WHIPSTOCK PLUG SLURRY DESIGNS OVER A WIDE RANGE OF TEMPERATURE EXTREMES

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ABSTRACT

Whipstock plugs provide an essential tool for deviating from the primary hole direction to sidetrack an impenetrable object such as drill pipe or a bit, or initiate a planned hole deviation to complete a lateral or multilateral hole. The successful setting of whipstock plugs and the completion of the sidetrack operations can be very intricate, complicated by high slurry densities, high viscosities, and very low to very high bottom hole temperature extremes where costs escalate with each attempt.

The whipstock slurry design should balance the requirement for adequate thickening time with the minimum time necessary to develop sufficient compressive strength for "dress-off" and "kick-off" and the rheological characteristics suitable for mixing and placement. In addition compressive strength should not deteriorate or retrogress during the time necessary for dress-off and drill-out.

This paper will discuss the specific design of whipstock slurries applicable in a wide range of temperatures from 80F to 299^o F.

INTRODUCTION

The successful application of whipstock plugs have been inherently difficult and costly due to many variables that include the condition of the hole, depth, temperature, drilling mud type and density, high slurry density and the detrimental mixing of drilling mud and other well bore fluids with the cement slurry. Setting a whipstock plug is often complicated and problematic many times requiring different hole conditioning methods, slurry designs and placement methods from one plug to another, even where hole similarities exist. Although these techniques often vary, some common methods can be identified and successfully applied over a wide range of areas, depths and temperatures. A key to a successful whipstock plug program is identifying and systematically applying these proven methods.

"Green cement" is a term used by the industry to describe cement that did not develop adequate compressive strength for its designed purpose or for cement that did not set and/or was circulated out of the hole. Extensive testing from 1995 to 2004 on field samples of whipstock plug cements, suspected to be "green cement", has indicated that the cements when mixed at the proper density did set and did develop sufficient compressive strength for "kick-off" operations. This would indicate that the conditions that led to the plug failure were most likely realized after the cement was mixed and during or after it was pumped. Therefore, hole conditioning, placement techniques, wellbore hydrostatics and the time the cement was allowed to set prior to "kick-off" must be carefully and thoroughly examined.

PROVEN METHODS

The best slurry design has a potential to fail if it is not placed using proven hole conditioning practices and placement methods. One of the most important and commonly overlooked factors in the application of whipstock plugs is the proper conditioning of the hole. Too often, this basic process is thought to require no special treatment or design to successfully set and sidetrack a plug. This may be due in part to economics and the focus on other dynamics of the operation such as equipment needs, planning and scheduling. Notably, the slurry design, although important, cannot solely determine the success of the plug.

Proper Mud Displacement. The proper hole conditioning or displacement of the mud can significantly improve the prospect of a successful first-time placement and "kick-off " of a whipstock plug. Contamination[1] by drilling muds, displacement fluids and other down hole fluids will have a detrimental impact on the compressive strength of the slurry and other anticipated properties, by the absorption of contaminates. These contaminates include various salt brines, bentonite, barite, fluid loss additives, emulsifiers, non-emulsifiers, organics such as diesel and other solvents. The chemical impact of these contaminates are compounded by the diluting effect of the fluids which further reduce the compressive strength of the plug whereas the net result can be the failure of the plug.

A successful procedure commonly employed to displace the hole effectively of mud and contaminates is to circulate the hole with at least two full wellbore volumes. A gauge of adequate circulation is where little or no cuttings are observed in the drilling mud prior to cementing. The mud can also be conditioned to improve the mud's displacement by decreasing the yield point, where hole conditions allow.

Minimizing Contamination. Another factor that can also significantly contribute to a successful whipstock plug is minimizing the mixing of downhole fluids and subsequent contamination of the slurry after the placement of the plug. The plug can remain in liquid for several hours (or more) after placement giving it the potential to move with the differential hydrostatic forces of the wellbore fluids[1]. In the Permian Basin whipstock plugs are commonly designed and pumped at 17.0 to 18.0 pounds per gallon (ppg) whereas the drilling muds and displacing fluids are normally of a lesser density i.e., 9.0 ppg to 10.0 ppg. This provides the impetus for the commingling of the fluids to the detriment and possible failure of the whipstock plug. Some mixing of downhole fluids with the whipstock plug is predictable, should be anticipated and minimized.

An effective method to place a whipstock plug is to set the plug on the bottom of the hole where the greater weight of the plug at the bottom aids in reducing plug movement, contamination and dilution. Where this is not possible, an artificial bottom should be placed just below the plug. An example of this is in a balanced plug placement, which is one of the most common placement methods employed. The method requires circulation to be established through the placement tubulars by the cement pump which then mixes and pumps the cement slurry. A spacer is then pumped separating the slurry and drilling mud. The placement tubulars are then displaced, often with drilling mud. This method places the slurry between two columns of lighter fluids, one above and one below. Once the plug is balanced the displacing tubulars filled with cement are withdrawn from the cement slurry, pulled up-hole and circulation continued. The speed at which the placement tubulars are withdrawn from the cement slurry can directly impact the integrity of the whipstock plug and its expected compressive strength development. If the tubulars are withdrawn too quickly, a void is left in the slurry that is filled with contaminating wellbore fluids[2] rather than the slurry from the tubulars above. The differential hydrostatics[2] between the slurry and upper and lower fluids provides the wellbore dynamics for the fluids to commingle. An artificial bottom composed of viscosified mud (pill)[3] or other fluid can be placed just underneath the slurry to reduce fluid movement. The increased viscosity, gel strength and fluid friction of the viscous pill restricts the movement of the slurry until the cement hardens. Viscous pills can be composed of water based drilling muds and bentonite or other more specialized fluids.

Effective Plug Length. A 500-foot whipstock plug is recommended, where hole conditions allow, to ensure that a sufficient length of plug is set that will allow for some loss of the plug due to interfacial mixing of the slurry, drilling and displacement fluids and spacers. Although the top and bottom interfaces of the slurry may mix, the core of the plug will remain competent and provide predictable compressive strength development for the "kick-off" operation. Numerous plug failures can be attributed to plugs that were set with insufficient length to allow for the expected interfacial contamination and dilution of the slurry and the subsequent detrimental impact on compressive strength.

Downhole Tools Improve Plug Performance. Specialized hardware and downhole tools have been developed to improve the placement effectiveness and performance of whipstock plugs. These include small diameter stingers that are placed below the placement tubulars of the same length as the plug to reduce the amount of cement that is pulled from the plug when the tool is withdrawn. Diverter subs can also be used that direct the slurry upward at a 45-degree angle during pumping rather than direct it downward into the drilling fluids as by open-ended tubulars (Fig.1). Plug catchers can help by providing a positive surface indication and prevent flowback until reverse circulation is established. Plug isolation tools can eliminate the need for viscous pills or diverter plugs (Fig. 2). Mechanical plugs[1] can eliminate the need for cement whipstock plugs in the case of an extremely hard formation rock or where a short-radius "kick-off" is required. These tools should be considered in all whipstock plug applications, especially where extreme conditions are encountered.

High Compressive Strength and Low Mix Water. High compressive strength has long been associated with low mix water ratios especially in whipstock plug designs. Testing has confirmed this effect at bottom hole static temperatures (BHST) of 80^{o}F to 220^{o} F with 12-hour compressive strength in excess of 2,000 pounds per square inch (psi) and 6,000 psi in 24 hours common. Whipstock plugs in West Texas and Southeast New Mexico are normally designed between 17.0 and 18.0 ppg density. These slurries are most often composed of Class H, 1% to 1.2% cement dispersant, accelerators and retarders (where needed) and mix water ratios as low as 25.69% by weight of cement (BWOC) at 18.0 ppg. (The water ratio for an API Class H is 38.0%.)[4] A common slurry is Class H + 1.2% Dispersant mixed at 18.0 ppg and applied from 80^o F BHST surface conditions to approximately 170^o F BHST and 9,000 feet. A cement retarder is used from 170^o Fahrenheit (^{o} F) to 220^o F BHST to obtain adequate thickening times for placement.

Waiting on Cement: "Dress-Off" and "Kick-Off" Times. The complexity of the cement blend and the diversity of bottom hole temperatures (BHT) may be such that testing with an Ultra Sonic Compressive Strength Analyzer[5] (UCA) is necessary for more accurate assessment of compressive strength development and the determination of critical "dress-off" and "kick-off" times. Predetermined times are not recommended since a misjudgment may result in premature drilling and plug failure. "Dressing-off" is usually conducted at approximately 12 hours after plug placement or when sufficient compressive strength is developed. "Dressing-off" is where the top of the plug is drilled slowly until a hard plug is encountered. Once the plug is detected, the slurry is allowed to set for an additional 12 hours or when sufficient compressive strength is developed when the slurry is "kicked-off. "Kick-off" is where drilling commences until a sidetrack is achieved or the whipstock plug is drilled out. "Dress-off" and "kick-off" times should be determined for each slurry and temperature from UCA charts which indicates compressive strength as a function of time at a specific BHST (Fig 3). "Dress-off" compressive strengths routinely exceed 1,000 psi while "kick-off" compressive strengths can exceed 4,000 psi.

High Temperature Extremes and Specialized Slurry Designs at 230^o F+. Recent testing at a BHST and BHCT of 299^o F has determined several factors that directly impact the competency of a whipstock plug at such temperature extremes. Where low mix water ratios are commonplace at temperatures less than 230^o F, it was discovered that at 299^o F a water ratio exists that allows for the optimum development of compressive strength with respect to the additive chemistry and BHST (Fig. 4). Interestingly, the optimized water ratio was determined to be higher than in whipstock plugs set at less than 230^o F. The optimized mix water ratio was 39.92% BWOC where 989 psi was developed in 12 hours, 6896 psi in 24 hours, and 7256 psi in 72 hours (Fig. 3). It is important to note that a BHST and BHCT of 299^o F was used to determine the Total Thickening Time and compressive strength. The expected increase from the BHCT to the BHST that normally aids in the early development of compressive strength did not occur, which necessitated "dress-off" and "kick-off" times be exacted from UCA charts.

Strength retrogression is the loss of compressive strength due to high temperatures and is known to occur at temperatures of 230$^{o.}$ F and above[6]. Since this was thought to occur after the useful life of a whipstock plug[7], additives that prevent strength retrogression such as silica are not normally included in the slurry designs. Testing at 299^o F concluded that strength retrogression occurs within the critical first 72-hours (Fig. 3) where "dress-off" and "kick-off" operations are normally conducted and may impact the whipstock plug to the extent of failure. Testing has also concluded that 30 pounds per sack (pps) silica flour (200-mesh) is more efficient in preventing strength retrogression than 100-mesh silica sand (Fig. 3). A minimum of 30 pps silica flour should be included in slurry designs at a BHST of 230^o F or greater to prevent (early) compressive strength regression.

Adequate time should be given, where possible, for the extensive testing required for the placement of whipstock plugs at BHST's of 230^o F and greater to ensure the optimized development of compressive strength, the prevention of strength regression, and the accurate determination of the critical "dress-off" and "kick-off" times.

Final Slurry Design at 299^o F. The slurry design at 299^o F consisted of Class H + 30 pps Silica Flour + 20 pps Hematite + 1.75% Dispersant + 0.3% Free Water Control + 2% Boron Complex + 1.3% Retarder + 39.92% Mix Water mixed at 18.0 ppg density.

CONCLUSIONS

1. Mud Displacement: Displace at least two complete hole-volumes to ensure proper hole conditioning or mud displacement. As a gauge to proper hole conditioning, drill cuttings should not be observed in the mud prior to cementing operations. Use spacers to enhance the mud removal as needed. Reduce the yield point of the mud where necessary and where hole conditions allow to enhance mud removal.

2. Whipstock Plug Volume: Where possible, design whipstock plugs for least 500 foot of length to allow for the predictable contamination and dilution of the plug interfaces due to the differential hydrostatics of the wellbore fluids.
3. Whipstock Plug with a Bottom: Place the whipstock plug on the bottom of the hole where possible. Where this is not possible, such as in balanced plug operations, place a viscous pill bottom just below the cement slurry to restrict fluid movement and minimize the contamination and dilution of the plug.
4. Specialized Downhole Tools: Consider specialized tools and hardware as part of a sound whipstock program to include: (a) small diameter stingers that are placed below the placement tubulars, normally the same length as the plug, (b) diverter subs that direct the slurry and displacing fluids upward at a 45 degree angle rather than downward into the drilling fluids such as by open-ended tubulars, (c) Plug catchers that can provide a positive surface indication and prevent flowback until reverse circulation is established, (d) plug isolation tools that can eliminate the need for viscous pills or diverter plugs, (d) mechanical whipstock plugs for extremely hard or tough "kick-off" rock or where a short-radius "kick-off" is needed etc.
5. Proven Cement Slurry Designs: Consider whipstock plugs consisting of Class H + 1% to 1.2% Dispersant + Accelerators/Retarders mixed at density between 17.0 and 18.0 ppg for BHST's less than 230^{o} F.
6. "Dress-off" and "kick-off" Times: Use UCA test charts to determine the proper time to "dress-off" and "kick-off". Consider "dressing-off" when a minimum of 1,000 psi is developed and "kicking-off" when 4,000 psi is developed.
7. Strength Retrogression at 230^{o} F+: Test whipstock plugs at BHST's 230^{o} F greater to determine the optimum water requirement for maximum early compressive strength development and include a minimum of 30 pps silica flour at BHST's 230^{o} F or greater to prevent strength retrogression.
8. Slurry Design at 299^{o} F BHST: Consider Class H + 30 pps Silica Flour + 20 pps Hematite + 1.75% Dispersant + 0.3% Free Water Control + 2% Boron Complex + 1.3% Retarder + 39.92% Mix Water mixed at 18.0 ppg or similar designs for whipstock applications at 299^{o} F BHST.

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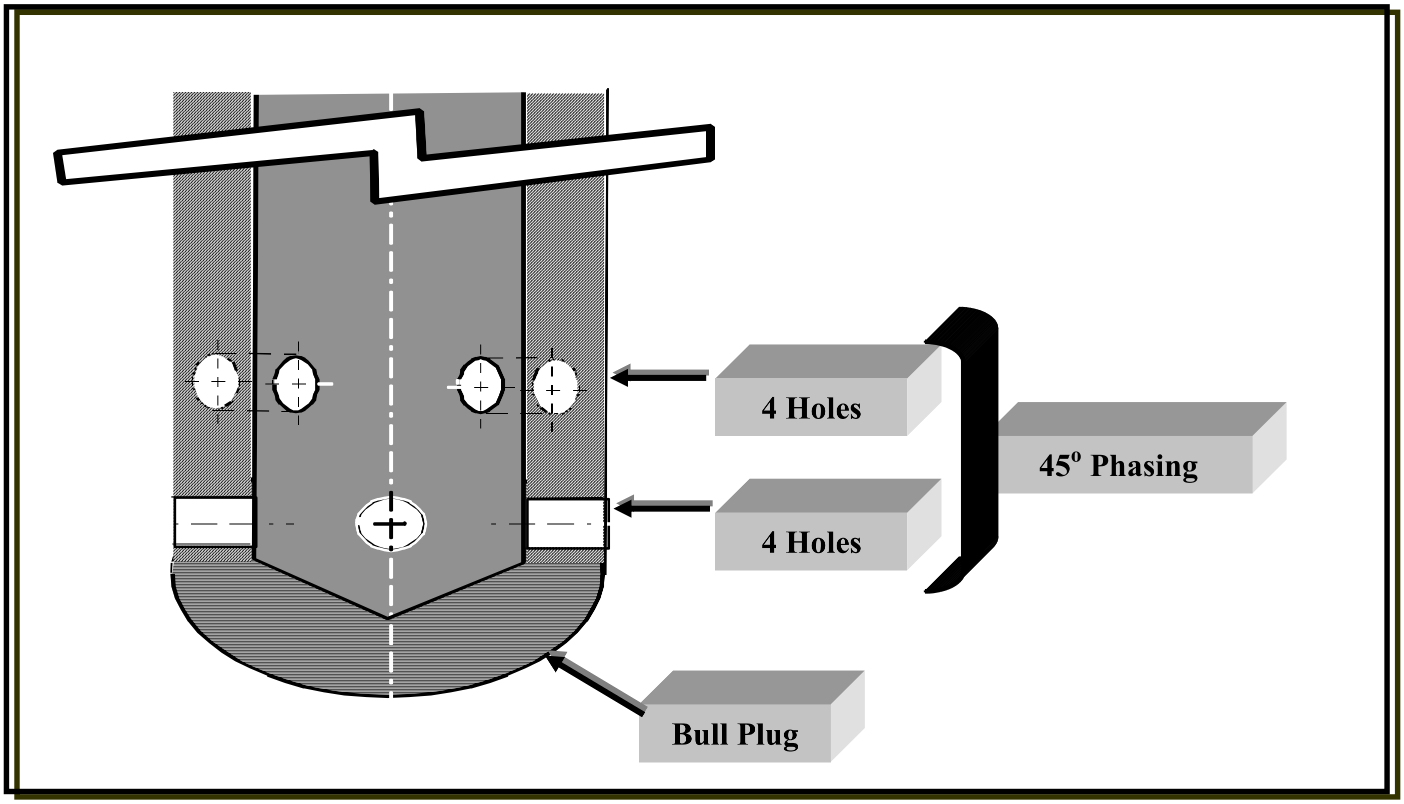

Fig. 1 – Diverter Sub

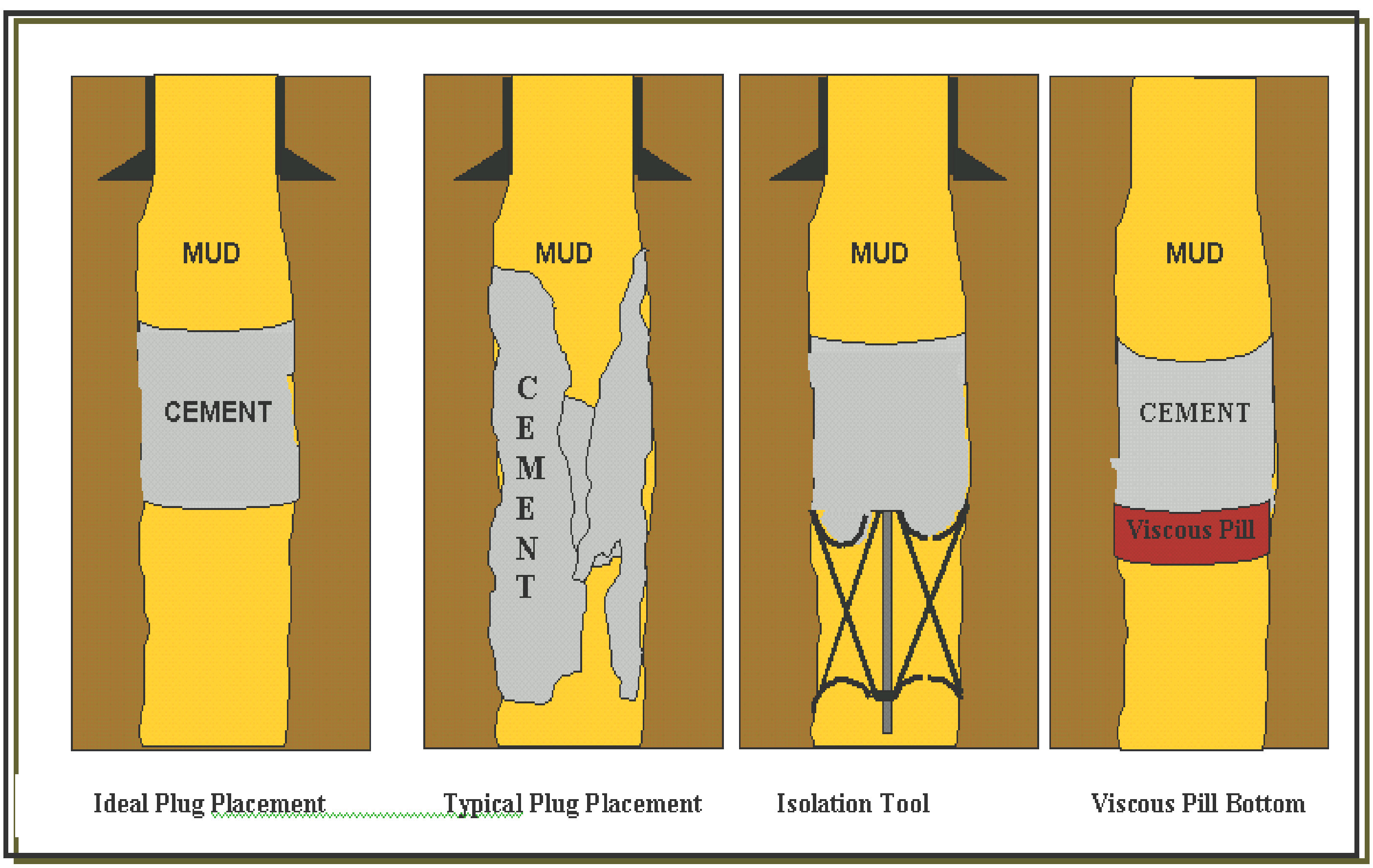

Figure 2

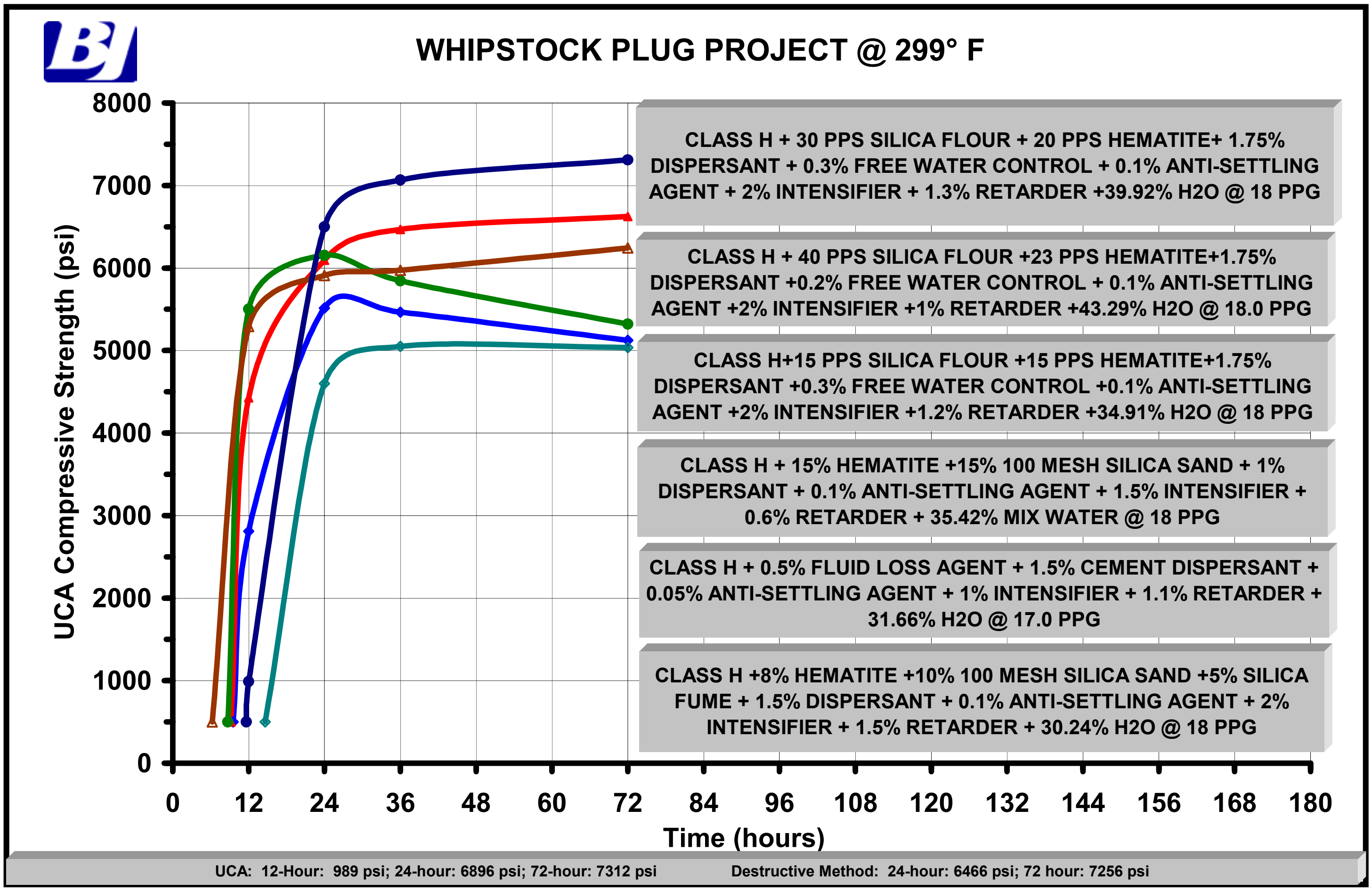

Figure 3 – Compressive Strength as a Function of Time

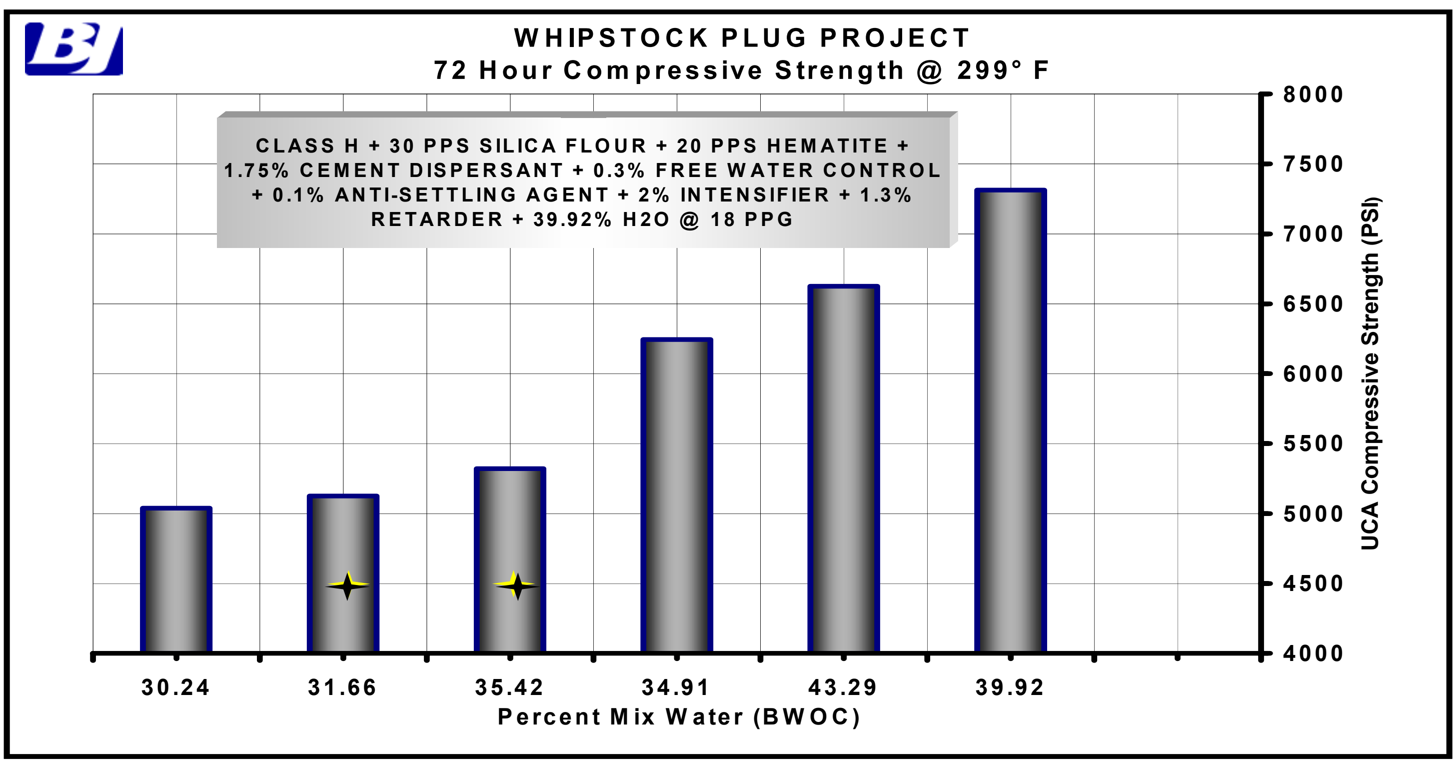

Figure 4 – Compressive Strength as a Function of Percent Mix Water at 299° F