UMYU Scientifica, Vol. 4 NO. 2, June 2025, Pp 313 – 324
https://doi.org/10.56919/usci.2542.031
ISSN: 2955 – 1145 (print); 2955 – 1153 (online)
A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina

ORIGINAL RESEARCH ARTICLE

Determination of Slurry's Properties of Oil Well Cement Produced from Local Raw Materials

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ABSTRACT
Oil well cementing is a critical step in well construction, where cement slurry is pumped into the annular space between the casing and the borehole wall to achieve zonal isolation, provide casing support, and ensure long-term well stability. This research investigates the slurry's properties of oil well cement made from locally sourced raw materials, focusing on three types of cement: BUAC, POWCC, and newly developed Class G MSR cement (POWCGMSR). The POWCGMSR cement exhibited mineral compositions typical of Class G cement, including 54.47 wt% C_3S, 17.26 wt% C_2S, 5.82 wt% C_3A, and 15.72 wt% C_4AF, along with a specific surface area of 331 m²/kg, in accordance with API specifications and as supported by literature. Compressive strength testing revealed a reduction when 5% laterite was added, an effect attributed to the dilution of the C_3S and C_2S phases. However, strength increased over time with continued curing. All slurry formulations complied with API RP 10B-2 (2013) standards for rheology, with plastic viscosities ranging from 35 to 60 cP and yield points between 5 and 15 lb/100 ft². Setting time evaluations also met API 10A standards, with initial setting times exceeding 45 minutes and final setting times remaining below 600 minutes. Expansion testing showed that BUAC exceeded the API limit (>1.0%), indicating potential durability concerns, while POWCC and POWCGMSR remained within acceptable limits (<0.6%). Thickening time results were consistent with API guidelines: POWCC (140 minutes) is suitable for shallow wells (<3000 ft), BUAC (160 minutes) for intermediate depths (3000–8000 ft), and POWCGMSR (190 minutes) is also appropriate for intermediate wells, with potential for application in deeper wells. POWCGMSR was the most effective for fluid loss control and is suitable for use in critical wells because the addition of laterite acted as a pozzolanic material, which improved water retention. BUA Cement was deemed suitable for standard wells, though it could benefit from the addition of fluid loss control agents. POWCC, on the other hand, requires formulation improvements to enhance its fluid retention capacity.

ARTICLE HISTORY
Received January 20, 2025
Accepted June 28, 2025
Published June D30 2025

KEYWORDS
Clinker, Bua Cement, Prepared oil well cement class G moderate sulphate resistant(POWCGMSR), POWCC (Prepared Oil well cement control) and BWOC (Byweight of cement).

INTRODUCTION
Cement is a binding material widely used in construction. It serves as a primary component in the production of concrete and mortar, providing strength and durability to structures (Das *et al*., 2022).

The compressive strength of cement is a critical property that defines the ability of cement to resist axial loads applied to a structure. It is a primary indicator of the performance and quality of cement. This property is essential for ensuring the structural integrity and durability of concrete and mortar (Yuan *et al*., 2023).

Oil well cement was developed from Portland cement type CP III 40 RS (Blast furnace slag Portland cement – sulfate resistant), a Brazil brand from CIMEC Company. The methodology used for the obtainment of the new cement consisted of the sieving of the CPIII through ABNT 200 and ABNT 325 sieves. The Characterisation of the new cement developed revealed chemical compositions as CaO, SiO2, Al2O3, SO3, MgO, Fe2O3, K2O, TiO3as 46.6, 23.5, 12.9, 7.6, 6.6, 1.1, 0.6, and 0.6 percentage respectively, while quantitative phases as C3S,

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How to cite: Bagudo, A. U., Abubakar, G. A., Bello, A. M., Shamsu, M. B., & Ibrahim, I. B. (2025). Determination of Slurry's Properties of Oil Well Cement Produced from Local Raw Materials. *UMYU Scientifica*, 4(2), 313 – 324. https://doi.org/10.56919/usci.2542.031

C2S, C3A, C4AF, and C4AF+2.C3A as 5, 7.13, 12.20, 3.92, 26.74, and 34.59 Wt% respectively.

The physical analysis of the new developed cement revealed initial setting time and final setting time as 561 (mins) and 646 mins respectively, while Compressive Strength for 1 day and 14 days as 1.55 Mpa and 13.05 Mpa respectively (Khalaf *et al.*, 2023).

Panda (2020) reported that mineralogical compositions of class H oil well cement as C3S (63.94), C2S (15.84), C3A (0.57), C4AF (11.33), Specific surface area of 200-260m^2/kg, and

SO3 (1.8).

Aslani *et al.* (2022) reviewed broad classes of additives that play a significant role in the oil and gas industry for cementing job. The right additive must be selected, and the right quantity must be added in an attempt to formulate appropriate cement slurry for any cementing job. The broad classes of additives are accelerators, which speed up the rate of reaction between cement and water, thereby shortening thickening time, increasing early strength of cement, and saving expensive rig time. In the design of shallow oil wells, where temperatures are low, Calcium chloride works best at a temperature of 4 °C and 49 °C, and in a concentration range of 1.5 bwoc to 3.7% bwoc, reducing the time required for waiting on cement (WOC) before drilling operations can be resumed. Conversely, in deeper wells, higher temperature promotes the setting process. Accelerators may not be necessary. Retarders in deep and hot wells, such as calcium lignosulfonate at a temperature of 200°F and optimum concentrations of 0.1% bwoc-1.0 % bwoc, decrease cement hydration and delay setting, allowing sufficient time for slurry placement. This increases the thickening times for pumping the cement into place. Other broad classes of additives include extenders, heavy-weight agents, and fluid loss additives, among others.

Dawood Salman *et al.*, 2020, prepared and characterised CaCO3 nano-particles from eggshell waste and incorporated them into oil well cement to improve mechanical properties. The results of the study revealed that incorporating CaCO3 nano-particles into oil well cement mixtures (2%, 4%, 6%, and 10% BWOC) enhanced mechanical properties and performance by yielding a higher compressive strength than the control mixture (0% BWOC), and the optimal result was obtained at 6% CaCO3 nano-particle BWOC. The results supported the notion that the CaCO3 nano-particles not only act as a filler but also as an activator in the hydration process (reaction of water and cement).

The incorporation of CaCO3 nano-particles increases the reaction rate of tricalcium aluminate (C3A) to form a carboaluminate complex, thereby increasing the total hydration products and delaying the formation of microcracks and consequently the compressive strength. Furthermore, it also reacts with tricalcium silicate (C3S) and accelerates setting time and early strength.

Thakkar *et al.* (2020) investigated the effect of nano silica on the physical properties of oil well cement. The results showed that incorporating nano-silica into the cement mortars increased both the compressive and flexural strengths. The results also indicated that by using this nano silica, the setting time and length of the dormant period were decreased. Nano silica behaves not only as a filler to improve the structure of mortar cement but also as a promoter of pozzolanic reaction based on the results of the compressive tests. Furthermore, it can be considered as an agent for improving the microstructure of the cement paste.

Qin *et al.*(2021) investigated the influences of different admitures-coarse and fine silica flour, silica fume and various colloidal nano materials (nano-silica, nano-Al2O3 and nano-Fe2O3materials) on the physical and chemical properties of four series of oil well cement slurries cured for 14 days under high temperature and pressure conditions(200^{o}C, 20Mpa), the results showed that increase in silica flour dosage from 40% to 60% BWOC, generally decreases slurry viscosity 400% increase in compressive strength and more than one order of magnitude reduction in permeability of set cement, and maximum strength is obtained at 80% silica dosage. Replacing fine silica with silica fume will increase slurry viscosity at low shear rate but decrease slurry viscosity at high shear rate. Adding nano-colloidal silica increases slurry viscosity at all shear rates.

The effects of these solid admixtures on cement slurry rheology are significantly less than those of chemical additives. The combined use of silica fume and nano-colloidal nanosilica may have detrimental effects on the mechanical properties of the silica-cement system.

However, in the absence of silica fume, the addition of various colloidal nano materials (nano-silica, nano-Al_2O_3, and nano-Fe_2O_3 materials) in the silica-cement system can reduce the water permeability of set cement by 50%. However, colloidal nano-Fe2O3 is the best candidate in enhancing the set cement properties. The limitation of the work was the use of only one curing time and temperature, 14 days and 200 °C, respectively.

Davoodi *et al.* (2024) synthesized an amphoteric composite polymer (PAADM) as a high-temperature-resistant cement retarder by in situ intercalated polymerization method with 2-crylamido-2-methyl propane sulfonic acid (AMPS), acrylic acid (AA), and two diallyldimethyl ammonium chloride (DMDAAC) as monomers, and modified montmorillonite as an active polymerization filler. Performance evaluation evidenced that the cement slurry containing PAADM has good retarding property in the range of 120 ˚C–200 ˚C, and demonstrated the rapid development of compressive strength under both high-temperature and low-temperature conditions. This property could guarantee that the retarder PAADM could be applied to the depths of oil wells and long-interval oil wells.

On XRD analysis of Class G MSR oil well cement used in the research revealed chemical compositions as CaO, SiO_2, Fe_2O_3, Al_2O_3, SO_3, MgO, K_2O, Na_2O and Others as 59.80 22.40 7.60, 2.70, 2.40, 2.60, 0.60, 0.20 and 0.70 wt% respectively while the phases as C_3S, C_2S, C_3A, C_4AF, $CaSO_4$ and others as 49.30, 24.70,6.80, 11.0, 4.10 and 3.80 wt%.

Saidu and Lawal (2020) investigated the effect of limestone addition (5-15%) on the physicochemical properties of laboratory-prepared Portland cement, Sokoto Portland cement, and Dangote Portland Cement. XRF studies revealed an increase in CaO concentrations with a decrease in other oxides on limestone addition in all the samples.

The physical analysis studied viz compressive strength decreases on addition of limestone but at concentration considered that is 5-15% of limestone the cured cements had appreciable strength as the results are normal according to the Standard Organization of Nigeria's standard range of 10 Nmm^{-2} minimum for 2days and 42.5 Nmm^{-2} minimum for 28 days so also setting time decreases upon addition of limestone in all the samples studied but 5-15% limestone addition has no significant effect as the results falls within the range set by Standard Organization of Nigeria of 60 min minimum for initial setting time and 600 min maximum for final setting time.No expansion and weakening of cement structure was observed as revealed by soundness test.

Ahmed *et al.*, 2020 incorporated tire waste material as an additive into Saudi class G oil well cement slurry to improve cement matrix durability under high Temperature and Pressure conditions of 292°F and 3000psi.The results revealed that incorporating 0.3% by weight of cement (BWOC) of the tire waste material-plastic viscosity is decreased by 53.1%, yield point is increased by 142.4%, young modulus is decreased by 10.8%, and the Poisson ratio increased by 14.3% compared to the base cement.

Nuhu *et al.* (2020), in their study on Sokoto cement (BUA), reported a relatively low iron (Fe_2O_3) content and a correspondingly high tricalcium aluminate (C_3A) content, which resulted in a reduced amount of tetracalcium aluminoferrite (C_4AF). This composition contrasts with that of oil-well cement, as analyzed by Davoodi *et al.* (2024), which exhibited higher iron content, leading to greater formation of C_4AF and lower levels of C_3A.

These variations are critically important because the amounts of C_3A and C_4AF significantly affect how cement performs in harsh environments. Elevated C_3A content can enhance early strength gain but also raises the risk of sulphate attack, which poses challenges in oil well applications. On the other hand, increased C_4AF content tends to enhance sulphate resistance and lower the heat of hydration (Kammouna, 2023), making the cement better suited for deep-well and high-temperature conditions.

The effectiveness of cement largely depends on its intended application, as different uses require specific performance characteristics. The clinker phase composition and the selection of raw materials influence these characteristics. In this study, an iron-rich laterite was incorporated to enhance the iron content, thereby increasing the C_4AF phase in the clinker. This modification contributes to extended setting time and improved resistance to sulphate attack. The paper focuses on evaluating the slurry properties of oil well cement produced by modifying Type II cement clinker with locally sourced laterite, which is abundantly available in Nigeria.

MATERIALS AND METHODS

Material

Type II cement's Clinker, Buac, Standard sand, Gypsum, and Laterite (Lat A and Lat B) were all obtained from Bua Cement, Sokoto state, while POWCC and POWCGMSR were synthesized.

Methodology

2.2.1 Production of Prepared Oil well cement at zero percent Laterite (POWCC)

About 4800g of crushed clinker and 200g of crushed Gypsum representing 96% and 4% by weight of the cement (bwoc) respectively was crushed using crusher and grinded together (no laterite was added) using laboratory milling machine for about 45 minutes and allowed to discharge for 15 minutes which served as control and labelled POWCC (Bagudo *et al.*, 2025)

2.2.2 Production of Prepared Oil-well cement Class G Moderate Sulfate Resistant at5% laterite (POWCGMSR).

About 1365g of crushed clinker and 75g of laterite, representing 91% and 5% laterite by weight of the cement (bwoc), respectively, were ground using a laboratory milling machine for 45 minutes and allowed to discharge for 15 minutes. The product (ground clinker and Laterite) in a ceramic crucible (100ml) was placed in a furnace batch-wise and heated at 1000°C for 5 minutes.

The crucible was removed and cooled in a desiccator. About 60g of crushed Gypsum (representing about 4% bwoc) was ground using a vibrating cup milling machine for 5 minutes. The ground gypsum was mixed with the product (calcined clinker and laterite) and crushed together using a pestle and mortar batch-wise. The Oil-well cement produced was labeled POWCGMSR sieved with 200-micron sieves and stored in a plastic container (Bagudo *et al.*, 2025).

Compressive Strength Test

This test was aimed at determining the compressive strength of POWCC, BUAC and POWCGMRS oil well cement.

Procedure: Exactly 450 g of cement sample, 1350g standard sand, and 225g of distilled water were mixed using an automatic lab mixer. A prism mould was mounted on the jolting machine. The mixture was transferred into the three compartments of the prism and moulded into a cubic block after compaction for 2 minutes using a jolting or vibrating machine.

The prism mould was removed, covered and cured in a daily curing chamber for 24 hours with a temperature of about 27 ˚C and 90% humidity. After 24 hours, the cubic blocks were demoulded. Three blocks were tested using a compressive strength machine, while the remaining blocks were immersed in water inside the curing chamber and tested for 3 days, 7 days, and 28 days. Similar preparations and testing were carried out for other samples. (*CN.N.N.*, 2000).

Setting Time

About 400 g of cement sample was taken and mixed with distilled water until a consistent cement paste was obtained. The paste was transferred into a greased VICAT mould and then placed under the VICAT apparatus. The plunger was released gently to penetrate the cement paste. The procedure was repeated at an interval of 5-10 minutes. The initial setting time was taken when the needle stopped at 5mm or just above, and the volume of water was also noted from the measuring cylinder for consistency calculations. The VICAT needle was replaced with a final setting time needle, which had a circular mark. The final setting time was taken when the circular mark was no longer visible on the cement paste, but a dot was visible. Initial setting time was the time from which water was added to the time the VICAT needle refused to penetrate the cement paste to less than 5mm (CCNN, 2000).

Soundness (Expansion) Test

Exactly 200g of the cement was mixed with distilled water and placed into Le Chatelier's apparatus (mould) and placed on a greased glass sheet. A rubber band was used to hold it gently and then cured for 24hrs in a curing chamber.

After 24 hours of curing, the sample was boiled for 1 hour. The distance between the two tails of the apparatus was taken before and after boiling as L_1 and L_2, respectively (CCNN, 2000).

The Expansion was calculated as the change in length by the equation 2.1.

$$Expansion = l_2 - l_1 \ (mm) \qquad 2.1$$

Rheological Property Measurement

Three cement (water to cement ratio =0.44) slurries were formulated with the composition of BUAC, POWCC (96% clinker, 4% gypsum, and 0% laterite bwoc), and PCGMSR (91% clinker, 4% gypsum, and 5% laterite). These samples were prepared following the American Petroleum Institute (API) standards 10A. The cement slurries were prepared with a water-to-cement ratio of 0.44. The impact of incorporating laterite material on the rheological properties of cement slurry, specifically yield point and plastic viscosity, was assessed for all the cement slurries under study, including Bua cement, POWCC (composed of 96% clinker, 4% gypsum, and 0% laterite), and POWCGMSR (containing 91% clinker,4% gypsum, and 5% laterite). The evaluation was conducted at a temperature of 90°C under atmospheric pressure. During the rheological testing, the cement slurries were subjected to shear forces at increasing rates of 3, 6, 100, 200, and 300 rpm, followed by the same rates in descending order.

The corresponding shear stresses were recorded for each rate, and the average shear stress at each shear rate was determined by calculating the arithmetic mean of the two recorded values. These averaged values were then used to compute the yield point and plastic viscosity (Ahmed *et al*., 2020).

Thickening Time

To evaluate the thickening behavior of cement slurry under simulated well conditions, a High-Pressure High-Temperature (HPHT) consistometer is utilized. The device is initially heated and pressurized to match the target downhole conditions of 90°C and 1000 psi. The prepared cement slurry (water to cement ratio =0.44) is then placed in the consistometer's cup and securely positioned.

Next, the temperature and pressure within the consistometer are gradually increased following a standardized API schedule, mimicking real wellbore conditions. Throughout the test, the slurry's consistency is continuously monitored in Bearden Consistency Units (BCU).

As long as the consistency remains below 70 BCU, the slurry is considered pumpable. The "thickening time" is defined as the moment the slurry reaches 100 BCU, indicating it has hardened beyond pumpability.

Once the slurry reaches this 100 BCU threshold, the test is concluded, and the total time taken is recorded as the thickening time in minutes (Chen *et al*., 2021).

Fluid loss test

To conduct the API Fluid Loss Test at 90°C and 1000 psi, a pre-wetted filter paper is placed inside the assembled API Fluid Loss Cell. The prepared cement slurry (water to cement ratio=0.44) is then poured into the cell, which is securely sealed. A pressure differential of 1000 psi (6.9

MPa) is applied using either nitrogen gas or compressed air. If elevated temperatures are required, a heating jacket is used to maintain the test conditions.

During the test, the liquid that passes through the filter paper, known as the filtrate, is collected in a graduated cylinder. The test is conducted for 30 minutes or until the fluid loss stabilizes. The total volume of filtrate collected, measured in milliliters (mL), represents the fluid loss (Islamov *et al.*, 2024).

RESULT AND DISCUSSION

Laterite Compositions

Table 3.1 compares the oxide compositions of the two laterite samples (Lat A and Lat B), as obtained by Santoro et al. (2022) via XRF analysis. The XRF analysis indicates that the laterite samples are composed mainly of iron. The lat B sample was used in the production PCGMSR oil well cement due to its slightly higher iron content and lower LOI (amount of carbonaceous matter) than the Laterite sample A (lat A).

Oxides and Mineralogical Compositions

Tables 3.2 and 3.3 show the oxide and mineralogical compositions of Buacl, POWCC, Buac, and the POWCGMSR obtained by XRF analysis.

Compressive Strength

Table 3.1: Compositions of laterites

Parameter	LatA(wt%)	LatB(wt%)
Fe2O3	41.975	42.552
MgO	0.000	0.000
Al2O3	0.490	0.336
P2O5	0.516	0.620
TiO2	0.492	0.454
SO3	0.056	0.087
LOI	13.830	11.500
Mc	17.000	18.280
IR	0.7130	0.6900

Key: Lat A - Laterite A, LatB - Laterite B, Mc - Moisture Content

Figure 3.1 shows the mean strength test results of compressive tests of the samples for 1, 3, 7, and 28 days aging, respectively. The P values (Minitab 17 software) for all the curing times were found to be less than the α value, i.e, $P=0.000 < \alpha=0.05$which means there is a statistical significance difference, and also Pair Turkey's wise comparison shows the intervals of samples that does not contain zero are significantly different or otherwise (Al Jafa, 2024).

The graph (Figure 3.1) presented the compressive strength (MPa) of three different cement compositions, BUAC, POWCC, and POWCGMSR, measured at four curing times: 1 day, 3 days, 7 days, and 28 days.

Table 3.2: Oxides Composition

PARAMETER	BUACL	POWCC (wt%)	BUAC (wt%)	POWCGMSR (wt%)
CaO	67.986	69.942	69.942	63.0570
SiO2	20.099	20.530	20.530	21.1297
SO3	0.1815	1.8954	1.8954	1.6145
Al2O3	5.9796	5.5822	5.5822	5.3472
Fe2O3	4.3204	4.1283	4.1283	5.0313
K2O	0.1815	1.8954	1.8954	1.6145
Mn2O3	0.1321	0.1067	0.1067	0.1366
P2O5	0.6284	0.5769	0.5769	0.5245
TiO2	0.2752	0.2605	0.2605	0.2676

Table 3.3: Mineralogical Compositions

CEMENT SAMPLE	C3S	C2S	C3A	C4AF	C4AF+2C3A	Specific Surface Area (m^2/Kg)
POWCC	91.4316	-9.8515	8.3773	13.2512	30.0058	292
BUAC	86.1200	- 10.0600	8.1100	11.3916	27.6116	400
PCGMSR	54.4727	17.2568	5.8245	15.7196	27.3686	331
Class G Portland cement for oil well(MRS)*	48-58	-	≤8	-	-	Class G Portland cement for oil well(MRS)*

Key: C3S-Tricalcium Silicate, C2S-Dicalcium Silicate, C3A-Tricalcium Silicate, C4AF-Tetracalcium Aluminoferrite. *Requirement of the Standard API 10A for Moderate Resistant to Sulphate (MRS).

It was observed that in terms of early strength (1 day and 3 days), POWCC exhibited the highest compressive strength at both time points, followed by BUAC, while POWCGMSR showed the lowest values. This was due to the inclusion of laterite in POWCGMSR, which causes dilution of C3S, as it is the mineralogical composition responsible for early strength development of cement, and might slightly delay early strength development when compared to POWCC, which contained no laterite and consisted primarily of clinker and Gypsum (Mascarin, 2023).

At 7 days, POWCC was reported to maintain a slight advantage over BUAC and POWCGMSR, although the differences among them had narrowed. Despite containing 5% laterite, POWGMSR's compressive strength was found to be comparable to the other compositions, which indicated that laterite did not significantly weaken the cement at this stage (Basavana *et al.*, 2023).

By 28 days, POWCGMSR was noted to have surpassed both POWCC and BUAC, achieving the highest compressive strength, as it has the highest dicalciumsilicate (C2S), as shown in Table 3.3, a mineralogical composition responsible for the later strength development.

This was suggested to indicate that the laterite-modified cement (POWCGMSR) underwent significant strength development over time, possibly due to pozzolanic activity or delayed hydration reactions because of high tetra calcium aluminoferrite (C4AF) and low tricalcium silicate (C3A) (Obioma, 2023) compared to other cement samples as shown in Table 3.3. Meanwhile, BUAC and POWCC were reported to demonstrate comparable strengths, with BUAC slightly outperforming POWCC at this stage (Metekong *et al.*, 2021; Kong *et al.*, 2024).

Furthermore, the presence of laterite in POWCGMSR could introduce pozzolanic activity, where silica from the laterite reacts with calcium hydroxide to form additional calcium silicate hydrate (C-S-H), and enhance strength at later stages. This pozzolanic reaction is typically slower, contributing to strength development beyond the initial curing period (Wahab *et al.*, 2021).

When comparing these results with API standards and existing literature, it was stated that the American Petroleum Institute (API) specified that Class G oil well cement should achieve a minimum compressive strength of 2.1 MPa (300 psi) after 8 hours at 38°C under atmospheric pressure and 10.3 MPa (1,500 psi) after 8 hours at 60°C under atmospheric pressure. The data in the graph (Figure 3.1) revealed that none of the compositions met the 10.3 MPa thresholds at 1 day, leading to the suggestion that further optimization or improved curing conditions might be required to satisfy API standards for early strength.

Furthermore, it was highlighted that according to ASTM, Type I Portland cement paste should achieve a minimum compressive strength of 12 MPa (1,740 psi) at 3 days and 19 MPa (2,760 psi) at 7 days. The 28-day compressive strengths measured in the graph were reported to align with these standards, particularly for POWCGMSR, which exceeded 40 MPa. The delayed strength gain in POWCGMSR was suggested to be attributable to the presence of laterite, which might contribute to secondary hydration reactions.

These observations highlight the potential of laterite as a supplementary material in cement, particularly for applications where long-term strength development is desirable (Yehualaw *et al.*, 2025). Generally, the compressive strength of all the hardened cubes increases with aging, as shown in Figure 3.1. All the samples recorded values of compressive strength superior to the literature values reported by Thakkar *et al.* (2020) at 87.7 °C

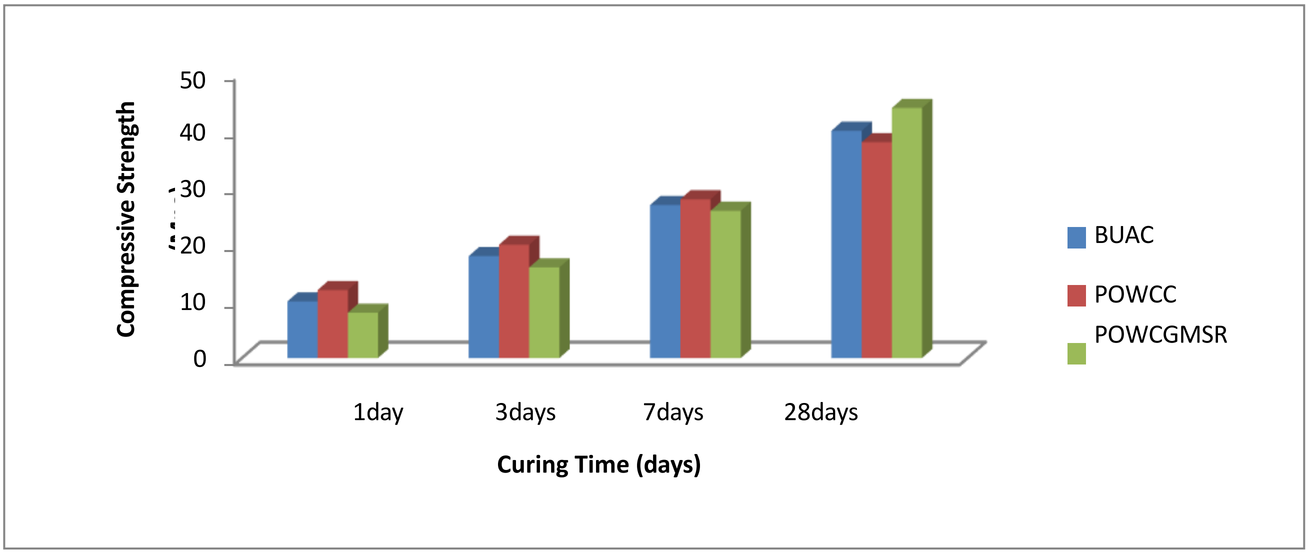

Figure 3.1: Compressive Strength of BUAC, POWCC and POWCGMSR

Setting Time

Figure 3.2 presents the Initial and Final setting times (in minutes) for three different cement types: BUAC, POWCC (0% laterite), and POWCGMSR (5% laterite). According to the graph, the Initial Setting Time (represented by blue bars) for BUAC is approximately 240 minutes; for POWCC, it is slightly lower at around 230 minutes; and for POWCGMSR, it is the highest at approximately 270 minutes. The Final setting time (represented by red bars) shows BUAC at around 300 minutes, POWCC slightly lower at about 295 minutes, and POWCGMSR again the highest, at approximately 340 minutes.

In comparing the materials, it was observed that POWCC (0% laterite) and BUAC had similar setting times, indicating comparable behavior in terms of the hydration reaction and hardening process. POWCGMSR (5% laterite) exhibited the highest initial and final setting times, suggesting that the inclusion of laterite delayed the setting process due to the dilution of tricalcium silicate (C_3S) and tricalcium aluminate (C_3A). Furthermore, the increase in laterite content from 0% in POWCC to 5% in POWCGMSR corresponded to a rise in both setting times, indicating that laterite slows down the hydration process (Komnitsas *et al.*, 2021).

The analysis reported that the setting times shown in the chart were compared with API (American Petroleum Institute) and ASTM (American Society for Testing and Materials) standards. According to API 10A, which defines cement properties for oil well applications, the minimum initial setting time is 45 minutes, and the maximum final setting time is 600 minutes. For general construction cement, ASTM standards C191 and C266 specify typical initial setting times between 30 and 90 minutes, and final setting times between 200 and 400 minutes.

It was observed that the initial setting times exceeded the API minimum of 45 minutes, while the final setting times were well within the API maximum of 600 minutes, making all values acceptable under API 10A. Additionally, although the initial setting times surpassed the ASTM range of 30 to 90 minutes, the final setting times were generally within the ASTM range of 200 to 400 minutes, which was considered acceptable.

The conclusion was that the final setting times complied with both API and ASTM standards. However, the initial setting times were longer than ASTM expectations, though still within API limits. Therefore, the cement would be suitable for oil well applications but may exhibit longer setting times than desired for general construction purposes.

Generally, both API and ASTM standards recommend that initial setting times should not be excessively long to avoid delays in construction. While longer final setting times may enhance workability, they can also delay strength development. The results indicated that the addition of laterite increased the setting time, which could be advantageous in hot weather conditions where rapid setting is a concern (Onyenokporo, 2022).

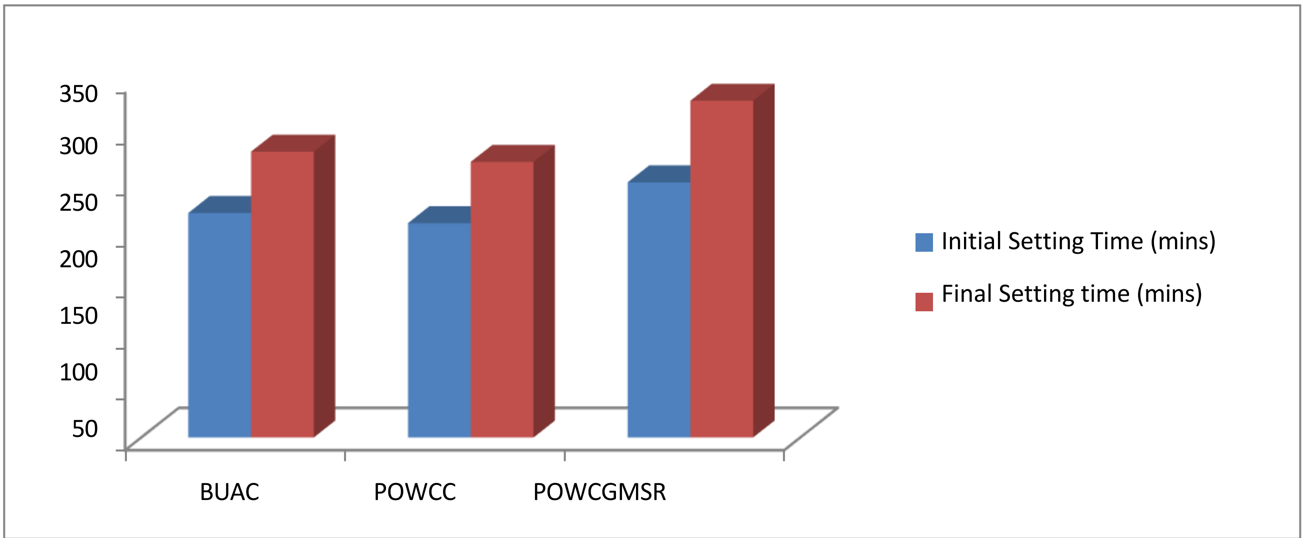

Figure 3.2: Initial and Final Setting Time of BUAC, POWCC, and POWCGMSR

Soundness (Expansion)

Figure 3.3 shows the expansion measurements of three distinct cement mixtures: BUAC (BUA Cement), POWCC (composed of 0% laterite, 96% clinker, and 4% gypsum), and POWCGMSR (containing 5% laterite, 91% clinker, and 4% gypsum). The vertical axis indicated expansion values, while the horizontal axis categorized the cement types. The data revealed that BUAC showed the highest expansion, reaching approximately 1.0. Conversely, POWCC displayed a significantly smaller expansion, indicating a decrease in expansion tendencies. Furthermore, POWCGMSR maintained a consistent expansion level compared to POWCC, suggesting that the addition of 5% laterite had a negligible effect on expansion.

Regarding the comparison with existing research and API standards, it was reported that expansion in cement-based materials is a well-documented area, with factors like hydration processes, the presence of expansive compounds such as ettringite, and the overall chemical composition playing significant roles (Fraj, 2022).

Because POWCC had 96% clinker and POWCGMSR 91%, it was highlighted that a higher clinker proportion generally increases strength but could also induce shrinkage instead of expansion (Hacini-Chikh and Arabi, 2024). The addition of 5% laterite to PCGMSR did not noticeably change expansion behavior, suggesting that laterite acted primarily as an inert filler (Kaze *et al.*, 2021). Studies have shown that substituting some clinker with laterite can reduce manufacturing expenses and carbon dioxide emissions without compromising the cement's long-term performance (Antunes *et al.*, 2021).

Concerning the comparison with API standards, it was explained that the American Petroleum Institute (API) standards, particularly API 10A for oil well cement, impose stringent limits on cement expansion to ensure stability, especially in high-pressure, high-temperature (HPHT) environments (API, 2019). The graph indicated that BUAC exhibited an expansion value exceeding 1.0, which surpassed API limits. This suggested potential issues such as sulfate attack or excessive ettringite formation, which could jeopardize structural stability (Ibrahim *et al.*, 2024).

Rheological properties: Plastic viscosity and Yield point

The study presented (Figure 3.4) the plastic viscosity and yield point results for three types of cement. BUA Cement had shown a PV of 52 centipoise (cP) and a YP of 12 hundred pounds per square foot (100 lb/ft²). The control POWCC, composed of 0% laterite, 96% clinker, and 4% gypsum, had exhibited a PV of 50 cP and a YP of 11,100 lb/ft². POWCGMSR, which contained 5% laterite, 91% clinker, and 4% gypsum, had shown the highest values, with a PV of 55 cP and a YP of 14,100 lb/ft².

Concerning the plastic viscosity analysis, it had been reported that values had ranged from 50 to 55 cP, with POWCGMSR having the highest value, which could be attributed to higher resistance to flow due to the presence of laterite. This is believed to have increased the concentration of solids and friction within the slurry (Yehualaw *et al.*, 2025). They had also observed that BUA Cement and POWCC had shown similar flow behaviors, but POWCGMSR had exhibited a higher viscosity, which they suggested could lead to better suspension stability but might require higher pumping pressures (Zheng *et al.*, 2023).

Regarding the yield point analysis, it had been reported that values had ranged from 11 to 14 100 lb/ft², with POWCGMSR having the highest YP. The study indicated that POWCC had shown the lowest YP, suggesting weaker gel strength and a reduced ability to suspend solids, while BUA Cement had demonstrated moderate suspension properties. POWCGMSR, with the highest YP, had shown improved gel strength and better particle suspension capabilities. A higher yield point was associated with improved particle suspension and reduced settling (Malkin *et al.*, 2023). They had reported that an increase in laterite content had contributed to a higher yield point, which had explained POWCGMSR's higher YP values (Wahab *et al.*, 2021).

Based on the findings, POWCC was recommended for shallow wells, as it had shown lower resistance to flow but weaker suspension properties. BUA Cement was suitable for intermediate wells, as it had provided a balance between flow ability and solid suspension. POWCGMSR was most suitable for deeper wells, as it had offered enhanced suspension characteristics but would require higher pumping pressures.

Thickening Time

The tests were conducted at a temperature of 90 degrees Celsius and a pressure of 1000 psi. Consistency was measured in Bearden units (Bc), and the final thickening time was defined as the time, in minutes, when the consistency reached 70 Bc.

A study investigated the thickening time of three distinct cement formulations: BUAC Cement, POWCC, and POWCGMSR. The results revealed that POWCGMSR had the longest thickening time of 190 minutes, indicating that the inclusion of 5% laterite contributed to a slower setting process (Wahab *et al.*, 2021), which in turn indicates high tetracalcium aluminoferrite phase (C4AF) and low alumina modulus (Am).

This effect was attributed to the fine-grained characteristics of laterite, which were thought to influence hydration kinetics by limiting the rate of water absorption (Mousi *et al.*, 2024).

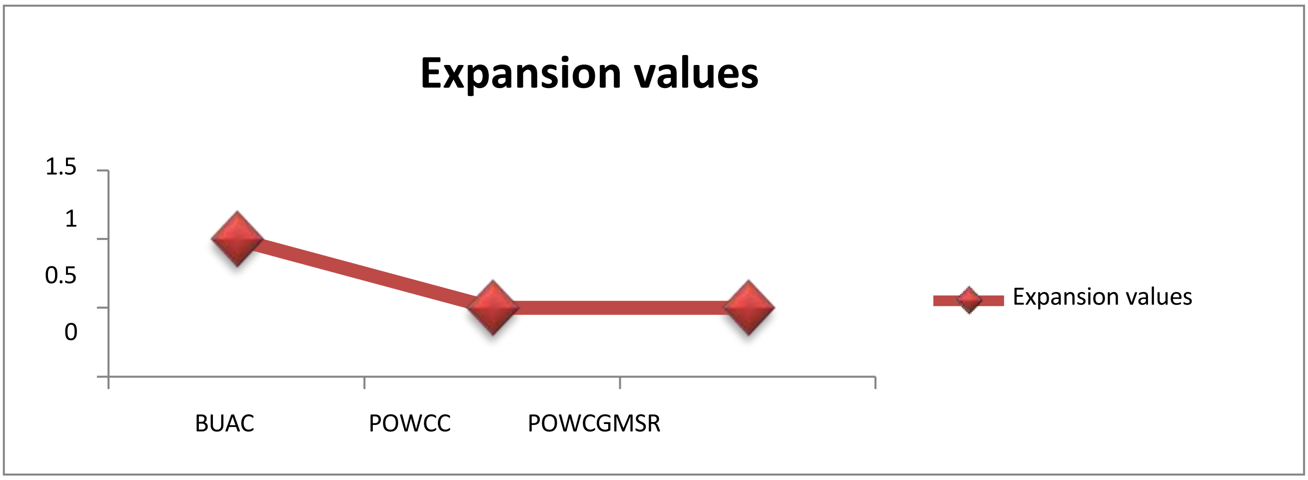

Figure 3.3: Soundness (Expansion) of BUAC, POWCC, and POWCGMSR

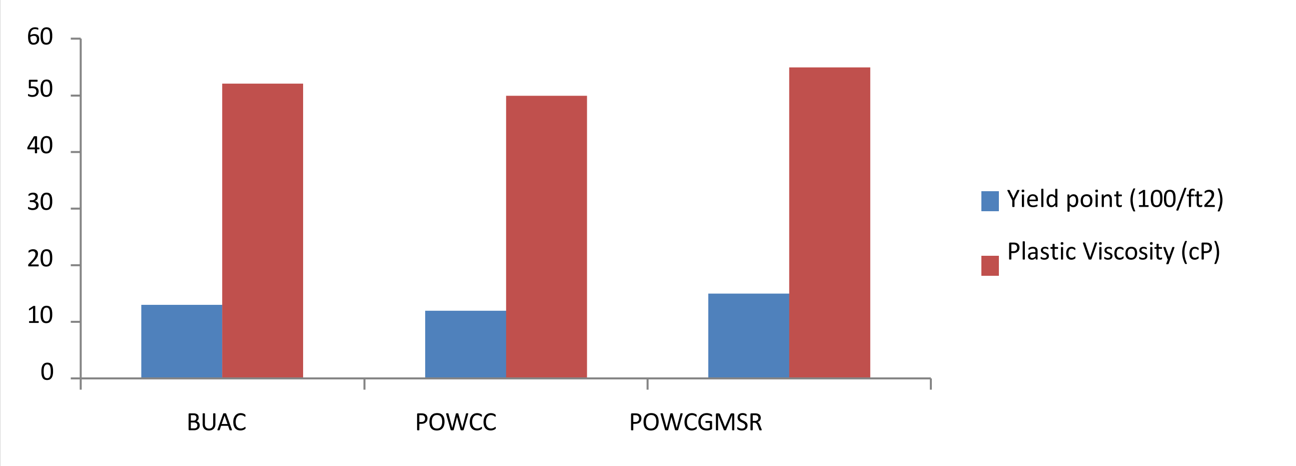

Figure3.4: Yield point and Plastic Viscosity of BUAC, POWCC and POWCGMSR

Additionally, the study found that BUAC cement had a thickening time of 160 minutes, placing it between the other two formulations. This suggested that BUAC cement offered a well-balanced setting time, making it a viable option for general cementing applications. In contrast, POWCC exhibited the shortest thickening time of 140 minutes, which was linked to its high clinker content (96%). Since clinker is the primary component responsible for cement strength development, its high proportion was believed to accelerate hydration and setting (Dorn and Stephan, 2022).

Comparing the results with the API recommended thickening times. According to Chukwuemeka *et al.* (2023), shallow wells (less than 3000 feet) should have a thickening time of 90 to 150 minutes, intermediate wells (3000 to 8000 feet) should have 150 to 240 minutes, and deep wells (greater than 8000 feet) should have over 240 minutes. They concluded that POWCC, with 140 minutes, was suitable for shallow wells, aligning with API recommendations.

BUA Cement, with 160 minutes, fell within the intermediate well range. POWCGMSR, with 190 minutes, also fit in the intermediate well category but leaned toward deeper well applications.

Robert (2024) had indicated that higher clinker content leads to a faster reaction with water, resulting in shorter thickening times. This aligns with the observation that POWCC, containing the highest clinker content (96%), exhibited the shortest thickening time. Furthermore, the study referenced research by Kaze *et al.* (2021), which suggested that the presence of laterite in POWCGMSR likely acted as a retarder, slowing down hydration and extending the thickening time. This observation was consistent with findings from Aslani *et al.* (2022), who reported that pozzolanic or clay-based materials could alter cement thickening and setting behavior.

In conclusion, POWCC was recommended for shallow wells due to its rapid setting time, BUA cement was considered appropriate for intermediate wells with a moderate setting time, while POWCGMSR was deemed most suitable for deep wells because of its prolonged pumpability.

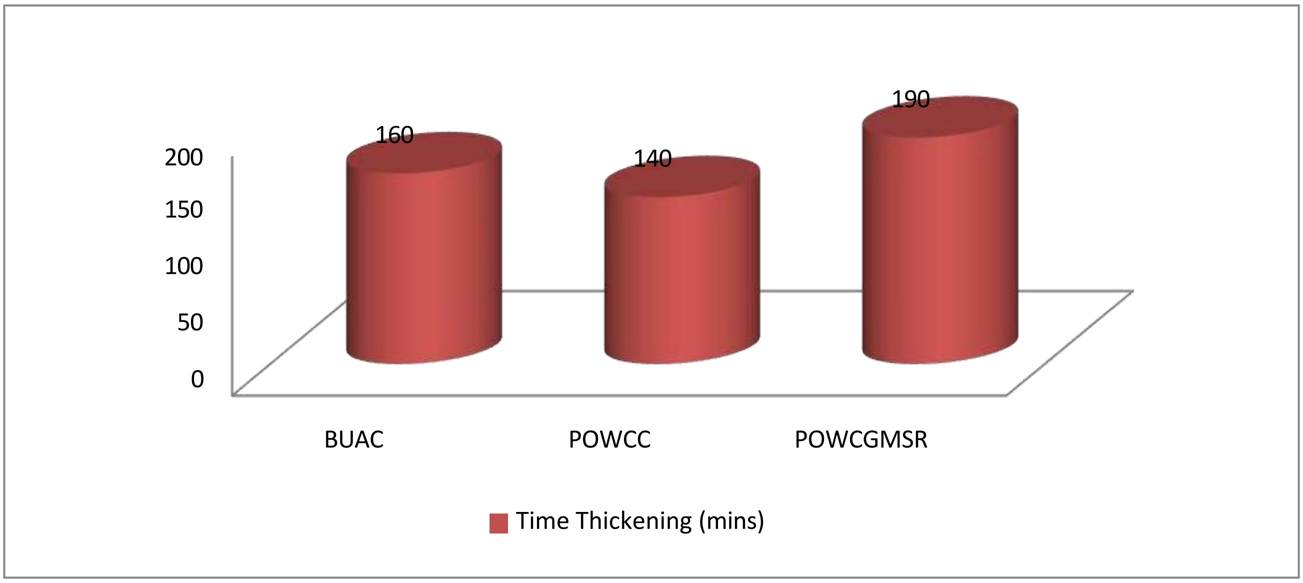

Figure 3.5: Time Thickening (mins) of BUAC, POWCC and POCGMSR at 90°C, 1000 psi and consistency 0f 70Bc.

Fluid Loss

Figure 3.6 illustrates the fluid loss performance of three different cement types. They stated that BUA Cement recorded a fluid loss of 250 mL, which they considered moderate. They mentioned that although this value met the API standard for standard wells, the cement might require additional fluid loss control additives to further minimize water invasion into the formation. They emphasized that controlling fluid loss was essential to avoid formation damage and to ensure adequate cement hydration (Yousuf *et al.*, 2021). They explained that POWCC, made up of 96% clinker, 4% gypsum, and no laterite, exhibited the highest fluid loss at 275 mL. They attributed this to the absence of laterite, which they believed increased the permeability of the slurry.

In contrast, the POWCGMSR, which contained 5% laterite, 91% clinker, and 4% gypsum, had the lowest fluid loss at 200 mL. This was credited to the inclusion of laterite, which functioned as a pozzolanic material that enhanced water retention within the slurry, supporting the findings of Okere (2020). This property made POWCGMSR more effective in preventing dehydration and maintaining well integrity.

Comparing these results to the literature findings of Brito *et al.* (2020), which recommend a maximum of 250 mL for standard wells and 100 mL for critical wells. They observed that BUA Cement met the requirement for standard wells, while POWCC exceeded the acceptable limit, indicating a greater risk of water loss. POWCGMSR performed the best by remaining well below the recommended maximum.

A higher clinker content generally led to increased fluid loss (Sharifi *et al.*, 2023), while pozzolanic materials like laterite improved water retention (Okere, 2020). The effective fluid loss control was crucial for preventing formation damage, ensuring cement strength, and minimizing the development of cracks (Alkhamis and Imqam, 2021).

In conclusion, POWCGMSR was the most effective for fluid loss control and suitable for use in critical wells. They regarded BUA Cement as appropriate for standard wells but noted that it could benefit from the addition of fluid loss control agents, while POWCC would require formulation improvements to enhance its fluid retention capacity.

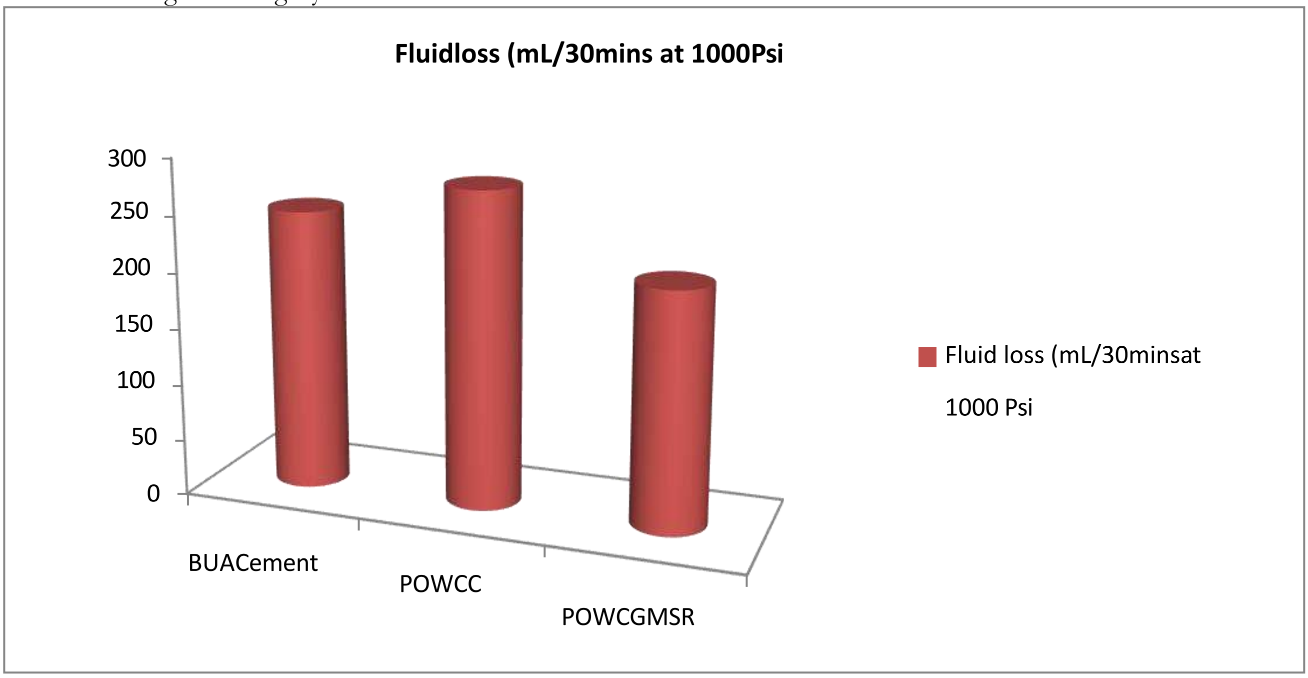

Figure3.6: Fluid loss of BUAC, POWCC, and POWCGMSR

CONCLUSION

The findings indicate that all tested cement slurry formulations, viz, BUAC, POWCC, and POWCGMSR, satisfied the API 10A requirements for rheology, setting time, and thickening time. Although the incorporation of 5% laterite in POWCGMSR led to an initial reduction in compressive strength due to dilution of key clinker phases (C_3S and C_2S), strength improved over time with continued curing, suggesting good long-term performance. Expansion testing revealed that BUAC exceeded the API limit, raising potential durability concerns, while POWCC and POWCGMSR stayed within safe expansion thresholds. In terms of thickening time, POWCC is best suited for shallow wells, BUAC for intermediate depths, and POWCGMSR demonstrated flexibility, making it suitable for both intermediate and potentially deeper wells. Overall, POWCGMSR showed balanced and reliable performance, highlighting its suitability for broader well depth applications.

RECOMMENDATION

Optimisation of laterite content: Although the addition of 5% laterite in POWCGMSR initially reduced compressive strength, the strength improved over time. It is recommended that future research investigate varying proportions of laterite to identify the optimal content that maintains long-term strength without compromising early strength.

Promotion Of Locally Sourced Material: The successful performance of cement formulations using local materials demonstrates the potential for cost-effective and sustainable alternatives to imported cement. Further investment in the development and standardization of local raw materials is encouraged.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge the PTDF chair, Usmanu Danfodiyo University, Sokoto, Nigeria, chapter, for the financial support throughout this research.

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