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A Comparative Study of the Rheological Properties of Class G Cement Sheath in Niger Delta

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ABSTRACT: *Cement sheath is considered a Well barrier because it prevents the unintentional and uncontrollable flow of fluids (either fluids or gases) from a formation into another formation or back to the surface. A lot of research has been conducted with regards to the mechanical durability of the wellbore cement sheath. These researches are classified into two major groups:*

a. Experimental lab techniques
b. Modelling methods (Finite element analysis)

or previous set casing. When the cement slurry hardens and sets, it creates a seal such that it isolates the well flow from unwanted formation fluids while permanently positioning the casing in place. The cement sheath is a crucial element in sustaining well integrity.
The cement failure is usually due to the stress on the cement sheath being greater than its yield strength**.** These are various mechanical factors that control the failure of the cement sheath in this system:

- Cement compressive strength
- Young's modulus
- Tensile strength
- Bond strength
- Loading conditions (in-situ stresses)
- Cement history (shrinkage)
- Wellbore architecture: cement sheath eccentricity and diameter, formation properties, wellbore trajectory

The failure of the cement sheath can either be due to shear and compressional stresses. These stress conditions can be due to radial loads, high pressures within the cement sheath and tectonic movement of the formation.When the stress conditions above are present in the wellbore, the set cement can fail either by:

- Radial circumferential cracking of the cement matrix
- Breakdown of bonds in the Casing-Cement Sheath-Formation system

Ghazbeloo et al. 2008 [1] performed lab test on a Class G cement under temperature and pressure. He observed creep effect under isotropic loading at high stresses and permanent strains on the cement during unloading, due to the heterogeneity of the cement. This is characteristic of cement micro cracking. Bois et al. 2012 [2] conducted and experiment to check when the cement-sheath integrity loss occurred. He observed that at the maximum ICP, no integrity loss but upon decrease of ICP loss of integrity occurred

Kiu Liu et al, 2018 [3] analyze the stress of cement sheath in horizontal shale gas wells by considering the location of the casing in the wells. He observed that for centered casing the tensile failure of the cement sheath occurred first at the inner wall of the cement sheath and for off-centered casing, the failure of the cement sheath was at a much lower external load. J. De Andrade et al, 2015 [4] assessed the mechanisms by which the cement sheath fails for realistic wellbore curing and operating conditions. He observed that cement hydraulic pressure provided a superior cement job than for previous cemented samples with no hydraulic pressure.

The purpose of primary cementing, when an annular cement sheath is placed around a casing or liner, is to provide mechanical stability to the well and to prevent fluids from flowing from one geological zone to another or up to the surface (zonal isolation). This zonal isolation, which is important with respect to well integrity, should last throughout the well's life cycle including the abandonment phase. The long-term sealing ability of annular cement is, however, difficult to maintain – and this is one of the reasons for why many wells develop annular pressure problems as they age. Goodwin and Crook, 1992 [5], conducted an experimental work to study the effect of pressure tests and high flowing temperature on cement sheath failure. The development of radial cracks as failure mode was part of their main observations.

It is vital that that set cement material behavior and the coupled behavior of casing, cement and formation should be more fully studied and analyzed. This is because there is increasing awareness of problems associated with cement sheath failure and subsequent loss of zonal isolation or sustained casing pressure have demanded that rational engineering decisions be made.

II. Equipment and processes

The cement compositions used for this study was obtained from an operational service company in the Niger Delta. The cement slurry used for production section of the well had their water cement ratio varied, and then rheology and mechanical properties investigated in a fluids lab.

Table 2: Cement slurry composition

Cement System	System 1	System 2	System 3
Density (ppg)	14.19	14.89	15.75
Water-cement ratio	0.6	0.5	0.4
Cement Type	Class G	Class G	Class G
Seawater %bwoc	0.4	0.4	0.4
Antifoam %bwoc	0.0044	0.0044	0.0044
Gasblok %bwoc	0.04	0.04	0.04
Dispersant %bwoc	0.01	0.01	0.01
Retarder %bwoc	0.18	0.18	0.18

The tests carried out on the cement systems include standard cement tests to investigate the workability of the cement, the following tests were carried out:

- Cement slurry density – measured with a pressurized mud balance

- Compressive strength – measured with an Ultrasonic Cement Analyser
- API rheology (Yield point/Plastic viscosity) – measured with a Fann Viscometer
- Free fluid tests
- Thickening time
- API static gel strength
- Shrinkage test

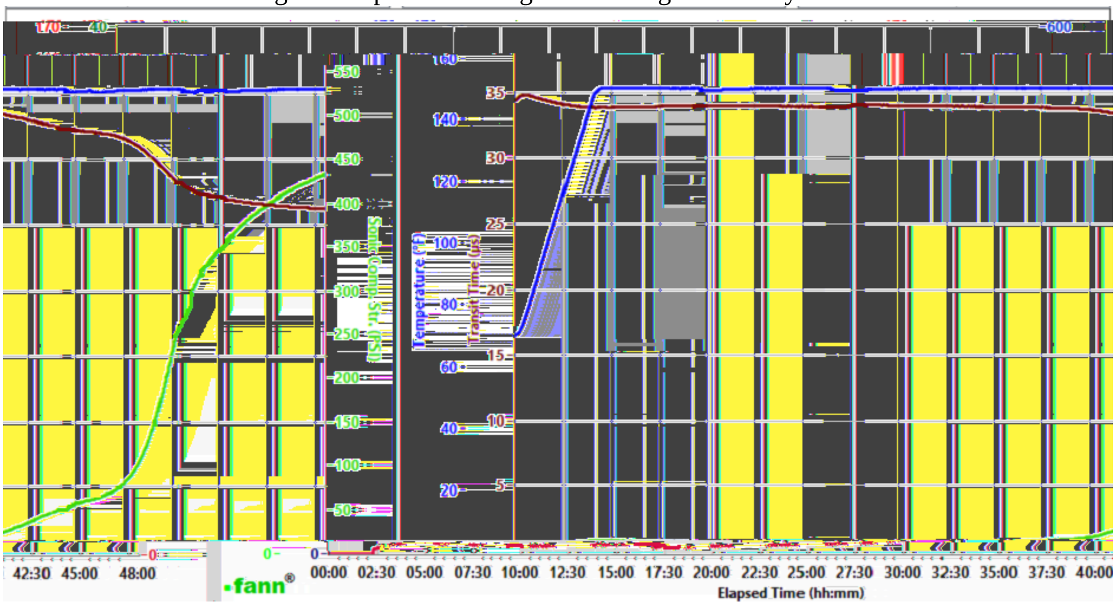
2.1 Slurry with water/cement ratio of 0.6

- Cement Slurry Density – 14.19 ppg
- UCA Compressive strength: At a temperature of 150°F and a pressure of 3000 psi (wellbore conditions

Table 3: Table of compressive strength at different curing time for system 1

Time (hr)	8	12	16	24	48
CS (psi)	7	9	11	11	432

Fig 3: Compressive strength vs. Curing time for System 1



- API rheology (Yield point/Plastic viscosity)

Table 4: Table of Yield point and Plastic viscosity for System

	Ramp	600rpm	300rpm	200rpm	100rpm	6rpm	3rpm	PV	YP
Surface @80 °F	Up		12	10	6	4	4	9	3
	Down	22		10	6	4	4		
Downhole @ 150 °F	Up		10	8	6	4	4	6	4
	Down	14		8	6	4	4		

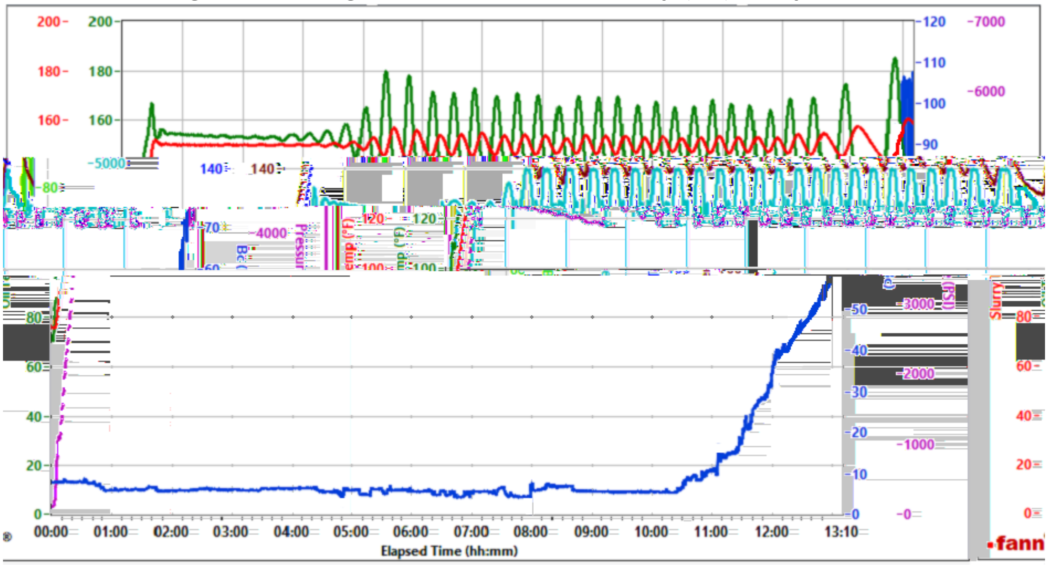
- Free fluid test: There was no free fluid observed

- Thickening time: At a pressure of 4500psi, temperature of 150°F and heating time of 28 mins

Table 5: Table of thickening time at surface and downhole conditions for System 1

TIME	11h:55m	12h:04m	12h:20m	13h:01m	13h:05m
BC	30	40	50	70	100

Fig 4: Thickening time vs. Bearden consistency (BC) for System 1



- API static gel strength

Table 6: Table of gel strengths for System 1

10 sec gel strength	4
10 mins gel strength	4

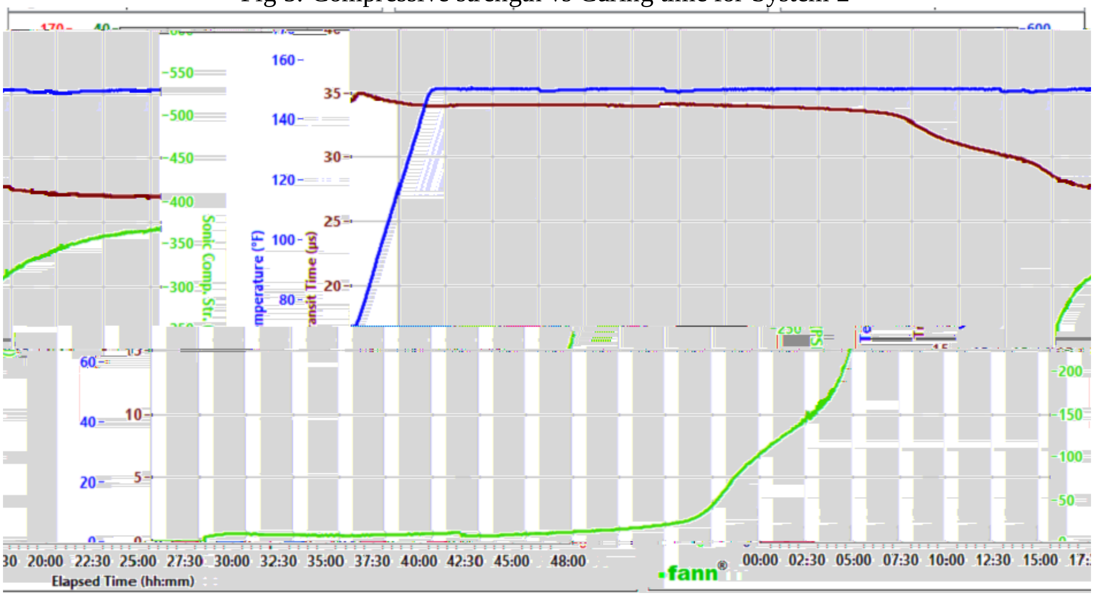
2.2 Slurry with water/cement ratio of 0.5

- Cement Slurry Density – **14.89 ppg**
- UCA Compressive strength: At a temperature of 150°F and a pressure of 3000 psi

Table 7: Table of compressive strength at different curing time for System 2

Time (hr)	8	12	16	24	48
CS (psi)	8	8	10	13	367

Fig 5: Compressive strength vs Curing time for System 2



- API rheology (Yield point/Plastic viscosity)

Table 8: Table of Yield point and Plastic viscosity at surface and down-hole conditions for System 2

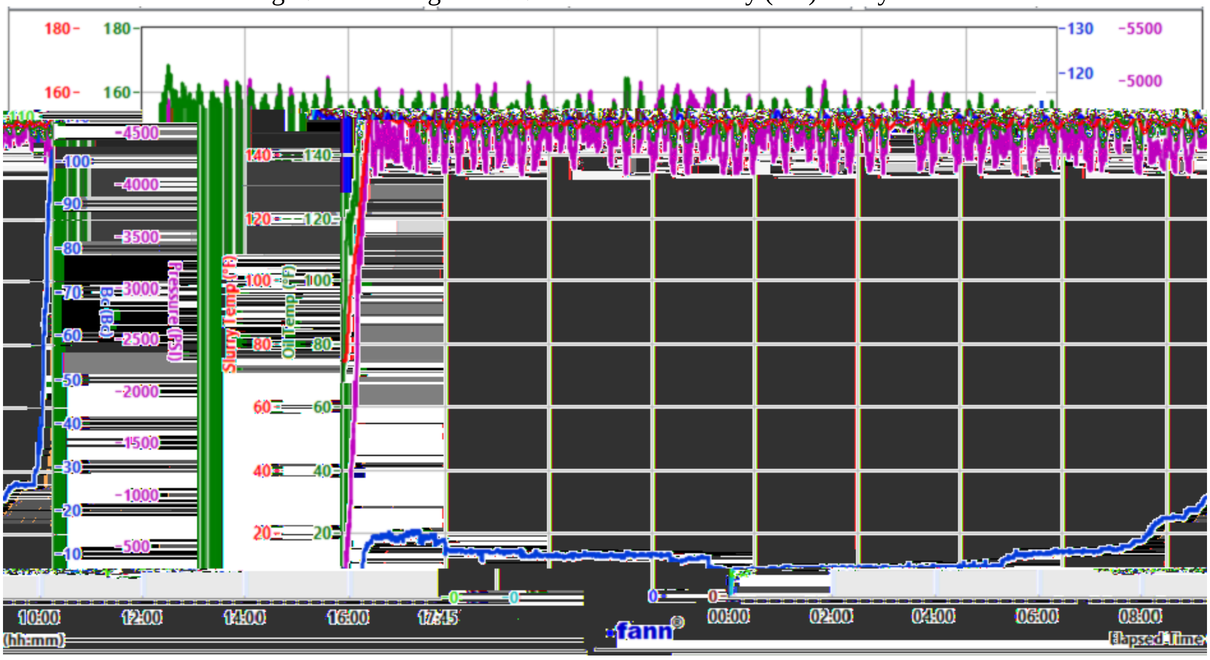
	Ramp	600rpm	300rpm	200rpm	100rpm	6rpm	3rpm	PV	YP
Surface @80 °F	Up		20	12	6	4	2	19.5	0.5
	Down	32		12	8	4	2		
Downhole @ 150 °F	Up		8	6	4	2	2	6	2
	Down	20		6	4	2	2		

- Free fluid test: There was no free fluid observed
- Thickening time: At a pressure of 4500psi, temperature of 150°F and heating time of 28 mins

Table 9: Table of thickening time at surface and downhole conditions for System 2

TIME	17h:27m	17h:32m	17h:33m	17h:38m	17h:43m
BC	30	40	50	70	100

Fig 6: Thickening time vs. Bearden consistency (BC) for System 2



- **API static gel strength**

Table 10: Table of gel strengths for System 2

10 sec gel strength	4
10 mins gel strength	12

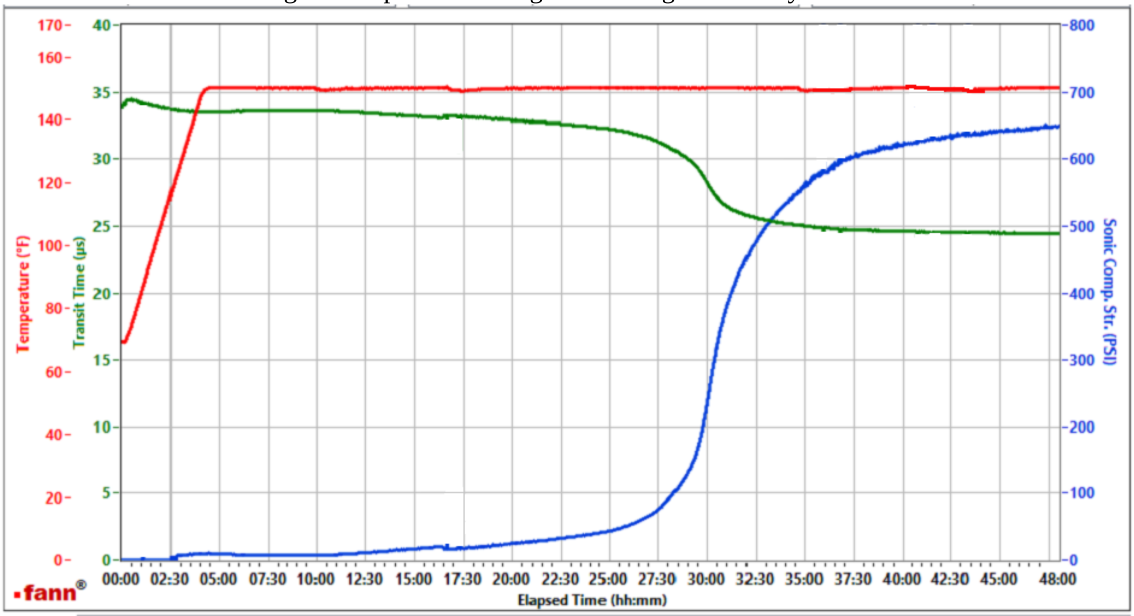
2.3 Slurry with water/cement ratio of 0.4

- Cement Slurry Density – **15.75 ppg**
- UCA Compressive strength: At a temperature of 150°F and a pressure of 3000 psi

Table 11: Table of compressive strength at different curing time for system 3

Time (hr)	8	12	16	24	48
CS (psi)	7	10	19	39	649

Fig 7: Compressive strength vs Curing time for System 3



- API rheology (Yield point/Plastic viscosity)

Table 12: Table of Yield point and Plastic viscosity for System 3

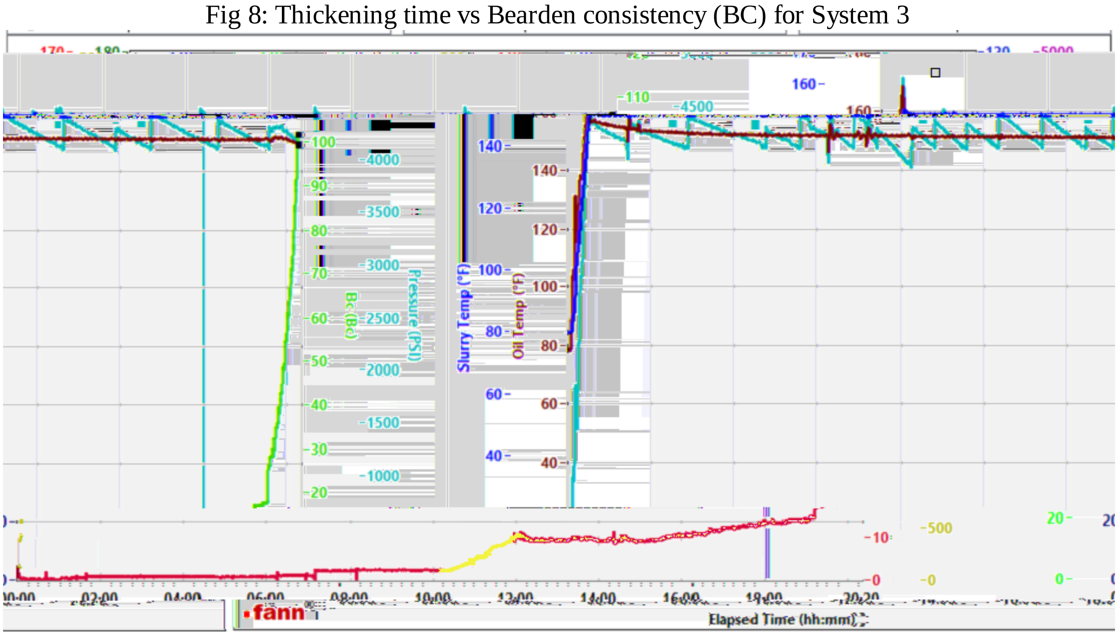
	Ramp	600rpm	300rpm	200rpm	100rpm	6rpm	3rpm	PV	YP
Surface @80 °F	Up		28	20	12	4	2	24	4
	Down	56		20	12	4	2		
Downhole @ 150 °F	Up		19	14	8	2	2	15	3
	Down	36		14	8	2	2		

- Free fluid test: There was no free fluid observed
- Thickening time: At a pressure of 4500psi, temperature of 150°F and heating time of 28 mins

Table 13: Table of thickening time at surface and downhole conditions for System 3

TIME	19h:40m	19h:49m	19h:57m	20h:06m	20h:16m
BC	30	40	50	70	100

Fig 8: Thickening time vs Bearden consistency (BC) for System 3



- API static gel strength

Table 14: Table of gel strengths for System 3

10 sec gel strength	4
10 mins gel strength	16

TIME @ 50 BC	19H:57M	17H:33M	12H:20M
TIME @ 70 BC	20H:06M	17H:38M	13H:01M
TIME @ 100 BC	20H:16M	17H:43M	13H:05M

- The cement gel strength is a physical property that measures the transition of the cement slurry from the fluid to solid phase. It is an indicator of attractive forces that exists between the particles in the mixture. When water is mixed with cement, a hydration reaction occurs resulting in a cement gel. This cement gel is responsible for the strength and binding in the cement structure. According to API standards, it is measured at 10 seconds and 10 minutes. Furthermore, the gel strength developed and the speed at which it occurs is used by service companies to measure a slurry's ability to resist gas intrusion and develop mitigative strategies when operating in high-risk formations. A lower water content results in higher gel strength.

Table 20: summary of gel strength values for the 3 different cement systems

Water-cement ratio	**0.4**	**0.5**	**0.6**
10 sec gel strength (lbf/100ft^2)	4	4	4
10 mins gel strength (lbf/100ft^2)	16	12	4

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