IMPROVED BONDING AND ZONE ISOLATION WITH A NEW EXPANDING CEMENT

T. J. GRIFFIN and L. B. SPANGLE
Dowell Div., Dow Chemical Co.

ABSTRACT

Cement bonding to the formation and subsequent isolation of productive intervals from non-productive intervals are essential to achieve the optimum results in stimulation and production of oil and gas. This paper describes a number of factors which cause poor bonding to pipe and formation and which can contribute to poor zone isolation and therefore ineffective stimulation treatments. A cementing system is described which combines the advantages of expansive properties with the other desirable properties of conventional cementing systems. The expansive properties of this system help to overcome the factors which contribute to poor bonding.

INTRODUCTION

Among the numerous techniques available to improve cementing results are mud conditioning[1], pipe movement,[1,2] and centralization,[2] use of scratchers,[2] and the efficient use of spacers and washes.[3] These techniques are designed to aid in mud removal resulting in the surface of the casing and formation being exposed. This allows for a more efficient bond between these surfaces and the naturally adhesive products of the cement. There are, however, certain conditions that can result in the formation of a micro-annulus and prevent good bonding, even though these techniques are employed. This paper describes conditions which can result in the formation of a micro-annulus and a new cementing system that is designed to overcome these problems and result in a tight bond between the cement, formation, and casing.

CONDITIONS LEADING TO THE FORMATION OF A MICRO-ANNULUS

Certain conditions leading to the formation of a micro-annulus (Figure 1) between the cement and the formation, or casing, are due to the chemical reactions of cement hydration and the mechanics of cement placement. Following the placement of cement, hydration reactions occur causing the cement to set, giving off heat. The liberated heat causes an expansion in the casing. After hydration is complete, the casing will eventually cool to the formation temperature and contract. The contraction of the casing causes it to pull away from the set cement forming the micro-annulus. Occasional failures of float equipment can also indirectly lead to the formation of a micro-annulus. When a piece of float equipment fails to function properly, it becomes necessary to hold pressure on the casing to prevent the cement from flowing back into it. This pressure expands the casing followed by a subsequent contraction when it is relieved.

H. G. Kozik reports contraction of casing can be in the range of 0.001 to 0.007 inch for 4-1/2 to 10-3/4 inch casing (depending on weight) for a 500 psi reduction in internal pressure. This contraction can also be caused by a temperature reduction of 60°F.

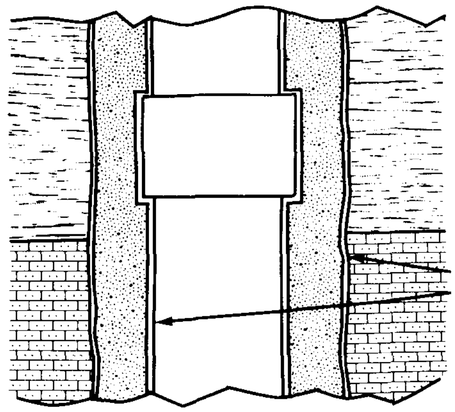

FIGURE 1—MICRO-ANNULUS FORMED WHEN CASING AND OR CEMENT CONTRACTS AFTER SETTING.

A micro-annulus of 0.002 to 0.003 inch would show intermediate to poor bonding on a bond log.[4] Gas could readily pass through such an annulus if such conditions existed.

A mud film on the pipe and formation, tar, paraffin, and mill scale can also cause incomplete bonding. Shrinkage and cracking of the cement sheath are other instances leading to the formation of a micro-annulus. Cementing dry formations, such as ones encountered in air, gas, or mist drilling can result in a water loss to the formation as the cement is setting, resulting in shrinkage of the cement.[5]

PAST METHODS OF PREVENTING MICRO-ANNULUS FORMATION

In the past, several expanding cement systems were used to prevent or reduce micro-annulus formation. One of these involves the use of salt in Portland cement to produce a cement which expands more than the neat cement. These systems rely on crystalline growth for expansion.[6] This expansion occurs as the result of water being taken up during cement hydration, causing the salt to become supersaturated and to crystallize. A problem with this type of system is that exposure to formation waters which are not salt-saturated may allow leaching of the salt from the cement, causing contraction of the cement and an increase in its permeability.

Another cement system used to prevent micro-annulus formation is ChemComp* expanding cement.[7,8] This is a patented system developed to overcome the dry-shrinkage problem associated with conventional Portland cement which shrinks because of evaporation of water from the cement or concrete as it sets. The system was adapted for oil field use with very good results under most conditions.[9]

Unfortunately, this cement has limited storage life and does not respond well to oil-well cement additives. Also, it is only manufactured at a few locations and is not readily available in most oil and gas well producing areas.

NEW TECHNOLOGY: EXPANDING CEMENT

A new product which creates a self-stress in the cement has been developed to fill the need for an expanding cement. This "self-stress" cement expands after the cement has set and before it develops its complete compressive strength. It occurs while it is still pliable. Consequently, this cement maintains its integrity yet expands to maintain a tight fit around the casing as it shrinks. This prevents the formation of a micro-annulus and exerts pressure on any mud film, scale or tar which may be left on the casing. It sometimes penetrates the scale or film by crystalline growth of the cement. This maintenance of a tight fit results in a positive seal and superior bonding (Figure 2).

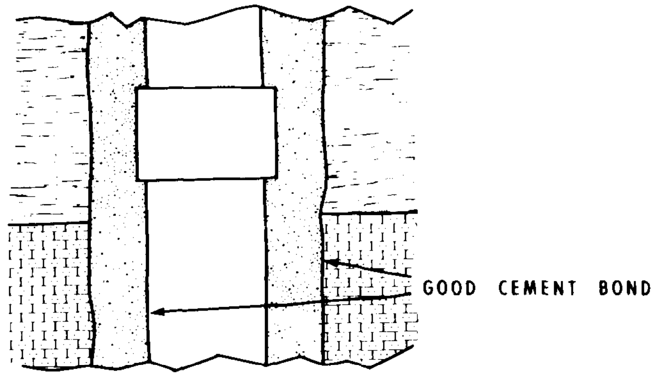

FIGURE 2 EXPANDING CEMENTS MAINTAIN TIGHT FIT AROUND CASING AS IT SHRINKS, THUS PREVENTING FORMATION OF A MICRO-ANNULUS.

Dowell's self-stress cement composition is more versatile than the commercial expanding cement described earlier, because it responds well to conventional oil-well cementing additives. As a result of this, it can be used in almost any circumstance where an expanding cement would be advantageous and other properties are desirable in the cementing system. An added benefit of the system is that the expansive reaction provides resistance to attack by sulfate waters.

LABORATORY DATA

Laboratory testing of the Dowell self-stress cement system indicates it is very suitable for use in oil and gas well cementing. Tests conducted confirm that it will respond adequately to retarders used in high temperature cementing. Figure 3 shows a comparison of the viscosity curves of two systems retarded for four hours pumping time at 302°F BHCT (16,000 ft casing schedule). Both systems contained silica for control of strength retrogression and an 0.8-percent high temperature retarder. Other results of thickening time testing are shown in Table

TABLE I THICKENING TIME & COMPRESSIVE STRENGTH OF SELF-STRESS CEMENT SYSTEMS RETARDED FOR DOWNHOLE CONDITIONS

Class Cement used for Prep. of Self-Stress Cement	Density (ppg)	Other Additives	Thickening Time (Hr:Min)	Compressive Strength (psi) 8 Hr	24 Hr
Thickening time at 80°F, BHCT (Scd 1); compressive strength at 95°F, BHST					
A	14.8	--	+6:00	170	780
H	14.8	--	+6:00	95	450
G	14.8	--	+6:00	295	1370
Thickening time at 140°F, BHCT (Scd 5); compressive strength at 200°F, BHST					
A	14.8	--	2:03	2000	2895
A	15.1	Salt Sat'd	+6:00	1065	1545
A	14.9	50:50 Flyash	2:18	955	1600
H	15.0	35% Silica +.5% Retarder	+6:00	Not Set	1925
Thickening time at 197°F, BHCT (Scd 7); compressive strength at 260°F, BHST					
A	15.0	35% Silica +.5% Retarder	3:23	2080	3280
A	15.0	35% Silica +.5% Diacel LWL	5:17	1745	2440
A	15.0	35% Silica +.5% HT Retarder*	4:43**	2055	3405
H	15.0	35% Silica +.5% Retarder	4:47	925	2400
G	15.0	35% Silica +.5% Retarder	4:38	1655	3650

* HT - High temperature retarder
** Thickening time at 233° BHCT (Scd 8)

1 along with compressive strength data for the same systems.

Compressive strength testing indicates that the Dowell self-stress cement system, although mixed with more water, develops early compressive strength at a faster rate than comparable neat cement systems (Table 2). The six-hour compressive strength of a self-stress cement system prepared from Class C cement cured at 80°F developed greater strength than a Class C cement (which is a high early strength cement) cured under the same conditions. The neat cement systems will rapidly overtake the self-stress cement system in compressive strength as indicated by the Class G cement in Table 2. These neat cement systems develop higher ultimate compressive strength than the self-stress system, but the ultimate strength of self-stress is more than adequate for almost all applications. Plug cementing is an exception to this because development of very high strengths in short periods of time is desirable. Ultimate compressive strength of the self-stress system is in the range of 2500-5000 psi, depending on the cement used, amount of mix water, and other factors.

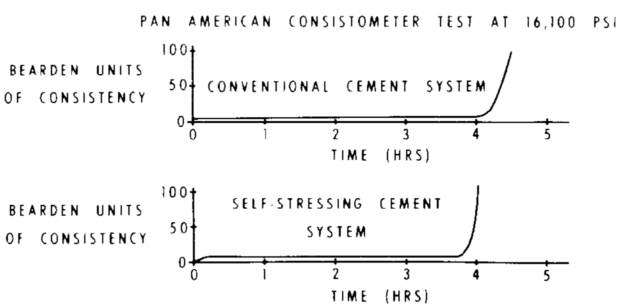

FIGURE 3 COMPARISON OF CONVENTIONAL AND SELF-STRESSING CEMENT SYSTEM RETARDED TO 4 HOURS PUMPING TIME AT 302°F.

Figure 4 shows expansion data of Dowell self-stress cement compared to neat cement, ChemComp cement, and salt-saturated Portland cement. Normally, the self-stress system expands in

TABLE 2 COMPRESSIVE STRENGTH DATA

System	Density (ppg)	Cure Temp °F	Compressive Strength (psi) 6 Hr	1 Day	7 Day
Class G	15.6	140	--	2275	3925
Class G - Self-Stress	14.8	140	--	1070	1660
Class C	14.8	80	195	1925	--
Class C - Self-Stress	14.8	80	544	2120	--

the range of 0.20-0.50 percent, depending on chemical factors (variations in cement), degree of retardation, and temperature. Salt systems used as expanding cement expand from 0.10 to 0.16 percent compared to neat cement which expands 0.02 to 0.08 percent, again depending on some of the same factors. Expansion occurs from the time the cement is first mixed with water. The desirable expansion is primarily that which occurs after the cement reaches a rigid state and will not flow or move as it expands. It is then necessary to design expanding cement systems to have a minimum pumping time plus a workable safety factor in order to take advantage of as much expansion as possible.

FIELD APPLICATION

Dowell self-stress cement systems have been applied under a variety of conditions across the United States and Canada. Over one hundred treatments have been performed. Excellent results have been obtained, where in the past, logs have indicated little or no bond. The self-stress cement system is used like any other system. The dry ingredients are blended together with API Portland cement in the service company's bulk cement blending equipment. After being transferred to the well site by cement transports, it is mixed and pumped into the well by conventional cementing methods. Of course, the cement must be mixed as designed or the slurry won't have the proper characteristics. Depths of use range from shallow wells of 1000 ft or less to greater than 10,000 ft. Bottom-hole temperatures have ranged from 95°F to over 250°F. Virtually all conditions encountered in oilwell cementing can be safely handled with this system.

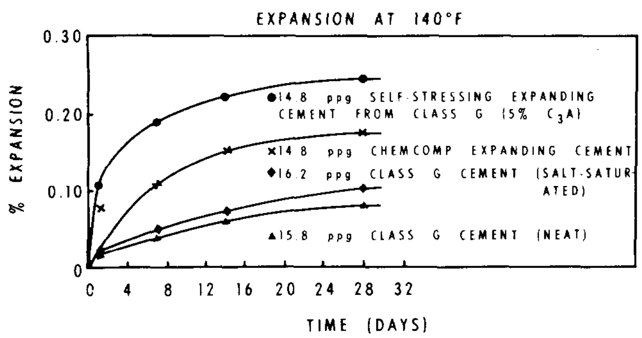

FIGURE 4 - COMPARISON OF SELF-STRESSING AND OTHER EXPANDING CEMENT SYSTEMS.

This system is so versatile that it is used in cementing where low density is required for control of lost circulation or high density for control of highly pressurized formations. By the use of conventional oil well cementing additives, the self-stress cement system can be adjusted to a wide variety of properties, such as fluid-loss control, dispersion for turbulent flow, and many more.

This system has been applied in shallow gas storage wells, deep liners in the Rocky Mountains, and medium depth liners and long strings. The following specific applications demonstrate the value of expanding cement in achieving zone isolation and good bond logs.

In Callahan County of West Texas, good bond logs of wells drilled through the Duffer Lime were very difficult to achieve. This is a fractured limestone at about 3300 feet. ChemComp expanding cement was used with good success to overcome the problems in achieving bond logs. However, since then the manufacture of ChemComp cement in this area has ceased. Self-stress expanding cement has been used in its place in numerous treatments with excellent bond log results. The wells in this area range from 2000 to 4500 ft deep with bottom-hole temperatures of 110-120°F.

Excellent results have also been achieved in Custer County, Oklahoma. A 2-7/8-inch liner (600-1000 ft long) was set to 10-11,000 feet in 4-3/4-inch hole. Bottom-hole temperature was in the range of 190-200°F. Following cementing, the liners were pressure tested and logged to evaluate the cement job. Quite often, the pressure test indicates incomplete seal at the top of the liner and the bond log indicated poor cement bond. Similar treatments with self-stress cement have shown excellent results. Pressure tests showed a positive seal at the liner top and bond logs indicated good bonding.

These results are typical of those achieved when Dowell self-stress cement is used to overcome problems of zone isolation and bonding due to micro-annulus formation.

CONCLUSION

Like any advance in technology, a self-stress cementing system is no cure-all. It must be designed for the conditions of the well, and it must be applied using the best placement techniques well conditions will allow. It is one more step toward getting the optimum results from oil or gas well cementing.

REFERENCES

1. Suman, G. O., Jr. and Ellis, R. C.: "Cementing Oil and Gas Wells - Part 4", *World Oil's Cementing Handbook* (1977) 32-40.
2. Tiplitz, A. J. and Hassenbroek, W. E.: "An Investigation of Oil Well Cementing", *Drilling and Production Practice*, American Petroleum Institute (1946) 76-103.
3. Griffin, T. J., Jr. and Root, R. L.: "Cementing Spacers and Washes Improve Production", *Oil & Gas Journal* (Sept. 12, 1977) 115-122.
4. Kozik, H. G.: "Notes on Cement Bond Logging", Squeeze Cementing Symposium, Tulsa (Dec. 1977).
5. Setter, N. and Roy, D. M. P.: "Mechanical Features of Chemical Shrinkage of Cement Paste", *Cement and Concrete Research*, Volume 8 (1978) 623-634.
6. Hansen, W. C.: "Crystal Growth as a Source of Expansion in Portland Cement Concrete", American Society for Testing and Materials, *Proceedings*, Volume 63 (1963) 932-945.
7. Klein, A.: "Calcium Alumino-Sulfate and Expansive Cements Containing Same", *U.S. Patent 3,155,526:* (Nov. 3, 1964).
8. Klein, A. and Troxell, G. E.: "Studies of Calcium Sulfoaluminate Admixtures for Expansive Cements", American Society for Testing and Materials, *Proceedings*, Volume 58 (1958) 986-1008.
9. Root, R. L. and Calvert, D. G.: "The Real Story of Cement Expansion", SPE 3346, Presented at SPE Rocky Mountain Regional Meeting, Billings, Montana (June 1971).

ACKNOWLEDGMENTS

The authors thank Dowell Division of The Dow Chemical Company for permission to publish this work. We would also like to thank our colleagues who have assisted in the testing and gathering of data for this work.