 0.0623X_3 - 0.0170X_1X_2 - 0.1264X_1X_3 - 0.0231X_2X_3 + 0.1325X_1X_2X_3 + 0.02072 \quad (5)$$

As regards Slurry fluid loss, samples blended with sawdust ash in combination with metakaolin kept the fluid loss within the maximum range of API RP-10B (50 to 250ml /30minutes) as compared to samples with only metakaolin blend as well as control samples $C_1$ and $C_2$ which had the highest mean fluid loss of (484.970 and 508.645 ml/30min) at 10 and 11minutes blow out compared to Others blended samples having lower fluid loss (204.483 and 197.898 ml/30minutes) with the lowest loss attributed to samples containing sawdust ash at high level; these values were within the API RP-10B of 50 to 250ml for liner cementing but also other samples show values within the recommended maximum fluid loss of (250 - 400 cc(ml) for primary cementing with reference report of Broni et al. (2016). Thus presenting sawdust ash (SDA) blend with metakaolin (MK) as a decent fluid loss and blowout control pozzolan reducing the slurry fluid loss by about 57%. The following regression model with respect to Equation (3). Corresponding to the yielded coefficient of effect from Table 6 a Figure 4 yielding the model in Equation (6).

Table 7 Fractional Factorial Fit: Estimated Effects and Coefficients for fluid loss

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 298.90 | 5.273 | 56.68 | 0.000 |
| cement | 21.66 | 10.83 | 5.273 | 2.05 | 0.070 |
| metakaol | -13.39 | -6.70 | 5.273 | -1.27 | 0.236 |
| sawdust | -37.09 | -18.54 | 5.273 | -3.52 | 0.007 |
| cement*metakaol | 7.52 | 3.76 | 5.273 | 0.71 | 0.494 |
| cement*sawdust | -13.78 | -6.89 | 5.273 | -1.31 | 0.224 |
| metakaol*sawdust | 129.11 | 64.55 | 5.273 | 12.24 | 0.000 |
| cement*metakaol*sawdust | 23.85 | 11.93 | 5.273 | 2.26 | 0.050 |
| Ct Pt | | 40.17 | 15.819 | 2.54 | 0.032 |
| | | | | | |

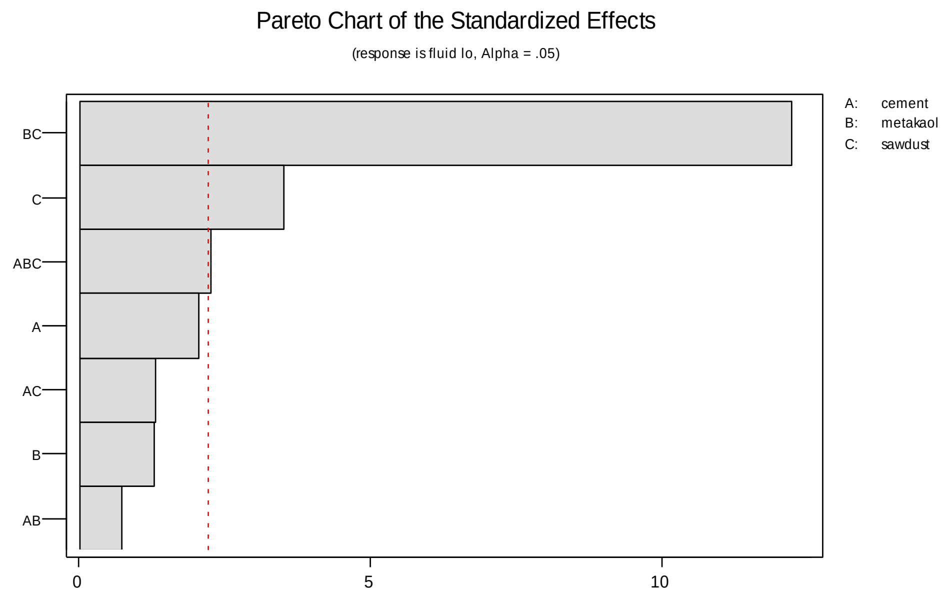


Figure 4 Interactive Effect Significant Plot for fluid loss of Slurry

$$\text{Fluid loss} = 298.90 + 10.83X_1 - 6.700X_2 - 18.54X_3 + 3.76\,X_1\,X_2 - 6.89X_1\,X_3 + 64.55X_2X_3 + 11.93\,X_1\,X_2\,X_3 + 5.273 \quad (6)$$

The rheology performance of the slurry samples, which is a function of plastic viscosity, yield point of shear stress and corresponding gel strength at 10 seconds as well as 10 minutes gel strength after 20minutes conditioning at 60ºC. The plastic viscosity where below 100 mPa.s (cp) which according to the report of report of Broni et al. (2016). regarded as the maximum limit for all cementing slurry to be kept pumpable; with exception of samples which contain only cement combination of Metakaolin at high level replacement yielding (129cp-132cp). The result from the gel strength at 10 seconds and 10 minutes as displayed in Figure 5 shows control samples to have lowest value of gel strength compared to other samples. Also, for yield point shear stress, samples with MK has higher yield point compared to the samples containing combinations of sawdust ash at 10% Hence, a clear indication of the detrimental effect of Metakaolin at high level blend (15%) on the cementing slurry in absence of Saw dust ash in the blend.

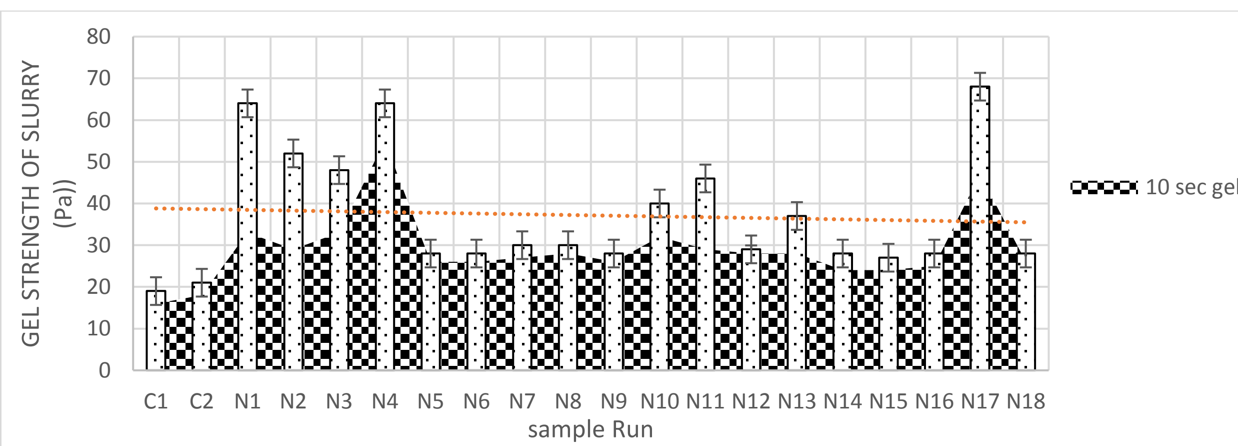


**Figure 5. Plot of Gel Strength of Slurry at 10 Seconds and 10 Minutes**

The following factorial regression model corresponding to the yielded coefficient of effect is given in Equation (7), (8), and (9); following the interactive effect on Tables 8,9,and 10 as well as Figure 6, 7, and 8 respectively.

Table 8 Factorial Fit: Estimated Effects and Coefficients for plastic

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 58.31 | 1.155 | 50.50 | 0.000 |
| cement | 30.37 | 15.19 | 1.155 | 13.15 | 0.000 |
| metakaol | 27.00 | 13.50 | 1.155 | 11.69 | 0.000 |
| sawdust | -23.25 | -11.63 | 1.155 | -10.07 | 0.000 |
| cement*metakaol | 10.50 | 5.25 | 1.155 | 4.55 | 0.000 |
| cement*sawdust | -16.50 | -8.25 | 1.155 | -7.14 | 0.000 |
| metakaol*sawdust | -16.88 | -8.44 | 1.155 | -7.31 | 0.000 |
| cement*metakaol*sawdust | -19.88 | -9.94 | 1.155 | -8.61 | 0.000 |
| Ct Pt | | -29.94 | 3.464 | -8.64 | 0.000 |

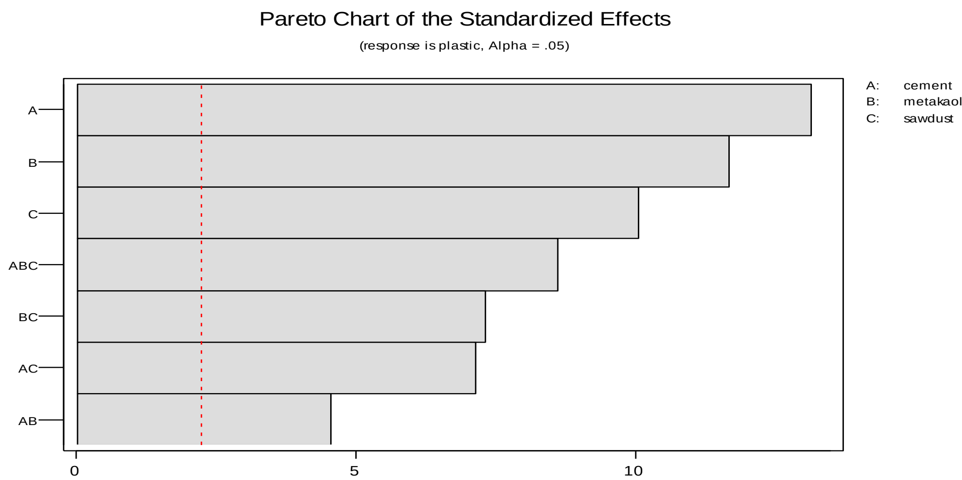


Figure 6 Pareto and interaction effect Plot of Plastic Viscosity

Table 9 Factorial Fit: Estimated Effects and Coefficients for yield point

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 59.19 | 0.7813 | 75.76 | 0.000 |
| cement | 3.16 | 1.58 | 0.7813 | 2.02 | 0.074 |
| metakaol | 5.49 | 2.74 | 0.7813 | 3.51 | 0.007 |
| sawdust | -7.63 | -3.82 | 0.7813 | -4.89 | 0.000 |
| cement*metakaol | -6.56 | -3.28 | 0.7813 | -4.20 | 0.002 |
| cement*sawdust | 4.06 | 2.03 | 0.7813 | 2.60 | 0.029 |
| metakaol*sawdust | -2.44 | -1.22 | 0.7813 | -1.56 | 0.152 |
| cement*metakaol*sawdust | 3.40 | 1.70 | 0.7813 | 2.17 | 0.058 |
| Ct Pt | | -27.94 | 2.3439 | -11.92 | 0.000 |

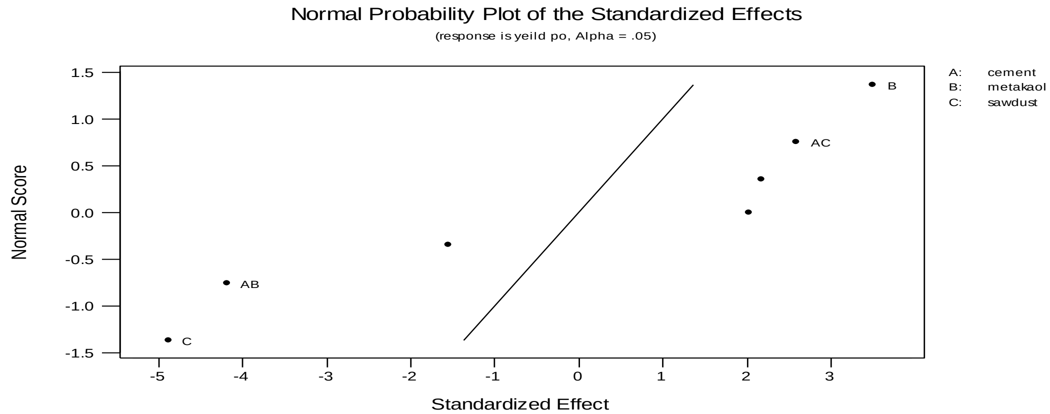


Figure 7 Pareto and normal probability interaction effect Plot of Yield Point of Shear Stress

Table 10 Factorial Fit: Estimated Effects and Coefficients for 10 sec gel

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 30.375 | 0.6719 | 45.21 | 0.000 |
| cement | 4.000 | 2.000 | 0.6719 | 2.98 | 0.016 |
| metakaol | 5.250 | 2.625 | 0.6719 | 3.91 | 0.004 |
| sawdust | -9.500 | -4.750 | 0.6719 | -7.07 | 0.000 |
| cement*metakaol | 6.000 | 3.000 | 0.6719 | 4.47 | 0.002 |
| cement*sawdust | -4.250 | -2.125 | 0.6719 | -3.16 | 0.011 |
| metakaol*sawdust | -6.500 | -3.250 | 0.6719 | -4.84 | 0.000 |
| cement*metakaol*sawdust | -5.750 | -2.875 | 0.6719 | -4.28 | 0.002 |
| Ct Pt | | -0.375 | 2.0156 | -0.19 | 0.857 |

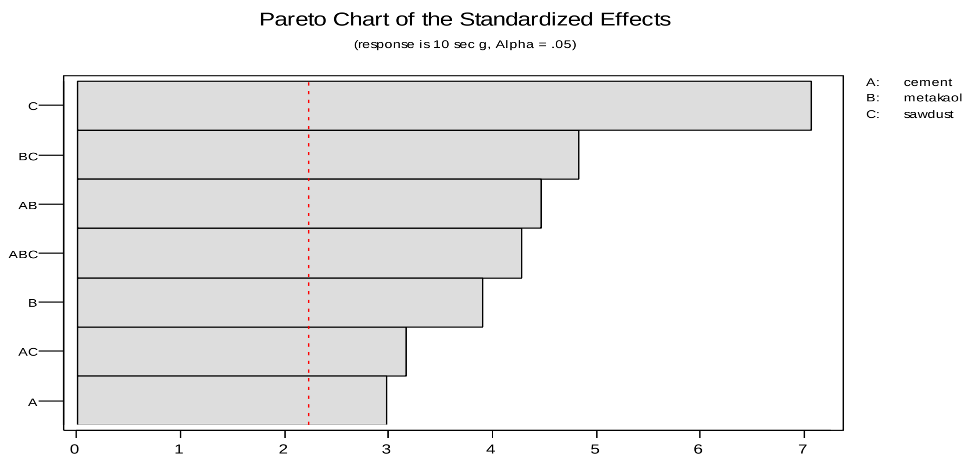


Figure 8 Pareto Interaction Effect Plot for 10 Seconds Gel Strength

Plastic Viscosity = $58.31 + 15.19X_1 + 13.50X_2 - 11.63X_3 + 5.25X_1X_2 - 8.25X_1X_3 - 8.44X_2X_3 - 9.94X_1X_2X_3 + 1.155$ (7)

Yield Point = $59.19 + 1.58X_1 + 2.74X_2 - 3.82X_3 - 3.82X_1X_2 + 2.03X_1X_3 - 1.22X_2X_3 + 1.70X_1X_2X_3 + 0.7813$ (8)

10 Sec Gel Strength = $30.375 + 2.00X_1 + 2.625X_2 - 4.75X_3 + 3.00X_1X_2 - 2.125X_1X_3 - 3.250X_2X_3 - 2.875X_1X_2X_3 + 0.6719$ (9)

**4.3 Mechanical Test Result:** The cube density were influenced by the blend of SDA and MK at higher replacement levels (10% and 15%). The density of the samples where within the range of (1746.667 – 1906.667 kg/m3) while samples blended with MK alone had lower density of less than 5.7% as compared to the controlled samples, on the other hand, the samples water absorption after 28 days curing were within the range (1-3%) as stipulated by Schlumber (2013). The control sample had the highest value of early strength after 24 hours of curing (13.9 and 14.4 N/mm2). However, Sawdust ash shows more influence in improving the compressive strength at 28days when in high level blend with Metakaolin at all levels of OPC incorporation. This could be attributed to the pozzollan filler tendency of the two combine materials in the micro matrix of the cemented cake. More strength increment is expected following the report of Ettu, et al.(2016) The resultant factorial regression model following the coefficient for 24 hours and 28 days strength is given by Equation (10), and (11) following the interaction effect in Table 11 and 12, Figure 9, and 10 respectively.

Table 11 Factorial Fit: Estimated Effects and Coefficients for 24hrs compressive strength

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 11.7250 | 0.08260 | 141.95 | 0.000 |
| cement | -0.5125 | -0.2563 | 0.08260 | -3.10 | 0.013 |
| metakaol | 0.0125 | 0.0063 | 0.08260 | 0.08 | 0.941 |
| sawdust | 0.9125 | 0.4562 | 0.08260 | 5.52 | 0.000 |
| cement*metakaol | -0.5000 | -0.2500 | 0.08260 | -3.03 | 0.014 |
| cement*sawdust | -0.3750 | -0.1875 | 0.08260 | -2.27 | 0.049 |
| metakaol*sawdust | -0.8750 | -0.4375 | 0.08260 | -5.30 | 0.000 |
| cement*metakaol*sawdust | -0.3125 | -0.1563 | 0.08260 | -1.89 | 0.091 |
| Ct Pt | | 0.3250 | 0.24780 | 1.31 | 0.222 |

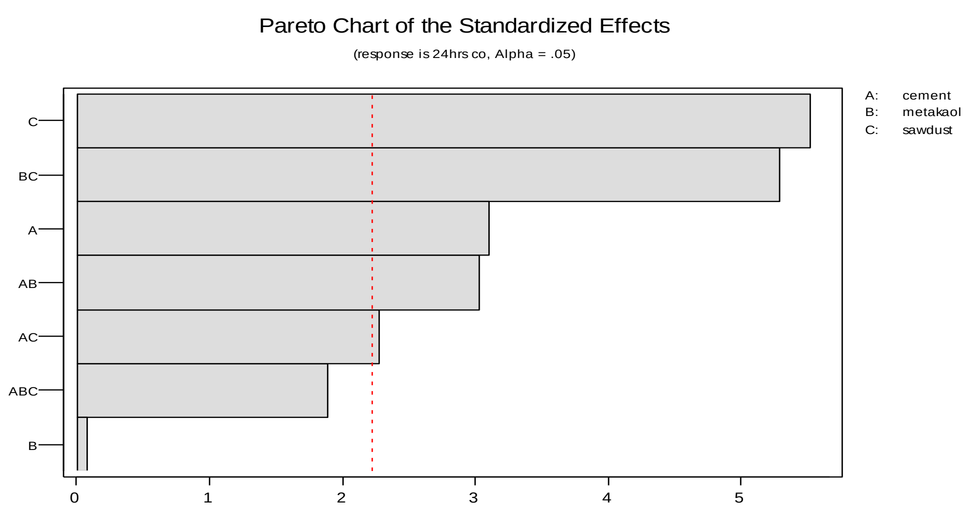


Figure 10. Interaction effect of material for 24 hour strength

Table 12 Factorial Fit: Estimated Effects and Coefficients for 28days Compressive Strength

| Term | Effect | Coef | StDev Coef | T | P |
|---|---|---|---|---|---|
| Constant | | 30.1864 | 0.1753 | 172.15 | 0.000 |
| cement | -0.4479 | -0.2239 | 0.1753 | -1.28 | 0.234 |
| metakaol | -0.4396 | -0.2198 | 0.1753 | -1.25 | 0.242 |
| sawdust | 0.9646 | 0.4823 | 0.1753 | 2.75 | 0.022 |
| cement*metakaol | 0.3396 | 0.1698 | 0.1753 | 0.97 | 0.358 |
| cement*sawdust | 0.0104 | 0.0052 | 0.1753 | 0.03 | 0.977 |
| metakaol*sawdust | -0.3729 | -0.1864 | 0.1753 | -1.06 | 0.315 |
| cement*metakaol*sawdust | -0.7271 | -0.3636 | 0.1753 | -2.07 | 0.068 |
| Ct Pt | | 0.3636 | 0.5260 | 0.69 | 0.507 |
| | | | | | |

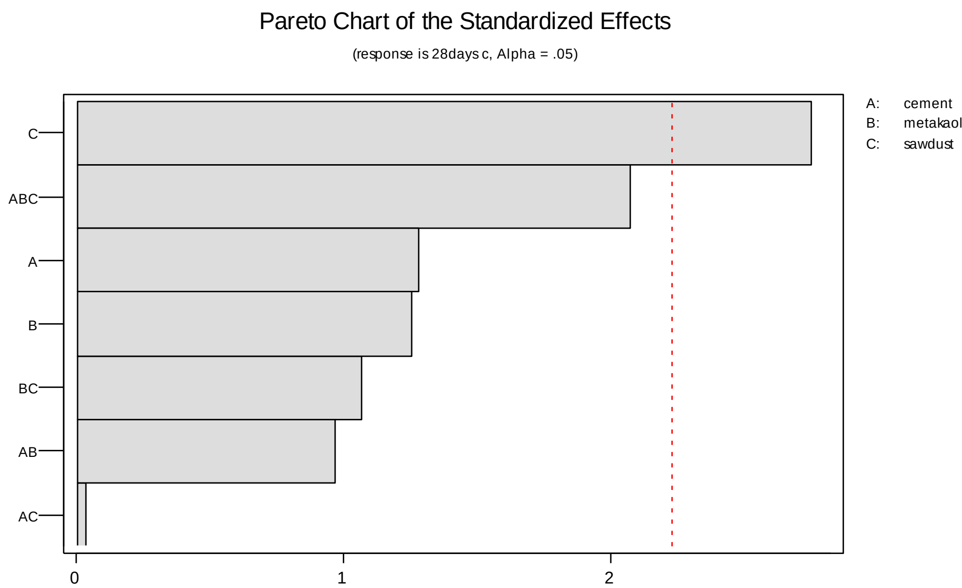


Figure 11. Interaction effect of 28 days compressive strength

24 hours strength = $11.7250 - 0.2563X_1 + 0.0063X_2 + 0.4562X_3 - 0.2500X_1 X_2 - 0.1875 X_1 X_3 - 0.4375X_2 X_3 - 0.1563 X_1 X_2 X_3 + 0.08260$ (10)

28 days strength = $30.1864 - 0.2239X_1 - 0.498X_2 + 0.4828X_3 + 0.1698X_1 X_2 + 0.0052 X_1 X_3 - 0.1864X_2 X_3 - 0.3636 X_1 X_2 X_3 + 0.1753$ (11)

Where: $X_1$ -Cement, $X_2$ -Metakaolin (MK), $X_3$-Sawdust Ash (SDA)

## 5.0 Conclusion

Factorial model has been successfully deployed in investigating and predicting the Engineering performance of Ordinary Portland cement when blended with Metakaolin and Sawdust Ash identifying and estimating significant interactive parameters; yielding models readily needed in formulating the blended material for optimal utilization in the oil well drilling industry for efficient cementing operation. The results of the slurry and mechanical property parameters were an indication of the cementing requirement based on the factorial output which showed that Sample formulations with (75%OPC, 10%MK, 10% SDA), had optimal performance with respect to both slurry and mechanical properties necessary to maintain excellent cementing process of new well as well as the integrity of the well over a longer period of its service life. Sawdust Ash serve as restrictive constituent in controlling the detrimental effect of Metakaolin which is a more active pozzolan when in excess or alone in the replacement blend. Therefore Ordinary Portland Cement (OPC) blend of Metakolin and Sawdust Ash fine granule is recommended in addressing excessive fluid loss and water pocket formation in cementing slurry paramount in geothermal and gas filled oil well prone to catastrophic failures. The study also recommend the blend as an environmentally friendly material in addressing the impact of imported oil well cement dependency, pollution and reducing global carbon foot print. Further studies and research are recommended into other forms of pozzolan to ascertain its effect when blended for oil well cementing.

**6.0 Acknowledgement**

The authors appreciate the assistance of the Laboratory officers and Department of Civil Engineering, Department of Chemistry, and Department of Petroleum Federal University of Technology Owerri. Thank you for your contributions toward the success of this work

**7.0 Conflict of interest**

There is no conflict of interest associated with this work.

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