UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 6(3), September (2026), 3666-3677
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Investigation and Modelling of Slurry Performance of Ordinary Portland Cement Blended with Metakaolin and Sawdust-ash for Oil Well Cementing

Silas, Ebenezar.O.*
Civil Engineering, Federal University Technology Owerri, Imo State, Nigeria
Ubachukwu Obiekwe A.
Civil Engineering, Michael Okpara University of Agriculture, Umudike,Abia State.
Onwuka, David. O.
Civil Engineering, Federal University Technology Owerri, Imo State, Nigeria
Njoku F. C
Civil Engineering, Federal University Technology Owerri, Imo State, Nigeria

**Corresponding Author's E-mail: silasebenezaronyedikachi@gmail.com*

Abstract

Oil well Cementing involves placing a special compound of cement grout formulated from constituents with relative weight to that of cement in the annulus between the casing and the adjacent rock formation to strongly join the casing to the 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 over long operation period. In this study, the viability of optimizing slurry performance using Sawdust Ash (SDA) and Metakaolin (MK) as a blend to Ordinary Portland Cement (OPC) allows combinations and percentages replacement of the Ordinary Portland Cement (OPC) with Metakaolin for 10%,12.5% and, 15% while Sawdust ash at 0%, 5% 10% making up for 10 to 25% of both pozzolan incorporation to modify the properties of ordinary Portland cement, and providing an efficient, cheaper oil well-cementing material. Materials for the study were synthesized and characterized based on physical, chemical, and pozzolanic properties. The slurry and mechanical properties were studied based on the mix formulation generated from design of experiment (DOE) using two domains three interactive factors (2^3) level factorial model following the specifications of (API SPEC 10A and 10B). Metakaolin blend with OPC alone at 15% was detrimental to rheology performance but incorporating Sawdust Ash up to 10% with Metakaolin at both low and high blend (10% and 15%) improved the slurry and mechanical performance; yielding an optimal blend sample of (75%OPC, 15%MK, 10%SDA).
Keywords: Oilwell, Cementing, Pollution, Metakaolin, Sawdust Ash, Slurry properties.

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). This operation involves placing a special compound of cement grout formulated from different constituents with relative weight to that of cement in the annulus between the casing and the adjacent rock formation and allowed to set, after a few hours or few days, to strongly join the casing to the formation (Abdullah, Jothibasu, and Vikrant, 2017). The main purpose of cementing is to displace the drilling fluid, isolating the permeable zone, supporting the axial load of the casing string, protecting the casing from corrosion, preventing fluid migration and hindering the escape of oil minerals into rock formation (Dhorgham, 2016). 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. It is further found that elevated temperatures lead to gradual damage of connections between admixture and cement paste while causing the generation of minerals with poor structure, resulting in bad mechanical behaviour (Khaliq and Kha, 2015). These backlash leads to increased rate of chemical attacks, formation movements and mechanical failure experienced in many cases of oil wellbore drilling. 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).

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; this is due to the high water-cement ratio of the mixture which is necessary to achieve the desired density, slurry quality, pumpability, and its sheath strength with regards to requirements of the American Petroleum Institute (API) and international standard organization (ISO) Specification (Qosai, and Radi, 2018). 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).

Presently, some supplementary cementitious materials have been proven to be effective in meeting most of the requirements of durable concrete such that blended cements are now used in many parts of the world. These materials could take a form of pozzolans of which the most common pozzolan materials are agricultural husk ash, fly ash (FA), silica fume (SF) and Metakaolin (MK) . Pozzolan materials serve to reduce the quantity of the deleterious calcium hydroxide in the concrete matrix during hydration as well as increase the quantity of the beneficial calcium-silicate-hydrate leading to high strength in early and later age, low porosity, high temperature resistance and good chemical corrosion resistance (Ettu, et al.2016). When choosing mineral additives and pozzolan admixtures, great attention is focused on their physical as well as their chemical properties, such as the size and shape of particles, water absorption, active chemical interaction with Portland cement and its micro structure (Qosai, and Radi, 2018). Researchers have reported Metakaolin to be an excellent pozzolan when blended in concrete. Nevertheless, it is high water demanding pozzolan when it comes to oil well-cementing jobs which require the slurry to remain pumpable till it reaches its target depth (Broni et al., 2016). This creates the need for modification of this pozzolan with lesser water demanding pozzolan like Sawdust Ash (Silas et al., 2022). The combination of these two pozzolan is a breakthrough in obtaining an efficient cementing material spurring the study. The study made use of factorial model of two domain three interactive factor 23 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 and Sawdust Ash at 25% OPC cement 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.

2.0 Materials and methods

2.1 Experimental Material:

The following materials were obtained, prepared and employed in conformation to the requirements and specifications of the experimental process. Sawdust ash obtained from sawdust in timber market Umuahia as well as kaolin for Metakaolin obtained from Umuariaga Oboro Ikwuano, Abia state; were prepared from standard methods within the specified temperature of calcination and heating time of 90 min for Metakaolin before being employed to the experimental module. Cement on the other hand were obtained prepare grade 42.5 OPC class B according to the classifications of (ASTM C150 and API 10A, 2015). The water for the study was clean tap water from the laboratory conforming to the standard spelt in EN 196 and API 10A.

2.2 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 as shown in Table 1 and the other set of control sample containing pure class B cement Where N_1 to N_{18} represents the run order for the randomised blended cementing sample from the factorial design, while the C_1 and C_2 run orders represent the sample with only class B Ordinary Portland Cement (OPC) in accordance to API 10B mix specifications.

The experimentation was carried out in phases thus actualizing the objectives of the study as follows.

The material preparation and characterization involved the physical, chemical and pozzolan testing of Sawdust - Ash and Metakaolin samples respectively. The slurry characteristic testing followed the formulation and slurry mix design based on pseudo mix ratio generated from two domain three factor (2^3) for two replica and centre points factorial model making up 18 samples per run and two control samples with only Ordinary Portland Cement shown in Table 1; following the domain of Design of Experiment (DOE) which have various combinations and percentages blend of the Ordinary Portland Cement (OPC) with Metakaolin for 10%,12.5% and, 15% while Sawdust ash at 0%, 5% 10% which made up for 10 to 25% .The model design allow 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). The water cement ratio W/C was maintained at 0.46 based on API standards API SPEC 10B for all the sample to be mixed as reported by Qosai, and Radi, (2018) for Mk dosage below 30%. The formulated samples slurry were tested for various led down simulated test by API 10A, (2015) for slurry required to be use in well bore; which includes thickening time, fluid loss, free water, rheology, and slurry density respectively. Using total of 360 run samples for both slurry and mechanical testing. The full model is given by Silas et al. (2022) as presented in Equation 1:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 - b_{23}X_2X_3 - b_{123}X_1X_2X_3 + e \quad (1)$$

Where X_1 represents Ordinary Portland Cement (OPC), X_2 -metakaolin (MK), and X_3-sawdust ash (SDA) respectively

Y = Response of the model, b_0 Intercept of the model

b_1; b_2; and b_3 Coefficients of main effects of X_1, X_2, and X_3 which is the various individual effects of factors at each level (low or High) in the mix.

b_{12}; b_{13}; and b_{23}; Coefficients of two interaction effects of X_{12}, X_{13}, and X_{23}, b_{123}; Coefficients of three interaction effects of X_{123}, and eijk = being the distributed error (Silas et al., 2022).

Table 1; Pseudo and actual mix ratio for the slurry formulation generated form Minitab DOE

StdOrder	RunOrder	OPC	Metakaolin (MK)	Sawdust ash (SDA)	Equivalent OPC (%)	Equivalent MK (%)	Equivalent SDA (%)
11	1	-1	1	-1	90	15	-
3	2	-1	1	-1	90	15	-
9	3	-1	-1	-1	90	10	-
12	4	1	1	-1	75	15	-
16	5	1	1	1	75	15	10
14	6	1	-1	1	75	10	10
10	7	1	-1	-1	75	10	-
2	8	1	-1	-1	75	10	-
15	9	-1	1	1	90	15	10
17	10	0	0	0	82.5	12.5	5
1	11	-1	-1	-1	90	10	-
13	12	-1	-1	1	90	10	10
18	13	0	0	0	82.5	12.5	5
7	14	-1	1	1	90	15	10
8	15	1	1	1	75	15	10
5	16	-1	-1	1	90	10	10
4	17	1	1	-1	75	15	-
6	18	1	-1	1	75	10	15

3.0 Result and Discussion

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 Silas and Ubachukwu. (2017)

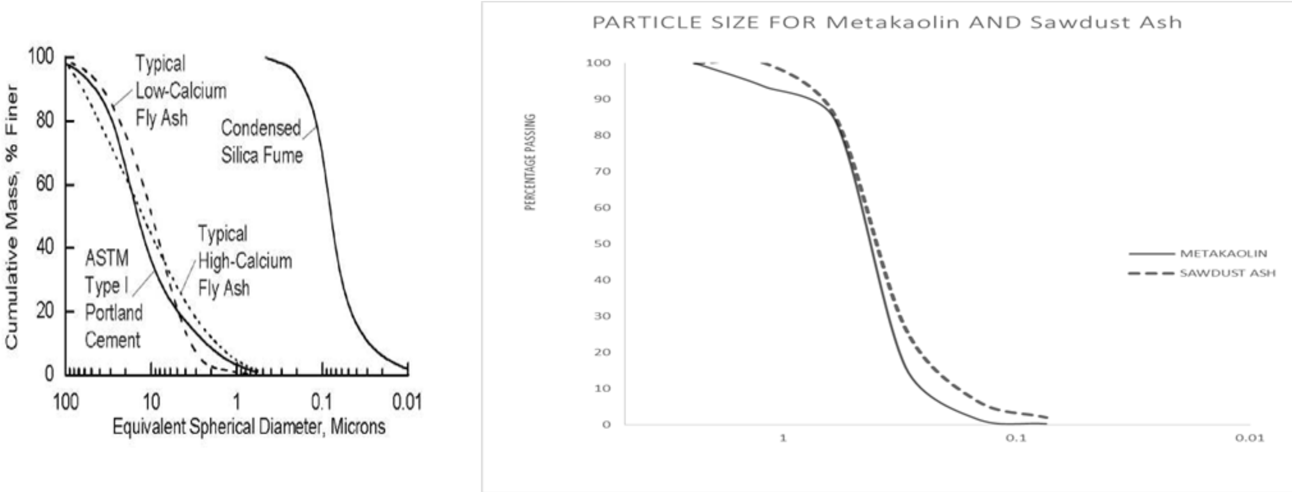

Figure 1. Particle Size Distribution of Metakaolin and Sawdust Ash as compared to other pozzolan

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 sawdust-ash as a positive constituent for tail cementing; while metakaolin (MK) makes a positive blending material in both case of lead or tail cementing respectively. 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 (Al_2O_3), Iron oxide (Fe_2O_3) and Potassium Oxide (K_2O)] as shown in Table 3 for metakaolin to be 84.26% and more than 70% of combined (SiO_2), (Al_2O_3), (Fe_2O_3) 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 70.02%, classifying it as Class F pozzolan in accordance to report of Oladipupu, et al. (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 as shown in Table 4; Hence its potential positive blend in cementing for geothermal and deep well where $Ca(OH)_2$ by product is more.

Table 3; Oxide Composition of Metakaolin and Sawdust Ash

Oxide/ Sample	Silica (SiO_2) %	Aluminuim Oxide (Al_2O_3) %	Calcuim Oxide (CaO) %	Magnesium Oxide (MgO)%	Iron oxide (Fe_2O_3)%	Potassium Oxide (K_2O) %
Metakaolin	59.11	16.18	1.44	1.03	6.82	1.53
Sawdust Ash	51.58	15.96	8.63	3.18	2.48	17.17

Table 4; Summary of Pozzolan test result of SDA and MK

Metakaolin

Sample	Duration Of Heating (min)	volume of HCl Used (ml)	Titration Duration (min)
A	16	15.2	**10**
B	16	11.4	**20**
C	16	4.8	**30**
D	16	1.1	**40**

SawDust Ash

Sample	volume of H_2SO_4 Used (ml)	Shake/Titration Duration (min)
A	24.6	**30**
B	11.5	**60**
C	7.4	**90**
D	6.0	**120**

3.2 Slurry Experimental Result: the result obtain from slurry experimentation in accordance to American Petroleum Institute spec 10A&B for both the control samples C_1 and C_2 as well as blended N_1-N_{18} showed that thickening time were more than stipulated 90 minutes minimum for all samples as compared to report of China National Petroleum Corporation, (2015); but the higher values of time for run samples which have a high level (15%) of Metakaolin compared to control samples and those containing Sawdust Ash at high level (10%) as shown in Figure 2 and agreement with the output of analysis following the factorial model fit in the Table 6 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 Silas et al., (2022). this is a clear indication that Metakaolin (MK) retard the slurry more from thickening than when incorporated alongside Sawdust Ash (SDA) hence potential in creating more handling and pumping time of the slurry to its target depth. The model prediction in Equation (2) is yielded from the factorial iteration output in Table 5.

$$\text{Thickening time} = 107.913 + 2.15X_1 + 5.90X_2 - 2.588X_3 + 3.037X_1X_2 + 3.90X_1X_3 - 2.85X_2X_3 - 0.963X_1X_2X_3 + 0.3626 \quad (2)$$

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

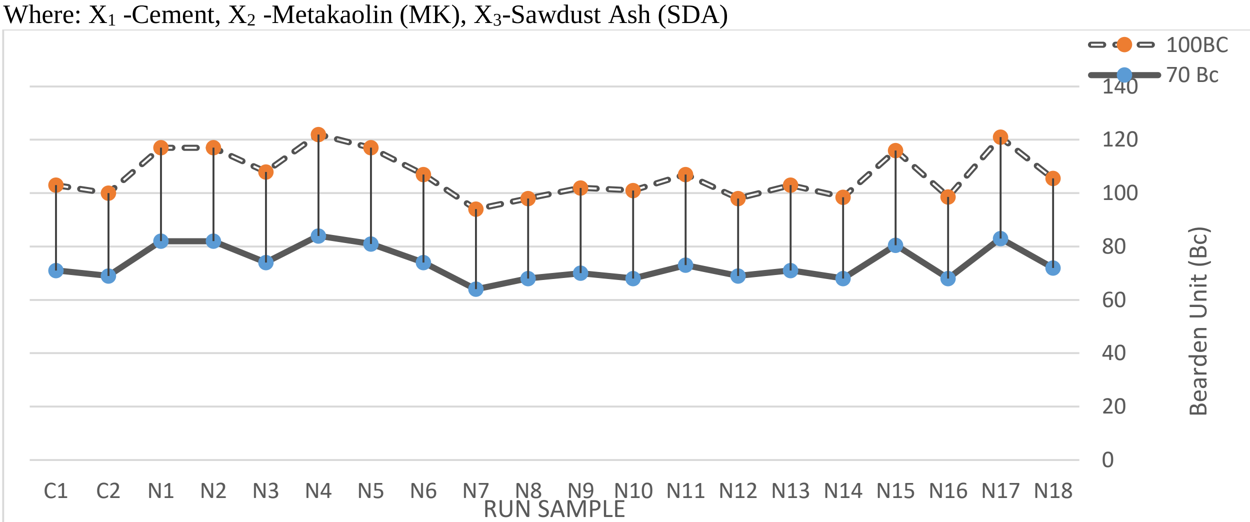

Figure 1 thickening time chart of blended Slurry for 70 and 100 bc

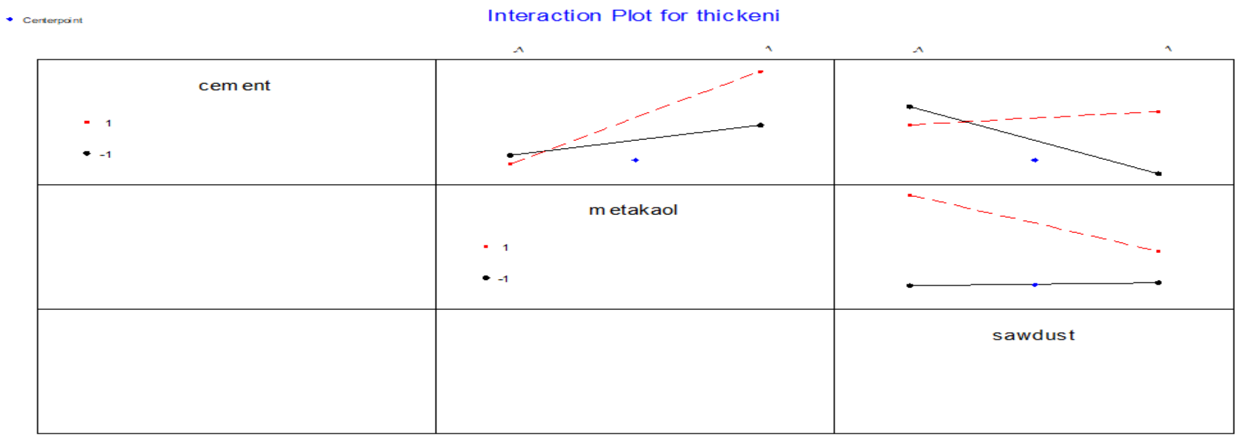

Figure 2 thickening time of samples (45° -65°C) and Interactive Effect Significant Plot for Thickening Time of Slurry

Table 5 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

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 10A, (2015). The specific density were in agreement with the range reported by Broni-bediako, et al. (2016) as within (1.45g/cm$_3$-1.84g/cm$_3$). Metakaolin increased the density of the slurry from the mean value of 1.75 to 1.785g/cm$_3$ 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, (2015) which 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 5 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 corresponding to the yielded coefficient of effect is given in Equation (3).

Table 5 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

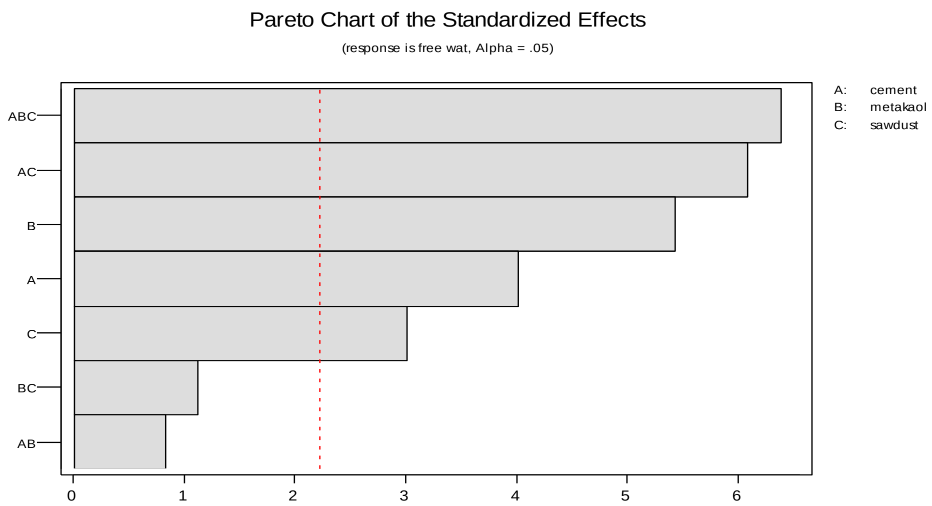

Figure 3 Interactive Effect Significant Plot for free Fluid (water) of Slurry

$$\text{Free water} = 0.3463 + 0.0831X_1 - 0.1126X_2 - 0.0623X_3 - 0.0170\,X_1X_2 - 0.1264X_1X_3 - 0.0231X_2X_3 + 0.1325X_1X_2X_3 + 0.02072 \quad (3)$$

Where: X_1 -Cement, X_2 -Metakaolin (MK), X_3-sawdust ash (SDA)

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% as agreed with the P values in Table 6 and were outside the critical region as shown and interaction plot showed in Figure 4. 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 (3).

Table 6 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

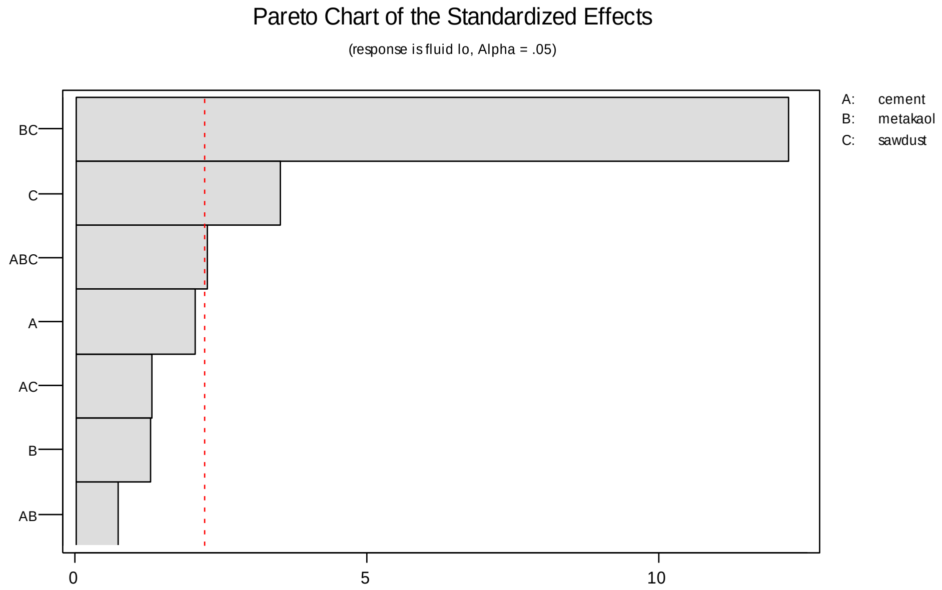

Figure 4 Interactive Effect Significant Plot for fluid loss of Slurry

Fluid loss = 298.90 + 10.83X_1 – 6.700X_2 – 18.54X_3 + 3.76 X_1X_2 – 6.89X_1X_3 + 64.55X_2X_3 + 11.93 $X_1X_2X_3$ + 5.273 (4)

Where: X_1 -Cement, X_2 -Metakaolin (MK), X_3-sawdust ash (SDA)

In terms of rheology performance of the slurry samples, which is function of slurry 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 60°C. The plastic viscosity where below 100 mPa.s (cp) compared to the report by Broni-bediako, et.al. (2016) and regarded as the maximum limit for all cementing slurry to be kept pumpable; with exception of samples N_4 and N_{17} (129cp, 132cp) which contain only cement combination of Metakaolin at high level replacement. The result from the gel strength at 10 seconds and 10 minutes as displayed in Figure 5 shows control samples $C_1$and C_2 to have lowest value of gel strength compared to other samples. The result also shows Metakaolin interactive effect at all levels of combination with sawdust ash in improving the rheology components. Also, for yield point shear stress, samples with Metakaolin (MK) N_1,N_2,N_8, as well as N_{17} had higher values (76.097, 68.702, 66.078,and 63.454) compared to the samples containing combinations of sawdust ash (SDA) at 10% (N_{13}, N_{10}, N_3,N_5,N_{18}) (28.865,33.635, 52.481, 57.252, 57.968). 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.

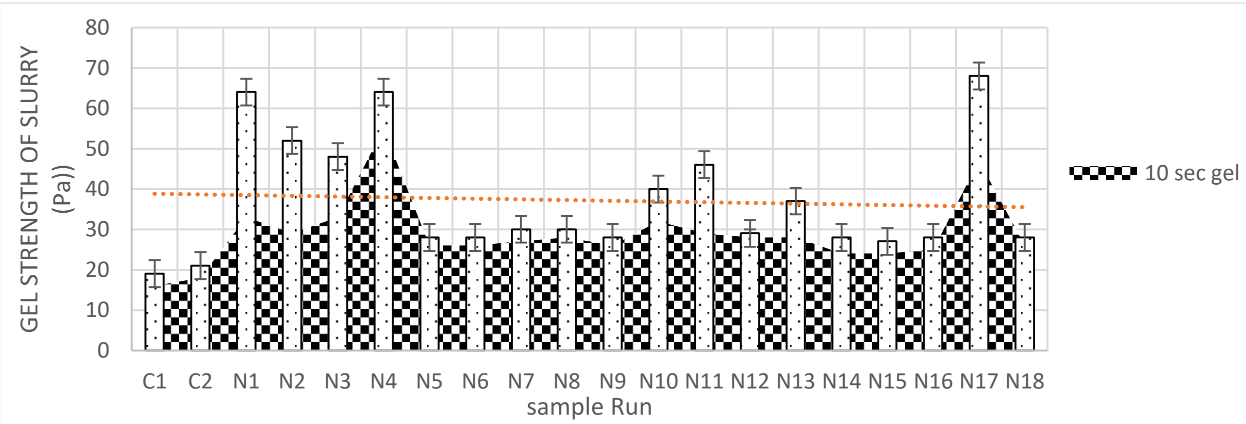

Figure 5. Plot of Gel Strength of Slurry at 10 Seconds and 10 Minutes

The following factorial regression model corresponding to the yielded coefficient of effect is given in Equation (4), (5), and (6); following the interactive effect on Tables 7,8,and 9 as well as Figure 6, 7, and 8 for plastic viscosity, yield point, 10 seconds gel strength respectively.

Table 7 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

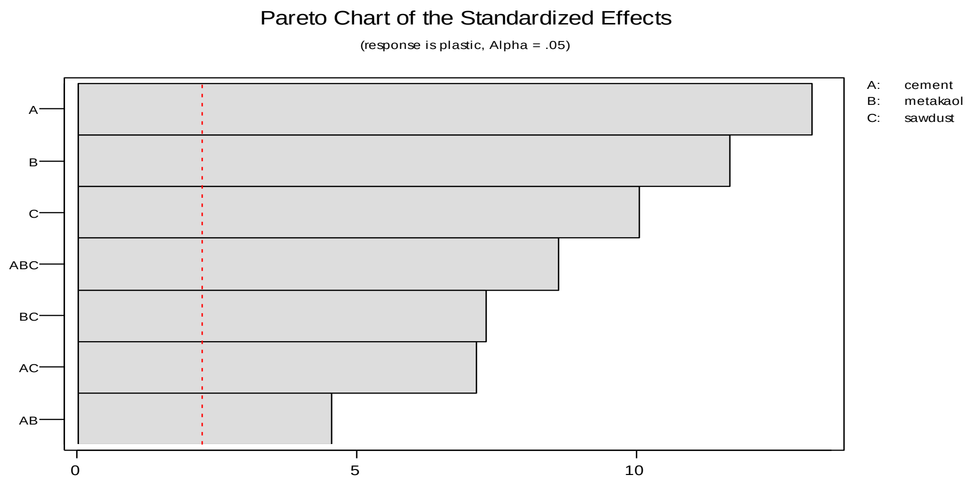

Figure 6 Pareto and interaction effect Plot of Plastic Viscosity

Table 8 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

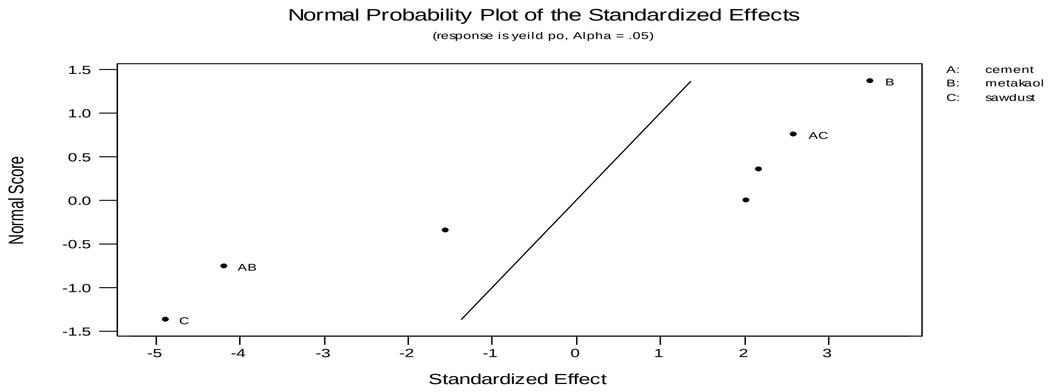

Figure 7 Pareto and normal probability interaction effect Plot of Yield Point of Shear Stress

Table 9 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

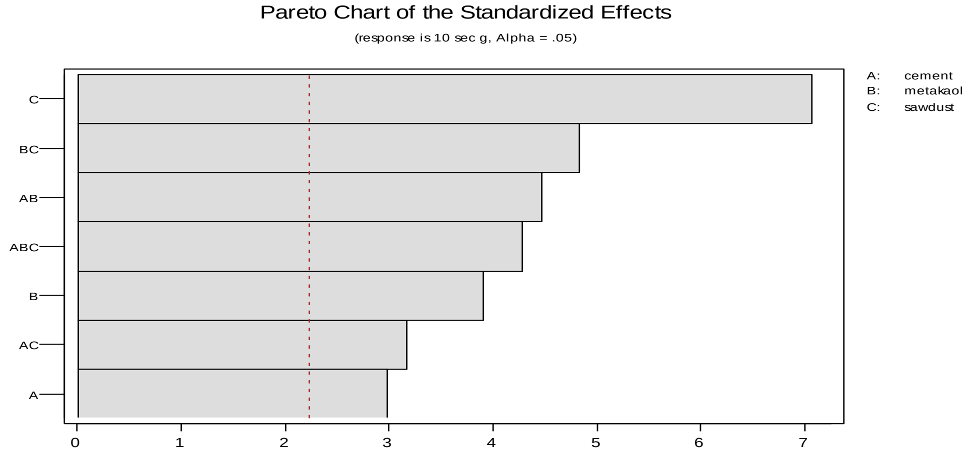

Figure 8 Pareto Interaction Effect Plot for 10 Seconds Gel Strength

Plastic Viscosity = $58.31 + 15.19X_1 + 13.50X_2 - 11.63X_3 + 5.25\ X_1X_2 - 8.25X_1X_3 - 8.44X_2X_3 - 9.94\ X_1X_2X_3 + 1.155$ (5)

Yield Point = $59.19 + 1.58X_1 + 2.74X_2 - 3.82X_3 - 3.82X_1X_2 + 2.03X_1X_3 - 1.22X_2X_3 + 1.70\ X1X_2X_3 + 0.7813$ (6)

10 Sec Gel Strength = $30.375 + 2.00X_1 + 2.625X_2 - 4.75X_3 + 3.00X_1X_2 - 2.125\ X_1X_3 - 3.250X_2X_3 - 2.875\ X_1X_2X_3 + 0.6719$ (7)

Where X_1= cement, X_2= metakaolin and X_3 sawdust-ash

4.0. Conclusion

The investigation and modelling of slurry performance of ordinary Portland cement blended with metakaolin and sawdust-ash for oil well cementing is a unique world trend study; as oil well cementing is a crucial process of drilling completion operation. The major influencing attribute for an oil well cementing material is basically its slurry properties as well as its influence on the well strength and durability. 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 blend of (75%OPC, 15%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. Also 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. Therefore the blend of OPC, Metakolin and Sawdust ash is as an environmentally friendly material in addressing the impact of imported oil well cement dependency, pollution and reducing global carbon foot print.

5.0 Recommendation

A recommended compromise between oil well cementing at both normal and deep well pumping duration, cake stability performance as well as economic and environmental implications allows optimal blend of metakaolin and sawdust ash with ordinary Portland cement up to 15% and 10% respectively. Further studies and research are recommended into other forms of pozzolan to ascertain its effect when blended for oil well cementing.

Acknowledgements

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.

Nomenclature

DOE=Design of Experiment
C-S-H = Calcium Silicate Hydrate
HPHT =High Pressure High Temperature
BHTC = Based High Consistency Temperature
TT =Thickening time, Bc
Bc =Bearden unit of consistency
μ (cp)=Plastic viscosity
τ_o = Yield point shear stress

References

Abdullah, S. A., Jothibasu, R., and Vikrant, W., (2017), Chemical additives for oil well cementing: Drilling Technology Team, *EXPEC Advanced Research Center, Research & Reviews*: *Journal of Chemistry (RRJCHEM)* | Volume 6 | Issue 4 |, e-ISSN:2319-9849 p-ISSN:2322-00Saudi Aramco, Dhahran 31311

API, (2015), SPEC 10A, "Cements and Materials for Well Cementing" twenty-fifth Edition (Ed25), pp. 3-50.

ASTM C150/C150M-22, (2024) "Standard Specification for Portland cement", dio: 10.1520/C0150_C0150M-22, ICS Code: 91.100.10

Broni-bediako, E., Joel, O. F., and Ofori-sarpong, G. (2016). Oil Well Cement Additives: A Review of the Common Types Oil and Gas Research Oil Well Cement Additives: A Review of the Common Types. https://doi.org/10.4172/ogr.1000112

China National Petroleum Corporation, (2015) "Complex oil and gas well cementing technologies," pp 3-21

Dhorgham, S.I., (2016) Schematic-simulation-of-the-oil-well-cementing-process-in-southern Iraq-Zb-pp229-1.

Efstathios, K., (2016) "Fly ash-based geopolymer cement as alternative to ordinary portland cement in oil well cementing operations" A Thesis in Oil and Gas Technology Aalborg University Department of Chemistry and Biotechnology(pp. 9-49)

Ettu, L. O., Ezenkwa C. S., Awodiji .C. T. G., Njoku. F. C., and Opara H., (2016), Tensile strengths of concrete containing sawdust ash from different calcination methods, *International Journal of Engineering Research and Technology IJSRSET* | Volume 2 | Issue 4 | 2016 [(2)4: pp349-355]

Falode, O. A., Salam, K. K., Arinkoola, A. O., and Ajagbe, B. M. (2013). Prediction of Compressive Strength of Oil Field Class G Cement Slurry Using Factorial Design. *Petrol Explore Production Technology* vol.3, pp.297–302.. https://doi.org/10.1007/s13202-013-0071-0

Labibzadeh, M., Zahabizadeh, B., and Khajazfuly, A., (2010) Early-age compressive strength assessment of oil well class G cement due to bore pressure and temperature changes. *Journal of American Science, volume* 6(7):pp.38–46

Magarini, P., Lanzetta, C., and Galletta, A., (2015), Drilling Design Manual. Eni-Agip Division. pp: 97-107.

Oladipupu, S. O., William, K. K., Emmanuel, R. S., Jacques, S., and Julius, M.N., (2018), Characterization of Corncob Ash (CCA) as a Pozzolanic Material, *International Journal of Civil Engineering and Technology (IJCIET),* Volume 9. 1sssue 12, PP. 1016-1024

Qosai, S. and Radi, M., (2018) Benefits of Using Mineral Additives, as Components of the Modern Oil-Well Cement Case Studies in Construction Materials Vol 8, pp455–458

Silas, E.O, Onwuka, D.O, and Njoku F.C (2022), Factorial model prediction for performance of Ordinary Portland Cement Blended with Metakaolin and Sawdust Ash for Oil Well Cementing., NIPES Journal of science and technology research, vol.4No2. https://dio.org/10.37933/nipes/4,2.2022.7

Ubachukwu, O.A. and Silas, O.E (2017). Engineering properties of concrete made with sawdust as partial replacement of sand; innovative and low-cost materials for sustainable national housing development: innovation and adaptive technology for national development. 11th -13th November 2017, *Journal of Engineering and Engineering Federal University of Technology Akure* Vol. 2: pp.983-991.