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Performance Analysis of Cementation using Drilling Fluid in Ovhor Oil Well of Niger Delta Area of Nigeria

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Abstract:
Well cementing is one of the key processes performed during drilling and completion of wells. The main purpose of primary cementing is to provide zonal isolation. Failure of cement to provide zonal isolation can lead to contamination of fresh water aquifers, sustained casing pressure, or blowout. For effective cementing, the cement slurry should completely displace the drilling fluid. The performance analysis of cementation and drilling fluids will be investigated by the physical and chemical contamination on cement composition. Berea sandstone and clay rich rock discs cores had cement bonded with them to simulate cement-formation interfaces. These interface were contaminated either physically by dehydrated clays deposited on the surface) or chemically by intermixing drilling fluids with cement slurry. Shear bond tests were performed on the composite cores after complete hydration of cement occurred after 28 days in order to determine the shear bond strength. Preliminary results suggested that the detrimental impact of the contamination is higher when the cores are physically contaminated precisely when we have mud cake present at the surface of the well bore before a cement job is performed. Also, the results showed that shear bond strength is higher for sandstone formations when compared to shale formations, implying that the low permeability formations form much weaker bond with cement. This is of particular interest to well integrity issues in hydraulic fracturing, where high injection pressures of fracking fluids can easily cause de-bonding of weak rock-cement interface. Material characterization analysis was carried out to determine the micro structural changes at the cement-formation interface. Electron microscopy provided coupling of chemical/mineralogical composition with geomechanics of the interface. The phase compositions were characterized using a Jeol 8530F EPMA with 5 wavelength dispersive spectrometers and a SDD energy dispersive spectrometer. Line transects were used to assess variations in the bulk Composition. Abundances of phases were estimated using the Thermo NSS and Compass software on a Hitachi S3500N SEM with a energy dispersive spectrometer.

Key words: Performance Analysis, Cementation, Drilling Fluid, Well cementing, Zonal isolation

I. INTRODUCTION

Oil plays an important role in the development of day to day societies, being known as the main strategic product of today's global energy. Due to the continuous development of society, the demand for energy is increasing, resulting in the need to explore and produce more oil. It is in this conquest that the oil industry is a main sector in the fundamental functioning of modern economies. The problem is that, with the increased in usage, more accessible oil reserves are depleted at a fast pace and it becomes necessary to explore new areas where the complexity and the risk of operations are larger, requiring knowledge, technologies and personnel (El-Sayed *et al*, 1995). Cementing is one of the operations carried out in oil production. Cementing has come a long way since Frank Hill first used Portland cement to seal off a water bearing formation in 1903 at the Lompoc field in California (Stout K.,2000). Cement job design and placement has moved in a regular procession over the years, but the primary objectives of well cementing have remained the same. Primary cementing is carried out to provide zonal isolation, provide structural support for the casing, and protect the casing from attack by corrosive fluid (Smith,1984). Various studies have shown that cement failure can occur in both active and abandoned wells and provide pathways for leakage of well fluid. The pathways could be created by failure at the cement-casing interface, cement formation interface or even within the bulk cement, due to channels of fractures (Bradford, 1982). To stop a leakage path from being created at the cement formation interface, a good bond is needed between the cement and the formation. The bond should be good enough to withstand the effects of cyclic loading and exposure of cement to corrosive fluids (Tasong *et al*,1998). Unfortunately, poor cement bond exists in a large number of wells and it has been identified as one of the leading causes of sustained casing pressure (Tasong *et al*, 1998)

Process of Well Cementing: The process of well cementing involves gathering information for cement job design, designing the cement slurry, calculating the cement volume, cementing time requirements, selecting cement placement technique, and placing the cement (Ollivier, 1995). The quality of a cement job is heavily dependent on how good the cement job design was. Information about well configuration and environment are crucial to a cement job design as they affect the cement slurry design and determine the cement placement technique to be utilized. The well configuration information includes measured depth, open-hole size, and casing properties. These strongly influence the slurry volume required, hydrostatic pressure and friction pressure (Yong and Yang, 2007). Information about the well environment includes the pore and fracture pressure profiles, type of formation being cemented, temperature profile, presence of gas, and mud properties. All the information listed above are processed prior to cement slurry design. During slurry design, additives are added to basic Class H or G cement, to provide the cement with the desired properties. The additives include retarders, dispersants, fluid loss additives, and viscosifiers. Retarders (e.g. lignosulfonates), extend the setting time of cement while dispersants (e.g. polynaphthalene sulfonate), reduce the viscosity of the cement. The slurry design process is a complex process involving additives that interfere with the performance of each other. Once the slurry design is available and the cement volume and cementing time required for the cement job are calculated, the process of cement placement can be initiated (Bourgoeyn et al, 2000). Several primary cement placement techniques like normal displacement method, stage cementing, multiple string cementing etc are available. The cement placement technique selected for a cement job depends on various factors like the objectives of the cementing, string type to be cemented, and pressure profile of the well section (Gray and Nawrocki, 2000).

Overview of Drilling Fluid: Drilling fluid (Mud) is a common on-the-job name for the most popular circulating fluid associated with rotary drilling, and is used to perform any or all of the various functions required in the drilling operation. Drilling fluid serve many functions such as, controlling formation pressures, removing cutting from the well, transmitting hydraulic energy to down hole tools and the bit maintaining well stability and well control (Argillier et al, 1995). Drilling fluid composition vary based on well demands, rig capabilities and environmental concern. In addition, because a large percentage of modern wellbores are highly deviated, drilling fluid systems must help manage hole cleaning and stability problems specific to these wells (Mungan, 1989**).** Drilling fluid, or mud, is used during drilling of wells. The fluid is pumped from the surface, down the drill string, through the bit, and back to the surface via the annulus (Bourgoyne, 1986). This is done for the following reasons:

i. To remove the drill cuttings from under the bit and transport them to the surface.
ii. To cool and lubricate the bit and drill string.
iii. To exert hydrostatic pressure to prevent influx of formation fluids into the wellbore.
iv. To maintain stability of open hole.

Different drilling fluids are available and they are classified according to the base fluid in the mud. The types of mud include oil based mud (OBM), water based mud (WBM), synthetic based mud (SBM) and gaseous drilling fluid. The type of drilling fluid to be used is selected based on properties of the formation being drilled, environmental considerations, and cost. Gaseous drilling fluid is usually used in drilling hard well consolidated formations. OBMs give very good rate of penetration in shales, but do not allow for easy detection of kicks. WBMs are cheap but do not perform well in shales and under very high temperatures. SBMs have higher initial cost but disposal costs can be considerably low as they are less toxic. WBM is widely used in the Gulf of Mexico but recently, Internal Olefin (IO) SBMs with densities between 1078.47kg/m^3 and 1797.45kg/m^3 have become the most commonly used muds in Gulf of Mexico. WBM's usually contain water, barite, bentonite, caustic soda, and lignosulfonates (Elsevier, 2005).

Nature of Cement-Interface: The cement-formation bond is critical in preventing inter-zonal communication and maintaining well stability but very few studies have been done with samples taken from wells for the purpose of understanding alterations in the cement-formation bond over the life of wells (Carey and Wigand, 2007). Most of the studies on the nature of the cement-rock bond have been done in civil engineering. Based on these studies, bonding mechanisms of the cement to the formation have been shown to be a combination of mechanical interlocking of cement hydration products with the rock grains and the chemical reaction between the cement paste and rock grains (Tasong et al, 1998).The bonding due to mechanical interlocking of rock grains increases with increasing surface roughness. Greater surface roughness also provides larger surface area for bonding thereby increasing the bond strength. This means that the roughness of the well wall increases the bond strength between the cement and the formation (Bradford B.1982). The chemical reaction component of the cement formation bond is more complicated as different formations possess different minerals with different reaction mechanisms and products when brought in contact with the cement.

II. MATERIALS AND METHODS

Sample Preparation

The compound cores were made by bonding 300mD Berea sandstone and Catoosa shale to cement. The length and the breadth of the compound cores was 50.8mm and were prepared for physical and chemical contamination experiments. The cement slurry used for the experiment was prepared following the American Petroleum Institute (API) Recommended Practice for Cements, API RP 10B protocols, mixed in a commercial blender at 20,750 revolution per minute (rpm) for 45 minutes, using the recipe with slurry weight of 1845.38g/cm3, as shown in Table 3.1. A vacuum pump was then used to degas the cement slurry before it was poured into the mould for processing.

Table.1. Cement Slurry Recipe

Description	quantity(g)
Distilled water	1080
API Class H Cement	2860

The mud used in the experiment was prepared according to the recipe in Table 3.2 to obtain a weight of 898.725G/cm^3. The bentonite was added to the distilled water and blended for 5 minutes. The carboxyl-methyl cellulose (CMC) and sodium hydroxide were then added and stirred continuously for 3 minutes. The mud was poured on the surface of the rock and sucked into the rock with a vacuum pump.

Table .2. Mud recipe

Description	Amount (g)
Distilled water	350
Bentonite	15
CMC	0.5
NaOH	0.2

The rocks were cut into 25.4mm long smaller cores to create the compound cores. The cores were then wrapped with duct tape, leaving a 25.4mm overhang on top of the cores to act as mold for the cement. The cement slurry was then poured into the 25.4mm overhang and then aged for 28 days after a wait on cement (WOC) of 24 hours. Three different scenarios of mud contamination were demonstrated for this study as seen in Table 3

Table.3. Sample Designs for Physical Mud Contamination

Physical Contamination	
Compound core with no drilling fluid contamination at the surface.	
Compound cores (sandstone/cement & shale/cement) scraped of the mud leaving a slight residue of mud at the interface.	
compound cores (sandstone/cement & shale/cement) washed of the mud leaving some mud particles at the interface.	

The chemical contamination was done at three different concentrations, 0%, 5% and 10% of mud contamination. For the 0% mud contamination which serves as the control, no mud was added to the boundary between the cement and the formation, while mud was added to the boundary in amount equivalent to 5% and 10% mud for the 5% and 10% mud contaminated samples respectively. For the physical contamination, three levels of contamination was done. First sample was not contaminated with mud and this serves as the control. Then for the other samples, the surface of the rock was first contaminated with mud and left to dry. For the second physical contaminated sample, the mud sample was scrapped off the surface of the rock leaving a small remnant at the boundary between the cement and the rock. Then for the third physical contamination, the mud was washed off the surface of the rock using sodium silicate as the pre-flush leaving some mud particles at the boundary. The cement was then emptied on the surface of the pre-contaminated rocks. The composite cores were then placed in a water bath after a 24 hour wait on cement (WOC) period at room temperature for 18 days to achieve at least 70% hydration. Sodium hydroxide (NaOH) with pH level of 12 was added to the water to maintain the pH level of the cement between 12 and 13.

Shear Strength Test: The Chandler Engineering 4207D compressive strength tester was used for the shearing test. The model 4207D compressive strength tester is an automatically digitally controlled hydraulic press designed to test the compressive strength of standard 50.8mm cement cubes. The equipment which was modified to accommodate our sample design has a maximum load of 22679.61kg and a maximum loading rate of 302.388kg/s. The compound cores were mounted on the compressive strength tester and the rock section of the compound core was placed in the mount and the 25.4mm cement section of the compound core was left outside the mount as an overhand. The equipment was then used to introduce pressure on cement section of the compound core until failure occurs. The final pressure applied at the point of failure per unit contact area was used to ascertain the shear bond strength.

Figure.1. Chandler Engineering 4207D Digital Compressive Strength Tester

Material feature Experiments

Scanning Electron Microscopy (SEM) and Backscattered Electron Micrograph were the material feature techniques used for this study. The techniques aided us to determine the compound correct the point of interconnection, in order to visualize and confirm observations with measured parameters. Fractured fragments taken from the compound cores were covered with platinum covering before the experiments were performed. The FEI Quanta 3D FEG. FIB/SEM dual beam system interfaced with EDAX EDS/EBSD system located at Technology Partners International laboratory at Abuloma in Port Harcourt was used in this study.

Shear Bond Test

The Chandler Engineering 4207D digital compressive strength tester was used for this experiment. The samples were mounted on the compressive strength tester as shown in Figure 4.21.

Figure.4.1: Picture of a Post Shear Strength Test Showing the Fractured Surface of the Composite Core.

The gradual increment load was then applied on the samples to shear the bond between the cement and the formation. The compound core absorbed the applied load continuously until it

reached the point of failure where the bond between the cement and the formation was destroyed. The failure point happened when the maximum effective strength at the point of interconnection is equaled the applied stress and the weakest point within the cement-formation. Compound core is usually the point where failure begins. The final load applied to remove the bonds of the compound cores was used in the determination of the shear bond strength, by extracting the valuers from the machine.
The principle of determination of the Shear Bond strength by the machine was based on the following formula:

$$P = F/A \qquad (3.4)$$

Where P is the Shear Bond Strength (N/M2); F is maximum load (N) and A is the cross- sectional area of the core (M2).
Then, by conversion, 1 N/M2 = 0.001 kPa.
Two sets of experiments, physical and chemical mud were carried out in this study to determine the value of the effect of mud contamination on shear bond strength.

III. RESULTS

Figure 4.23 - Chemical Contamination
The minimum shear bond strength procured were 234.42kPa for the physically contaminated samples and 1585.79kPa for the chemically contaminated samples. The impact of physical contamination of sand-stone cement, shale-cement interfaces and chemical contamination of sandstone-cement from the experimental data are shown in Tables 4.4, 4.5 and 4.6 respectively. The test results demonstrate that both physical contamination of sandstone-cement, shale cement and chemical contamination of sandstone-cement has negative impact of share bond strength in Tables 4.4, 4.5 and 4.6. The comparison of the impact of physical contamination between sandstone-cement and shale-cement interfaces is described in Table 4.7 and Figure 4.4.

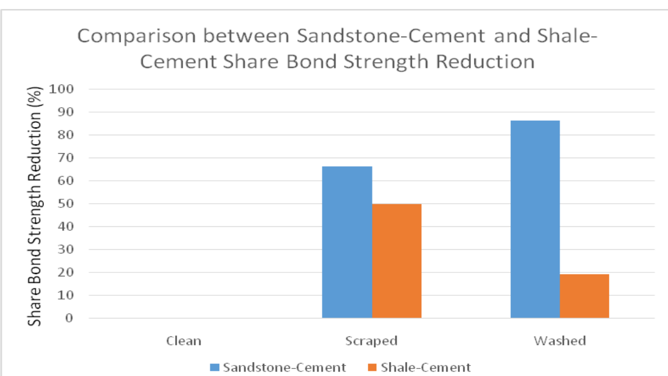


Figure .4.24. Comparison of Physical Contamination

The result showed that physical contamination has more impact on share bond strength of sandstone-cement interface than on shale cement interface. The results gave an opinion that physical contamination impacts more negatively on the shear bond strength than chemical contamination. When we compared the results obtained for physical contamination in sandstone and shale, the impact was less in shale because of the compatibility between shale and mud. The impact of various percentage of chemical contamination is shown in Table 4.8. The best fit model to express Share Bond Reduction for various percentage of chemical contamination is logarithmic, from mathematical regression using Microsoft excel as shown in Figure 4.25.

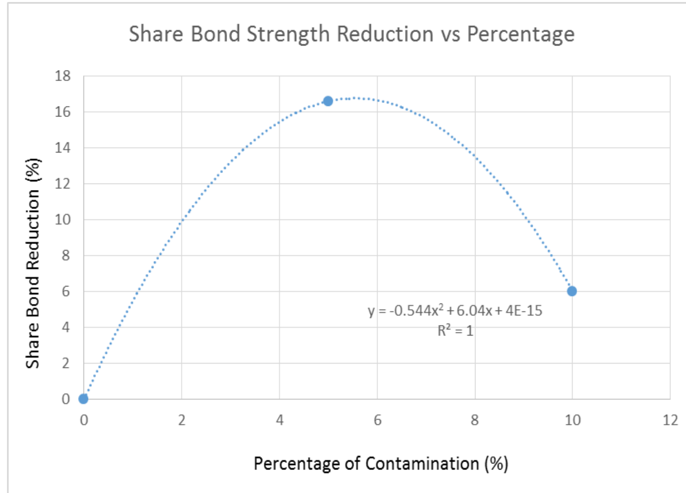


Figure 4.25. Plot of Shear Bond Strength versus Percent

Contamination

Therefore, Share Bond Reduction as a result of chemical contamination can be expressed as follows

$$\mathbf{S = 4x10^{-15} + 6.04C - 0.544C^2} \qquad (4.1)$$

Where, S is Share Bond Reduction in %; C is concentration of contaminants (%). The coefficient of determinant, R Squared, is 1 for the range of tested concentration of contaminant used in this experiment.

Material Characterization Experiments

The FEI Quanta 3D FEG. FIB/SEM dual beam system interconnected with EDAX EDS/EBSD was used for the SEM imaging. The results showed that the presence of mud within the interfacial transition zone, negatively force the bond between the cement and the formation.
Figure 4.26. Backscattered secondary electron microscope image showing the presence of mud at the cement-rock interface (cement top, rock at the bottom).
The Backscattered secondary electron (BSE) image shows the bonding point of inter connection between the cement and the rock. The dark sections exhibit pore spaces, while the bright sections are the grains. The sighting of the mud at the point of interconnection resulted in a reduction of the effective surface area for bonding. Further material characterization were performed using the BSE micrograph technique. The images were gotten after continuous flow experiments been conducted on the samples for 30 days using formation brine. The results obtained in figure 4.3 sheds more light on the interaction at the interface between sandstone and the cement for the 0% and 10% mud contaminated samples.

Figure 4.27 BSE micrograph for cement at the interface with corresponding elemental maps of Si, Ca and Al, (left to right) for 0% and 10% mud contamination.

The images revealed the increase in hydraulic conductivity at the interface due to leaching of the cement surrounding the pores at the interface between the cement and the formation. The sample with 10% mud contamination is likely to undergo fast deterioration than samples without no contamination.

Result suggested that:

- Physical contamination impacts more negatively on shear bond strength than chemical contamination.

- Impact of physical contamination was less in shale and higher in sandstone

- As such as literature test result confirmed that shear-bond strength is generally low for shale-cement core than that for sandstone-cement bond. Furthermore, the share bond strength measurements for the physical contamination of sandstone-cement shale –cement interfaces and chemical contamination can be expressed as shown in Figures 4.1, 4.2 and 4.3 respectively.

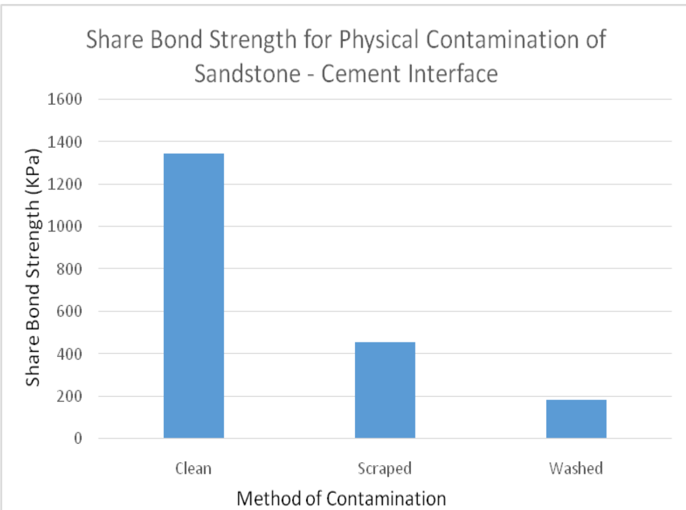


Figure 4.21: Physical Contamination of Sandstone Cement

Figure4.21 demonstrates the physical contamination of sand stone cement in relationship to the share bond strength. Result obtained revealed that clean method of contamination attained the highest value followed by scraped and washed as the less in terms of share bond strength for physical contamination of sandstone- cement interface.

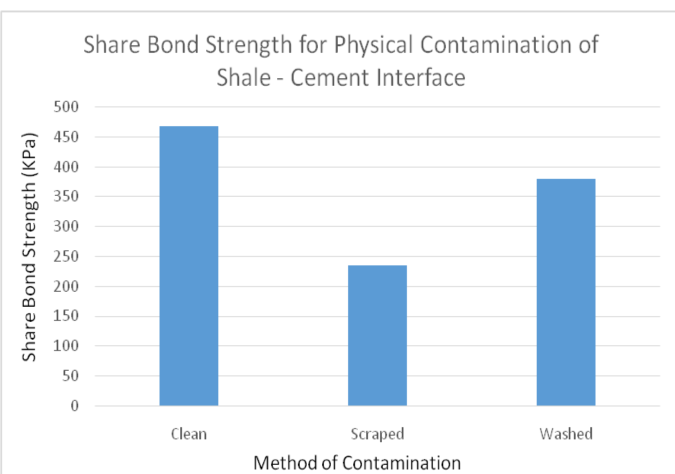
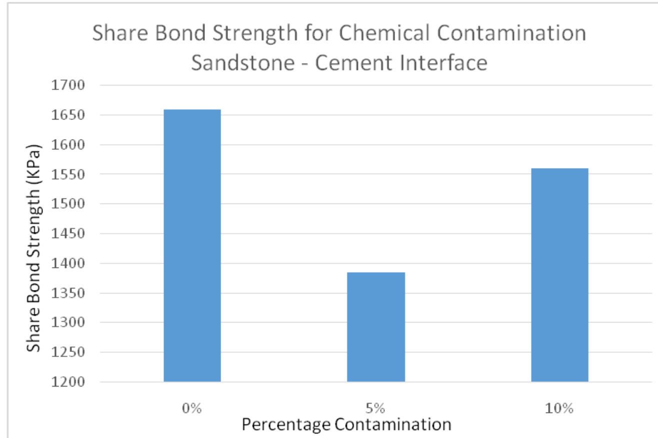


Figure.4.22: Physical Contamination of Shale-Cement

Figure 4.22 shows the physical contamination of shale cement in relationship to the share bond strength. Result obtained revealed that clean method of contamination attained the highest value followed by scraped and washed as the less in terms of share bond strength for physical contamination of shale cement interface.



IV. CONCLUSION

This work presents the performance analysis of drilling and cementation in Ohvor oil well. Sandstone-cement and Shale-cement composite cores were used for this study. The compound cores were made by bonding 300milli darcy Berea sandstone and Catoosa shale were bonded to the cement respectively to form a compound core. The nature of the bond between the cement and the formation was duplicated. The method used is standard for future investigation into the effect of drilling fluid contamination on cement formation of shear bond strength in an oil well. The effect of both physical and chemical mud contamination in sand stone and shale formations has been investigated. Physical mud contamination impacts more negatively on the cement-formation bond strength.

The presence of mud cake at the interconnection causes harm to cement-formation bond in the oil well. The calculated bond strength was maximum 1723.69kpa for sandstone-cement compound cores and minimum 475.74kpa for the shale-cement composite core. Failure of the bond happens at the interconnection between the cement and the formation when applied load exceeds the tensile strength at that interface. Therefore the nature of bond between cement formation is strongly dependent on the characteristics of the interface in the oil well.

V. RECOMMENDATION

In the drilling of an oil well, Properties such as depth, temperature, pressure, drilling fluid and cementation influences the operations and function of an oil well. All operations performed must be considered as critical and accomplished, taking into account the issues of safety and in accordance with international and local regulations.

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