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Research Article

Laboratory Investigation on Performance of Cement Using Different Additives Schemes to Improve Early Age Compressive Strength

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Abstract: It is essential to maintain the oil well cement integrity effectively and economically. The classical literature review of cement slurry preparation has shown high temperature in wellbore has influenced the mechanical properties of cement slurry, especially compressive strength. The compressive strength is the most important parameter when the ability of the cement to perform its necessary functions of down-hole faster placement analyzed. In past, the different additives were used to improve the performance of cement slurry by maintain compressive strength during placement. Laboratory tests carry out by Silica Fume (SF) with dispersants and fluid loss control additives at different concentrations to performed early age compressive test of nondestructive cement slurry through Ultra-Sonic Cement Analyzer (UCA). Measured result showed that 6:34 and 7:48 h aged sample have a maximum compressive strength at temperature above 120°C. It is observed that as concentration of SF increased with combined dispersants and fluid loss additives used to control& enhance compressive strength at above 120°C for the integrity of cement slurry.

Keywords: Additives, compressive strength, Silica Fume

INTRODUCTION

The Ultra Sonic Cement Analyzer (UCA) method is used to measure the early development of compressive strength under down-hole condition. Relative strength of energy is analyzed by the variation in the form of velocity of an ultrasonic signal moving through the sample of cement slurry. In NDT test increase the strength of cement slurry with decrease the transmit signal time through slurry (Carrión *et al*., 2011).

Petroleum industry believes on two type of compressive strength for durability and stability of the oil wells. First is the early compressive strength (CS), it is defined as the development of early CS of cement slurry is the positive sign to achieve zonal isolation and provide tabular support to the casing.

Secondly for long term Compressive Strength (CS) of cement slurry became harden and provide stability for many years with full of production without any remedy operation (Labibzadeh *et al*., 2010; Bois, 2012).

Design of cement slurry for developing high early age CS for oil well cement is the first priority for oil well cement (Gino di and Phil, 2000). The recommendation practices according to API specification prepared cement slurry for oil well require minimum strength for any well bore operation is 500 psi in 24 h at Bottom hole static temperature. Also minimum 500 psi for 8 h and 1000 psi for 24 h (Samsuri and Yeo, 2000).

In oil wells Long term stability and early compressive strength development in cement slurry design will be based on Bottom Hole Static Temperature (BHST). For the deep well where temperature condition will be varies with respect to depth as depth increase temperature will be increase and differential condition will be counted to top to bottom and sensitivity will increase for the stability of cement slurry (Shahri, 2005).

The design cement slurry for high early age compressive strength is utmost objective for oil wells (Gino di and Phil, 2000).

Acquiring early age CS will be ensure structural support and stability for long term to the casing and zonal isolation from unwanted fluids (Shahri, 2005).

Prepares cement slurry is used to pumped down to the oil well for casing cementing during this processes slurry behavior will be change from liquid to solid condition or transitional condition where slurry became gel and fluid state to moving to hydrostatic through cement slurry load; due to expansion and reduce pressure of pumping cement slurry static gel strength will occur.

The condition of transitional phase is very maze and critical because slurry is going to support it-self and does not transfer load for hydrostatic pressure so longer transition phase require more time for decrease volume of cement slurries (Johnstone *et al*., 2006).

Longer transitional time for cement slurry may cause of gas leakage or gas migration due to in

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competent of slurry performance, gas migration can be prevented by speed up the slurry from liquid phase to solid phase by using highly efficient slurry to develop early age compressive strength (Perenco, 2010).

Beginning time of cement slurry placing is very crucial because the time is Wait on Cement (WOC) time that compressive strength going to develop before when gel strength is begins to development end (Sabins and Sutton, 1986).

The simply it require WOC time to get minimum compressive strength development 500 psi (3.45) MPa according to API specification to prevent from drilling shocks (Pedam, 2007).

WOC time is very important to become harden and quickly to start further operation; if it takes abeyance then drilling rig will sit idle till cement slurry harden (Perenco, 2010; Al-Yami *et al*., 2007).

For long term durability and stability of cement slurry is very important in point view of compressive strength related with early age CS.

High strength slurry will provide tubular and vertical support to the casing string and prevent from unwanted fluid into the formation, also protect from external pressure and thermal loads during drilling operation (Asadi, 1983).

GENERAL DESCRIPTION OF SILICA FUME (SF)

Silica fume use as a cement slurry additive to reduce the density of cement and increase it is Cement slurry performance and, decreases hydrostatic pressure during drilling; in oil well cementing mixture used as primary source as a hydraulic seal in the well bore and function as secondary application (Memon *et al*., 2013).

It is also used such a way for remedial operations including depleted zone closing, splits and leaks repair. The increment of silica fume allows a well to reach full production potential besides producing a blocking effect in the oil well. It is also responsible for prevent gas migration and highly effective to enhanced flow for easier, proper placement and decrease permeability for better control of weak zones (Siddique and Khan, 2011).

It helps to improve the integrity of primary cementing in oil and gas wells. The use of silica fumes in low and depleted reservoirs it prevents loss circulation resulting from the failure of weak zones. In addition, the number of steps needed to cement the well may reduce chances of failure (Shadizadeh *et al*., 2010).

In addition, the number of steps needed to cement the well may reduce chances of failure. Silica Fume (SF) use as extender to reduce the quantity of cement and required amount to produce effective output during cementing operation; ultimately result of a greater economy (Memon *et al*., 2013; Siddique and Khan, 2011).

Different types of cement extenders are used as the additives, such as bentonite, cement, pozzolan, microspheres and foam are use as Lightweight cement slurry (Mueller *et al*., 1991). Silica can be used as an extender allows a mixture of 0.532 gallons (2.01 L) to serve Water per pound of silica fume (4.4 mL water/g) of silica was added to the slurry (Siddique and Khan, 2011).

SF is frequently referred to by other names such as, condensed silica, micro silica and volatilized silica. Commonly silica fume is available and cost-effective, due to presence of amorphous silica is composed of 58 to 95% Sio_2. The particles are very fine having (95% Sio_2 of less than 1 μm) and thus act as micro filler set in cement Micro-structure and pozzolanic reaction with the free lime in Solid response to natural temperature so thus substance imparts as much progress increase to physical and mechanical properties in Portland cements (Al-Suwaidi *et al*., 2008).

A contribution chemicals with silica fume high amorphous because silicon dioxide SF is very reactive pozzolanic in concrete and Portland cement in begin concrete react chemically, it release calcium hydroxide to form this interaction additional material binder called calcium hydrate silicates that gives SF concrete characteristics improved stiffness (Mueller *et al*., 1991).

It is recommended that silica fume is highly control effect towards gas migration as additive use, If the static gel strength of cement slurry rapidly from 100 $lb/l00ft^2$ to 500 $lb/l00ft^2$ that often cement transition taken place rapidly, so it is seen as desirable, and favorable to control gas migration (Mueller *et al*., 1991; Golapudi *et al*., 1993).

A key element in the design with high-purity amorphous silica cement, which produces and controls the tight gas (Golapudi *et al*., 1993).

For the stability of the Cement-Slurry-Density (CSD) and increase the concentration of silica fume it improves stress resistance in the early development and reduces the water for free, but it increases the viscosity of the cement slurry a little bit (Temiz and Karakeci, 2002).

The mixing of silica fume into cement several optimum conditions is noticed:

- Absorb more water of SF proves it to function as an extender and a pozzolan substitute for lightweight cements.
- Sufficient amount of water increased pozzolanic reactivity promotes enhanced compressive strengths.
- The strength and solubility of the material makes it suitable for combating strength retrogression in cements at temperatures above 230°F (110°C), improve the properties to reduce the loss of fluid and enhance stability (Mueller *et al*., 1991; Grinrod *et al*., 1988).

The hardened cement-micro silica better bond strength reduced permeability, improved durability and reduced less strength retrogression (Grinrod *et al*., 1988).

Silica fume particles in the filter cake to decrease the loss of fluid permeability of the formation, Particle size of silica fume is very small (less than 0.5 microns) and thus can result filter cake between the cement particles and mitigate the entry of a narrow path of fluids and finally decrease permeability of the cement slurry and enhanced Water Cement Ratio (WCR) improve the permeability which allow to increase the performance of cement slurry (Shahriar, 2011; Shadizadeh *et al*., 2010).

LITERATURE REVIEW

Inspection of oil well cement slurry performance is a great task for researchers to using different additive schemes to enhance slurry for long term and its direct impression goes toward integrity of cement slurry. Some researchers have been focused to their research on water and additives to analysis a mechanical properties inside the bottom hole of oil wells without considering the effect of temperature and pressure (Dahab and Omar, 1989). Prepared cement slurry mixing with sea water, fresh water and distilled water, their research deduced that cement slurry prepared by sea water showed more compressive strength than fresh water and distilled water. They also analysis the effect of additives such as bentonite, calcium chloride and lignosulfonate on cement slurry; that used certain level of concentration of each additives for compressive strength as it is increase with increasing curing time and additive concentrations increase (Grinrod *et al*., 1988; Shahriar, 2011; Shadizadeh *et al*., 2010).

The effect of long term curing time to compressive strength for the condition on cement to see the effect of water, salt water and crude oil; first mold with fresh and second mold with salted water as a curing fluid. The first mold test observed on an age for six month no significant changes found for compressive strength but after one year strength is going to start slowly to reduce. The result found from second mold contains salt water slurry which curing fluid it was replaced to every four month. Showed in first four months compressive strength is remain same to the condition that curing fluid was not change; after the age of sample four month its strength reduced again after one year see the compressive strength about 50%; but in third case unlike it was illustrated that compressive strength remain stable over a time due to absence of acidic compound in the crude oil (Lécolier *et al*., 2007).

The effect of temperature and concentrations is observed in HTHP environment has been compare four various compound behavior on class G cement slurry at 120, 140, 180°C, respectively. The effect is observed by silica sand with and without at above mentioned temperature ranges, it was found that without concentration of silica the compressive strength was low and with silica sand concentrations strength is high with addition of silica sand to improve the strength in HTHP environment (Noik *et al*., 1999).

The effect of fly ash was observed on cement slurry at 20°C temperature and atmospheric pressure cause in reduction in 28 and 91 days compressive strengths, for strength and durability with reference grout material (Mirza *et al*., 2002).

The strength and durability is observed by combination of pressure temperature that observed cement slurry containing hollow ceramic spheres was cured for one year at 149°C the strength reading is observed 20.7 MPa the sample has been decline in strength. The maximum reading was observed in one week the reading was 7.19 MPa, after a year of curing decreased to reduce the strength 7.3 MPa; the combination of this act of strength is reduced 81% in curing all most a year at 149°C (Jennings, 2005). The light weight cement slurry has been tested for enhance the performance in weak zone and for long term stability, slurry was prepared in class G cement with combination of crystalline silica, hollow glass microspheres; slurry was cured to enhance cement strength and finally using combination of additives to achieve reliable strength at 127°C at final strength was obtained 9.94 MPa which was significantly higher value then API recommended practice 10B 3.45 MPa is sufficient strength to hold casing pressure (Al-Yami *et al*., 2008).

Cement slurry design: Prepared cement slurry in G class with additives and distilled water according to API specification (Standard and All, 2005). In oil industry there are eight classes of A through H used according to depth requirement (Nelson and Guillot, 2006).

Oil well drilling; cementing and completion is very expensive job, over hundred million dollars spend to run such projects. It is essentially to require premium quality of cement slurry that with stand in any environment without any work over or remedial cement operation.

If the cement slurry lost its integrity than millions of dollars lost, so cement slurry should be design according to bottom-hole condition to sustained down-hole loads.

The condition of designing cement slurry at small scale testing after success it will implement on large scale that is field for integrity of cement various parameters should be follow (Ravi *et al*., 2004).

Slurry design with combination of dispersants and fluid loss control additives mix into silica fume at 15, 17, 19 and 21%, respectively for the enhance cement performance.

Experimental procedure for measuring compressive strength: The Compressive Strength (CS) test is performed by Ultrasonic Cement Analyzer (UCA) it is provide an indication of the relative strength development in a cement slurry sample while it is being cured under down-hole temperature and pressure conditions (Rao and Sutton, 1981; Rao *et al*., 1982).

Fig. 1: UCA model 2000

The model 2000 Ultra sonic Cement Analyzer (UCA) having system pressure up to 10000 psig/680 bar and temperature ranges can be cover up to 204°C; the UCA transmits an ultrasonic pulse through a cement slurry and measure the travel time of the pulse through the slurry (Nelson and Guillot, 2006).

The travel time of the pulse through the slurry given an indication of the compressive strength of the slurry, the compressive strength with temperature and pressure are monitored as a function of time for the purpose of providing a strength history of setting cement slurry (Carrión *et al*., 2011).

The relative strength is determined by measuring the change in velocity of an ultrasonic signal transmitted through the cement slurry one of the main advantages of non-destructive testing only a sample of slurry is required to measure compressive-strength development history at initial set of the cement condition to the final slurry profile (Standard and All, 2005; Nelson and Guillot, 2006).

Non-Destructive Cement Test (NDCT) design is based on; the transmission characteristics of ultrasonic compressional waves through cement slurries; in a principle, to analyzer measures the transit time (reciprocal of velocity) of an ultrasonic wave pulse through a slurry sample, converts it to apparent compressive strength and records the results continuously; The proper method is used to measuring cement slurry according to API specification (Standard and All, 2005) (Fig.1).

RESULTS AND DISCUSSION

Early age compressive strength at SF-15%: For the measuring property of early age compressive strength reading taken from slurry density 13-PPG at 15% SF with 0.31% dispersant and 1% fluid loss. The combination of additives gives immense readings of cement rheology for further measurements (Fig. 2).

Curing condition at 34.47 MPa (5000 psi) and temperature 121°C: The result of UCA indicated that minimum Gel Strength (GS) achieved at 4:21:30 of 0.34 MPa (50 Psi). According to API specification to obtain early compressive strength is overtaken (500 psi) (3.4 MPa) in 9:40:00. The final strength is achieved 3.86 MPA (850 Psi) in 15:00:00.

Then UCA test start it observed after four hour test running the strength curve fluctuated till first minimum strength 50 psi obtained, and then strength curve is stable and move linearly to overtaken early compressive strength 500 psi, in almost nine hours. After early compressive the strength curve is going to unsteady till end of final strength in fifteen hours. It is found that at 15% SF with combination of additives; decrease its strength due to the SF% and additives concentration which is not valuable for high temperature condition.

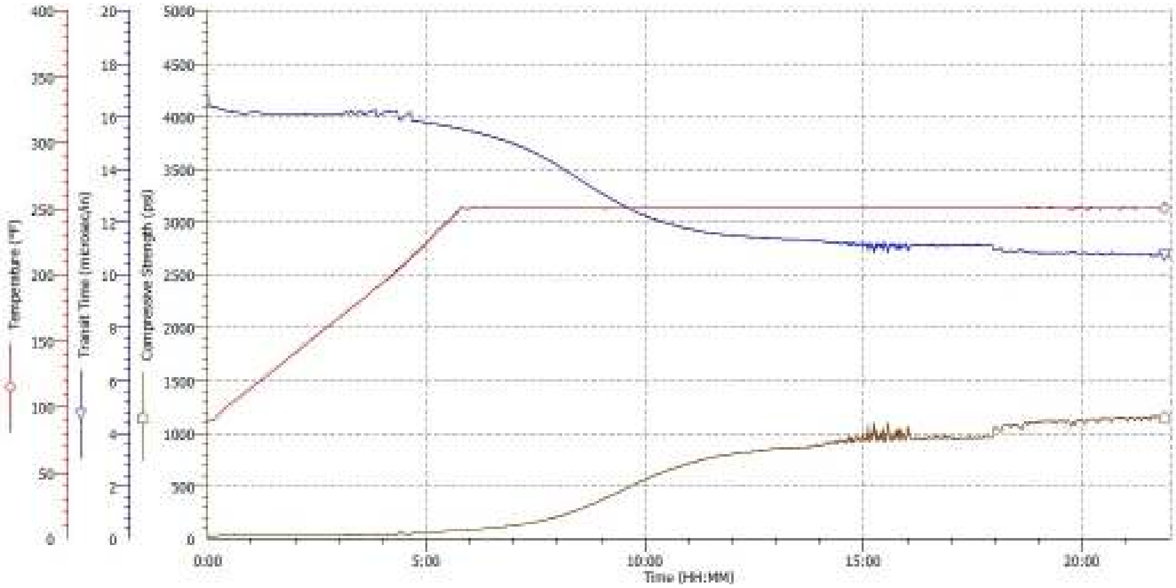

Fig. 2: 15% SF with 1% FL-66L and 0.31% CD-33L

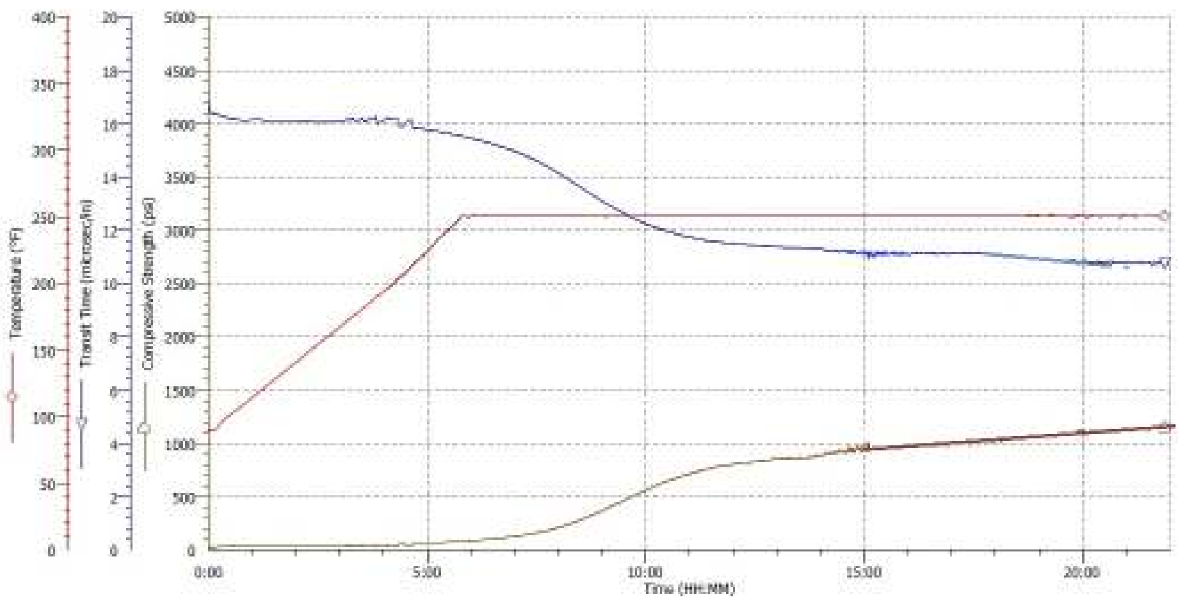

Fig. 3: 17% BWOC Silica Fume

Early age compressive strength at SF-17% BWOC: For the measuring property of early age compressive strength reading taken from slurry density 13 ppg at 17% BWOC SF with 0.31 Wt% dispersant and 1% fluid loss control additives; the combination of additives provides stable readings of cement rheology for further measurements (Fig. 3).

Curing condition at 34.47 MPa (5000 psi) and temperature 121°C: The result of UCA indicated that minimum Gel Strength (GS) achieved at 4:21:30 of 0.34 MPa (50 Psi). According to API specification to obtain early compressive strength is overtaken (500 psi) (3.4 MPa) in 9:40:00.The final strength is achieved 3.86 MPA (850 Psi) in 15:00:00.

Then UCA test start it observed after four hour test running the strength curve improve continually without any interruption as mentioned in 15% BWOC SF with additives concentration. Minimum strength 50 psi obtained, and strength curve move linearly to overtaken early compressive strength 500 psi, in almost nine hours. After early compressive the strength curve is going to unsteady till end of final strength in fifteen hours. It is found that at 17% SF with combination of additives; enhance its strength at high temperature condition.

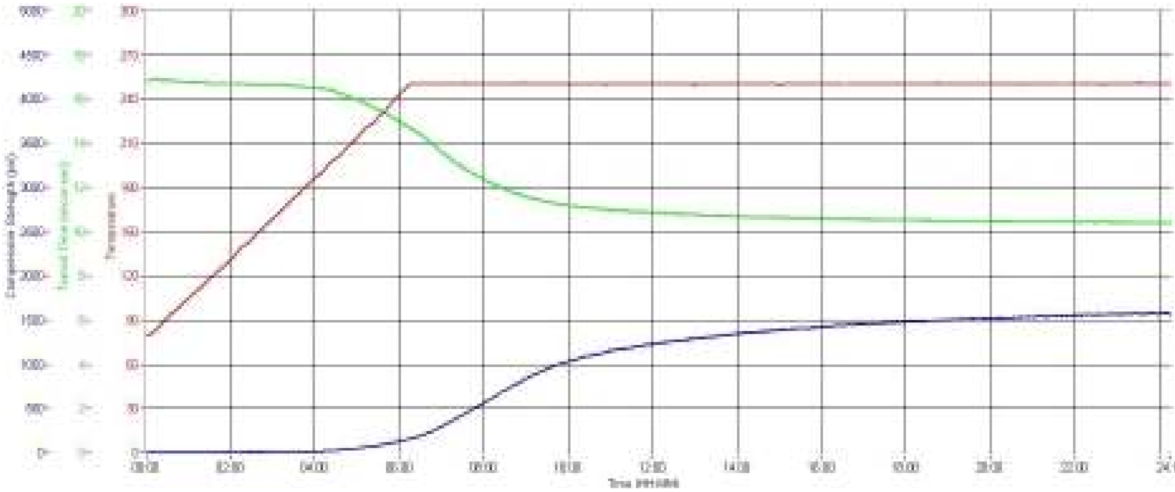

Fig. 4: 19% BWOC Silica Fume

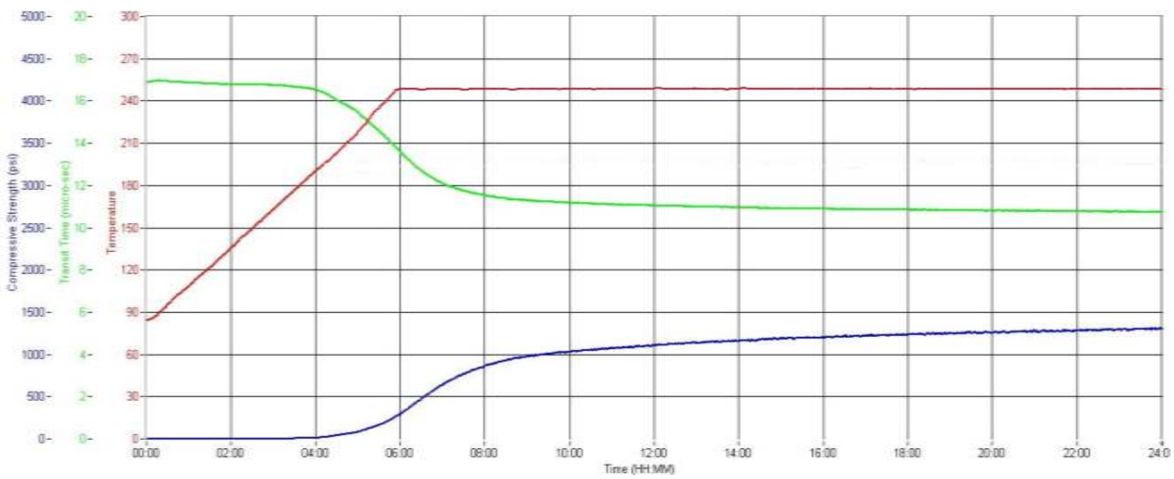

Fig. 5: 21% Silica Fume

Early age compressive strength at SF-19% BWOC: For the measuring property of early age compressive strength reading taken from slurry density 13 ppg at 19% BWOC SF with 0.31% dispersant and 1% fluid loss control additives; the combination of additives gives appropriate readings of cement rheology for further measurements; it is observed concentration increase provide vital effect to the strength and durability (Fig. 4).

Curing condition at 34.47 MPa (5000 psi) and temperature 121°C: The result of UCA indicated that minimum Gel Strength (GS) achieved at 5:04:00 of 0.34 MPa (50 Psi).According to API specification to obtained early compressive strength is overtaken (500 psi) (3.4 MPa) in 7:48:00.

The maximum compressive strength is overtaken (1300 Psi) (8.96 MPa) in 24:00:00.

The result is observed that early compressive strength develop is taken in more than seven hours. The using of 19% BWOC SF and combined additive dosage. In this condition not obtained early compressive strength due to inappropriate rheological properties, so this condition is not suitable for HTHP environment. The final strength is also observed that it is ongoing uniformly no change in condition. According to API specification to achieve the early compressive in short time that will promote to durability and long term integrity of the well to sustain well bore pressure.

Early age compressive strength at SF-21% BWOC: For the measuring property of early age compressive strength reading taken from slurry density 13-PPG at 19% BWOC SF with 0.31 Wt% dispersant and 1 Wt% fluid loss control additives; the combination of additives gives more immense readings of cement rheology for the measurements of strength (Fig. 5).

Curing condition at 34.47 MPa (5000 psi) and temperature 121°C: The result of UCA indicated that minimum Gel Strength (GS) achieved at 4:37:00 of

0.34 MPa (50 Psi). According to API specification to obtained early compressive strength is overtaken (500 psi) (3.4 MPa) in 6:34:00.

The maximum compressive strength is overtaken (1500 Psi) (10.34MPa) in 24:00:00.

The result indicated that the early compressive strength develop more rapidly than pervious results, in this condition the strength develop due to increase the concentration of silica fume (SF) with combination of additives to enhance the performance of slurry.

This concentration of SF with additives formulation is very helpful for deep environment to sustain the stability and prevent from strength retrogression.

CONCLUSION

- Silica fume has a singular effect for the improving cement slurry and set cement properties, such as decreasing fluid loss, increasing compressive strength and sufficiently decreasing cement slurry permeability.
- Faster development of early age compressive strength reduce the transitional time, at using SF 21% BWOC with combination of additive showing optimum strength to sustain down-hole loads.
- Light weight cement slurry will be helpful in week and unconsolidated formation also prevent from gas migration.

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