Materials for Better Hydraulic and Shear Bonds in Solution Mining

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ABSTRACT

A primary cement job is considered successful only when zone isolation is achieved and maintained throughout the economic life of a well. Unfortunately, there are no magic formulae or cure-all materials or techniques to assure success in cementing operations. Each job must be considered individually and then engineered to meet existing conditions. This generally requires a practical approach to the problems involved together with a thorough knowledge of hardware, materials, and techniques available. The purpose of this paper is to discuss all phases of drilling and completion operations that affect cementing in solution mining projects. It will show how methodical planning with regard to all factors can lead to better hydraulic and shear bonding with available materials and techniques. Data will be presented to show bonding strengths of cement under various conditions and how bonding can be improved. Early compressive strength development data for systems currently used in solution mining projects is also presented. These data have not previously been readily available, and can be used to reduce waiting-on-cement time to a degree that will greatly improve the economics of the cementing operation.

INTRODUCTION

Many reasons exist and often are listed in literature for cementing casing in a wellbore. Regardless of the number of reasons for cementing operations, however, a primary cement job can be considered successful only when zone isolation is achieved and maintained throughout the economic life of a well. Zone isolation is achieved only when the cement is tightly bonded to both the pipe and the formation. The required strength of these bonds will depend on the downhole conditions and pressures to which the well will be subjected during its life.

There are two types of bond-strength data which are investigated in the laboratory to determine the suitability of a cement system for various downhole conditions. These are shear bond and hydraulic bond strength.

Shear (or mechanical) bond strength is generally defined as the force per unit area required to break the bond between cement and pipe or cement and formation in a press with no confining pressure.

The type of apparatus used to measure shear bond strength is shown in Figure 1. The nature of the test shows that the shear bond strength is primarily an indication of the ability of the set cement to support the pipe in the hole.

Hydraulic bond strength actually refers to the hydraulic pressure required to cause failure of the cement-pipe or cement-formation boundary under a confining pressure. Unfortunately, there is no standard method or apparatus for determining hydraulic bond strength.

Several types of apparatus have been used and reported upon in the literature. Essentially, all of the hydraulic bond tests subject the cement to pressure, as shown in Figure 2. Where pressure is equally applied across the cement column and at both cement-pipe contacts, failure generally occurs at the outer pipe-cement boundary (Point A).

Shear bond strength can be related mathematically to downhole conditions so that a correct amount of cement of adequate shear bond strength

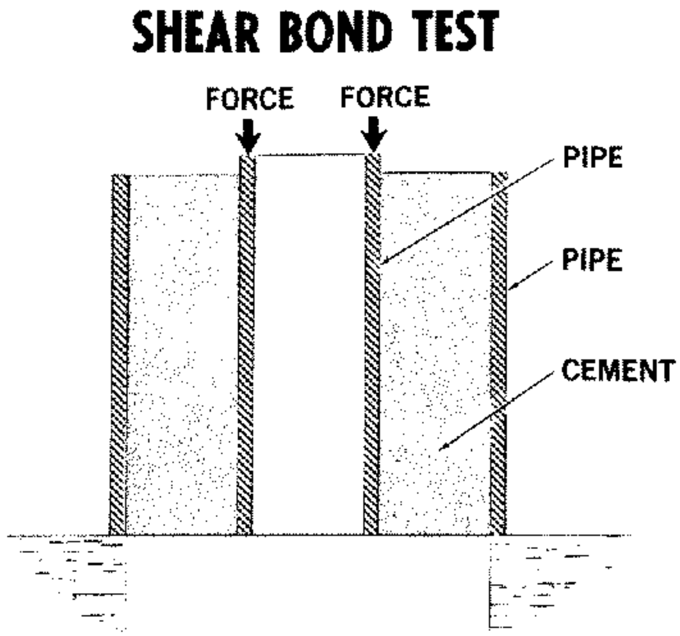

Figure 1.

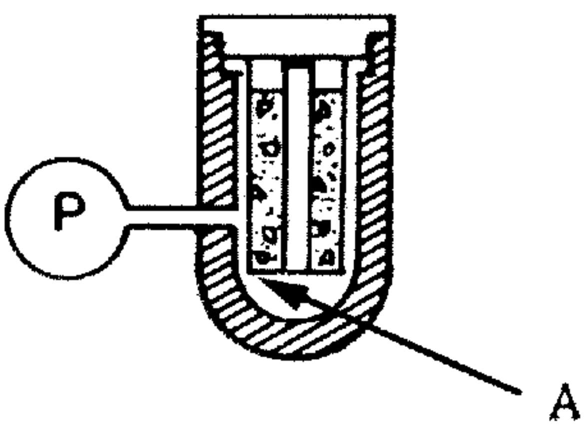

Figure 2.

can be used to support the pipe. Unfortunately, no direct correlation has yet been developed between surface hydraulic bond tests and downhole performance of cement. We know that systems which fail at pressures as low as 1200 to 1300 psi in surface tests successfully contain hydraulic pressures many times larger than down the hole. It would seem reasonable, though, that those systems performing better in surface tests would perform better downhole. However, there are no standards for hydraulic bond tests and data commonly are not reproducible. Therefore, it seems desirable to relate bonding tests to some more standard tests.

In 1968, W.K. Godfrey of Shell Oil Company conducted an extensive study of various cement systems and their hydraulic and mechanical bonding characteristics. He found that both the mechanical and hydraulic bond strengths increase as the compressive strength of the cement increases.

The relationship Godfrey found between compressive strength and mechanical or shear bond strength is illustrated (Fig. 3). His studies of the relationship between compressive strength and hydraulic bond strength are also shown (Fig. 3).

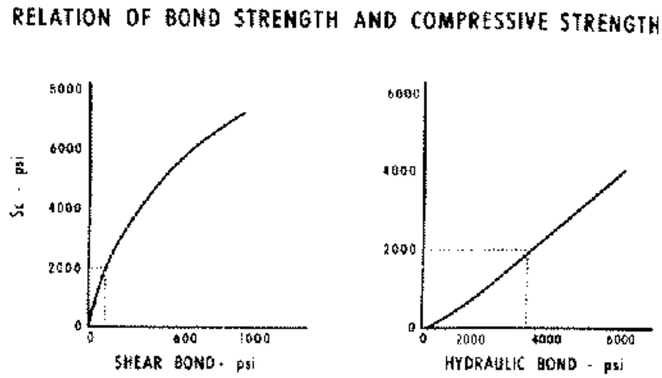

Figure 3.

Godfrey's study was aimed at determining the effect of perforating on bond strength. His work showed that cement systems with compressive strengths of 2000 psi or greater maintained their hydraulic and shear bonds after perforating. From these curves, cements with compressive strengths of 2000 psi or greater also exhibit shear and hydraulic bond strengths comparable to laboratory test data of cements which we know have performed satisfactorily downhole. Therefore, it appears that, from current data and experience, systems with compressive strengths of 2000 psi or more will also have bond strengths capable of providing zone isolation.

Table 1 presents data of several cement systems used in solution mining well completions. These tests were made at low temperatures. These data show a widespread comparison between the systems. Note that some of these, even after 72 hours, have not developed the desired 2000 psi compressive strength. Some of the systems develop the desired strength in 48 hours or less, even at low temperatures. This can mean significant savings in rig time spent in waiting on cement. Actually, 500 psi strength is considered adequate for drill-out op-

Table 1.

STRENGTH DATA OF VARIOUS SYSTEMS

		Sc					
		80°			100°		
SYSTEM	SHEAR BOND	18	48	72	18	48	72
1	443	165	1050	1600	702	1512	1800
2	151	61	285	450	207	440	646
3	792	206	1775	2575	881	2733	2775
4	336	70	1412	1662	375	1862	2077
5	1457	431	2265	2925	1500	3100	3725
6	1495	98	2810	2850	843	3875	3125
7	825	234	1110	1712	587	1600	2300
8	589	71	1086	1450	280	1450	1687

erations. It would not be desirable, however, to perforate or conduct stimulation treatments until after the 2000 psi strength develops.

A comparison of test data for an average of several portland systems and Chem-Comp, or expanding cement is presented in Figure 4. The ratio of shear bond strength to compressive strength for the Chem-Comp systems is much higher than for the more conventional portland systems. Since Godfrey found that there is also a definite relationship between compressive strength and hydraulic bond strength, it is reasonable to assume that hydraulic bond strength of the Chem-Comp systems will also be much higher than those of the more conventional systems. In fact, experience has proved that good hydraulic bonds have been obtained with Chem-Comp when cementing pipe in salt stock when repeated attempts with other systems had resulted in failure.

One recent example of the exceptional hydraulic bond strength of Chem-Comp is a well drilled into a salt dome on the U.S. Gulf Coast. This well, cased with 20-inch surface pipe to 2700 feet, was drilled to 5700 feet. Top of the salt was at 2500 feet. A 13 3/8 inch casing string was run to total depth and cemented with 2500 sacks of salt-saturated Chem-Comp cement. Cement top was 2000 feet, and a second stage of filter cement was used to bring cement from this depth to the surface. After cement had set, plug was drilled and well drilled on into the salt. It was then evacuated and pressure-tested with nitrogen. It retained a pressure of 4722 psi at the cement-salt and cement-pipe interfaces for 24 hours with no detectable leakage.

Although both shear and hydraulic bond strengths are important, there actually is no relationship between the two down hole. Channels exist both between the pipe and cement, and between the pipe and formation (Fig. 5). Since the

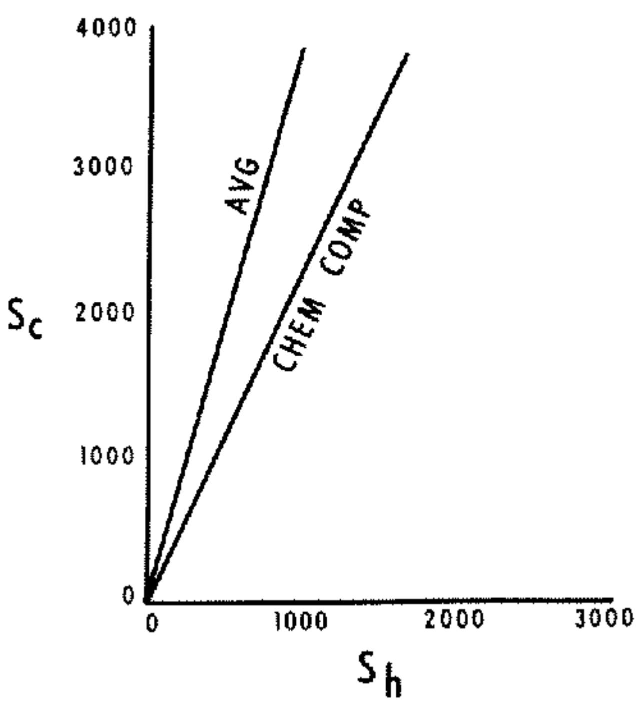

Figure 4.

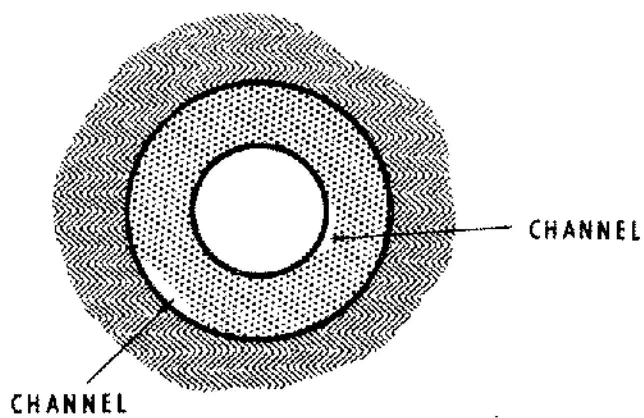

Figure 5.

channels are relatively small, tests could readily indicate high shear bond strength and bonding would be more than adequate to support the pipe. On the other hand, there is no hydraulic bond because fluid under pressure is free to flow through the existing channels. Thus, if a good hydraulic bond is not obtained, any primary cement job must be considered a failure, and a good hydraulic bond is a function not only of the cement system, but of the entire drilling and cementing operation.

Unfortunately, there are no magic formulae or cure-all materials or techniques to assure successful cementing operations. Laboratory data is only an indication that a particular cement system has the ability to perform satisfactorily downhole the functions desired of it. Even with this ability, it cannot perform unless each cement job is individually engineered from start to finish.

A carefully engineered job must be planned before a well is started. The factors involved in job engineering are: (1) drilling; (2) casing and hardware; (3) cementing materials; (4) cementing techniques; and (5) completion practices. There is a great amount of literature available on each of these subjects, and no attempt will be made here to discuss each in detail. The main factors to be considered in each category of job planning, however, can be stated.

DRILLING AND CASING

Actually, design of the casing string is the first step in well planning. The number of strings and the size and weight of each string will determine hole size required for adequate clearance between the outer casing wall and the formation face. Not only should there be enough clearance to permit pipe to be run easily, but enough annular space should exist for an adequate cement column. The thickness of the cement sheath must be great enough for the cement to perform its intended functions.

Other factors to be considered in the drilling phase of the well are hole condition and mud conditions. The condition of the hole insofar as maintaining gauge size and preventing excessive washouts, sloughing, or filter cake will depend on the drilling fluid. This fluid must also perform other functions during the drilling operation, and the requirements for these functions may be such that the drilling fluid is not suitable for a completion fluid. Quite often, the drilling fluid can be circulated and conditioned to become an acceptable completion fluid prior to cementing. On occasion, however, it will be necessary to replace the entire system prior to running pipe and completing.

Before running pipe, the casing surface must be prepared and casing hardware installed. In preparing the surface, mill varnish should be removed since it may prevent a good pipe-cement bond. Roughness may be beneficial as long as pits ARE NOT filled with mud cake.

"Casing hardward" normally refers to guideshoes, float and stage collars, centralizers, and scratchers. Type and amount of casing hardware will depend on operators' preference and experience, and hole conditions. Some casing hardware is controversial, and its use will depend entirely on the operators' personal experience and results.

CEMENTING MATERIALS

Cementing materials for solution mining and storage projects must meet the following requirements:

(1) Adequate strengths
(2) Durable
(3) Non-solvent at BHST
(4) Reasonable WOC time
(5) Reasonable cost
(6) Meet individual well conditions

The majority of the most commonly used systems in solution mining and storage projects (those shown in Table 1) meet the above requirements and can be further modified to meet individual well conditions. They can be salt-saturated or not, as necessary for requirement (3).

Again, one of the main points indicated in Table 1 is the WOC time required for these systems. Even at the low temperatures for which the data is presented, adequate strength for drill-out is achieved in 48 hours or less. Improved economics often can be achieved by reducing the WOC time from the 72 hours normally used. Other completion operations should not begin, however, until the desired 2000 psi compressive strength is attained. Depending on temperature, this also is often attained in much less time than common practice has allowed.

CEMENTING TECHNIQUES

Even if all drilling and casing factors mentioned have been designed and applied properly and the optimum cement system selected, a great deal of the success of the cementing operation will depend on the cementing techniques employed. There are two accepted methods of cement placement. These are turbulent flow and Sloflo.*

Turbulent flow has been an accepted method of placement in oilfield operations for nearly two decades and is still widely used. During the past few years, however, the Sloflo technique has gained rapid acceptance. It is a technique using plug flow placement of the cement. It has proved better

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where washouts and irregularities exist and provides an extremely high percentage of mud removal. It is more economical since less equipment is required and can be used where turbulent flow is impractical or not economically feasible.

The Sloflo technique requires designed differentials in weight and gel strength between the mud and cement (Fig. 6). Where this is not practical, a spacer material can be used between the mud

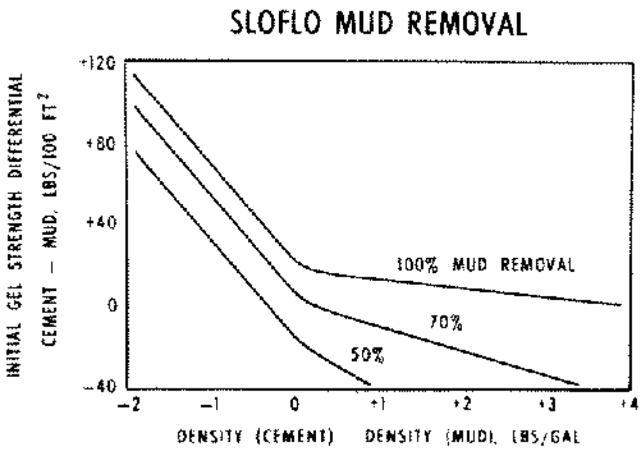

Figure 6.

and cement to accomplish the mud-removal benefits of plug flow. The cement system behind the spacer can then have other than the required mud-cement differentials and still be highly successful.

To maintain best plug flow characteristics, the mud and cement must move up the annulus at a velocity not greater than 90 feet per minute. While there is no sharp point of transition between plug and laminar flow, field experience has shown that at an annular velocity of 90 feet per minute or less, the cement will move as a plug with very little intermixing at the mud-cement interface. Primary limitation of the technique is control necessary to maintain the desired velocity, since U-tube effect of the heavy cement column will tend to increase it.

CEMENT SYSTEMS

1. Huron A, 2% D20, 2% D33, Salt Saturated.
2. 50:50 LP3, Huron A, 2% D20, 2% D33, Salt Saturated.
3. Huron A, 2% D33, Salt Saturated.
4. Huron A, Salt Saturated.
5. Class C, 2% D33, Salt Saturated.
6. Class C, Salt Saturated.
7. Chem-Comp, 2% D33, Salt Saturated.
8. Chem-Comp, Salt Saturated.

CONCLUSIONS

Good hydraulic bonding and shear bonding are required for successful cementing operations. Tests relating bond strengths with compressive strengths show that most cement systems are capable of providing adequate bond strengths, but that expanding cement will probably provide higher hydraulic bond strengths than more conventional systems. Lab tests further indicate that in most cases adequate strength is achieved in less than the normal 72-hour WOC time.

Placement techniques also play an important part in successful cement jobs as do casing hardware and drilling fluids. Any cementing operation should be planned so that all these factors are interrelated prior to the beginning of the drilling operation in order to assure high success ratios in cementing.