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Laboratory Evaluation of Cement Expansion and Shrinkage Using a Novel HPHT Cube-Mold Testing System

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Abstract

The dimensional stability of wellbore cement under downhole conditions is critical for maintaining zonal isolation and long-term well integrity. Expansion and shrinkage of cement slurries during hydration can create microannuli, while controlled expansion can improve sealing against casing and formation. Current industry-standard methods (API RP 10B-5) employ the Annular Ring and Membrane tests, but these are restricted to atmospheric pressure and simplified geometries, limiting their relevance for HPHT wells.

This paper introduces a novel laboratory device that directly measures cement expansion and shrinkage under representative downhole conditions. The system consists of a high-pressure, high-temperature curing chamber (rated to 400°F [204°C] and 5,000 psi [34 MPa]), a precision cube mold for controlled placement, and an integrated linear variable differential transformer (LVDT) that continuously records displacement on one free surface of the cube. By constraining five faces while allowing one to move, the device captures real-time dimensional change during hydration and after setting.

Initial testing shows the device can resolve micrometer-scale displacements throughout curing and hydration phases of the cement. Results correlate well with conventional atmospheric methods but also reveal behaviors that only occur under HPHT curing, demonstrating the importance of realistic test conditions.

This advancement offers a practical and accurate means to evaluate cement dimensional stability under field-representative environments. Its application supports the development of additives, improves cement design screening, and provides operators with new tools to enhance long-term wellbore integrity.

Introduction

The behavior of cements and their additives are greatly affected by the temperatures and pressures in the oilwell. Therefore, testing the cement at these expected wellbore conditions is critical to successful cementing operations. One of the primary goals of cementing oilwells is to provide Zonal Isolation. And one behavior of cement that can either be detrimental or beneficial to this goal is the tendency to shrink or expand. Cement will generally shrink without 'expansion' additives used to prevent this. Using too much of these additives may cause the cement to expand so much that failure will still occur. So it is critical when using expanding additives that the right concentration be used.

Once the slurry design is determined and the proper Expanding Additive (E.A.) is selected, the additive effects need to be tested. It is best to test the volumetric effects of the E.A. as close to the down hole conditions as possible. A curing chamber and mold designed to allow for expansion or contraction was used to test the cement slurry. This mold has one side which is free to move as the cement expands or contracts as it hydrates. The change in volume of the cement is measured with an hi-pressure LVDT assembly. These volumetric changes are taking place inside of the curing chamber exposed to downhole conditions.

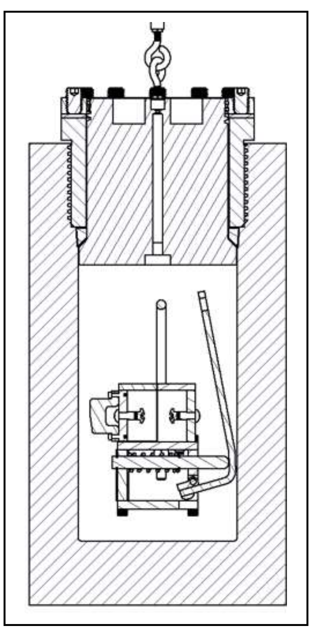
When the probe is extended to contact the mold, it is sensitive enough to measure the volumetric changes of the metal curing vessel and mold as temperature and pressure is changing. While some volumetric change is taking place in the cement slurry as the hydration process occurs (especially with some expansive additives) the critical volumetric changes happen after the cement has initially hardened. This 'setting or hardening' also generally takes place after the curing chamber has reached a stable temperature and pressure. So the initial point from which to measure volumetric change happens in a stable environment where the only displacement is coming from the cement contracting or expanding. Alternatively the baseline (initial) point can be at a time determined from UCA testing where the cement has reached some compressive strength value (ie. 50psi).

This device measures actual displacement of the cement at wellbore conditions. Current recommendations for Expansion/Shrinkage testing only refers to atmospheric testing (at temperatures lower than 200°F (93°C) (API - American Petroleum Institute 2020). When technicians need to test for expansion at elevated temperatures and pressures, they can remove the retarder and run the test as recommended at less than 200°F. Or they will put the expansion ring in a curing chamber, expose it to downhole conditions, and then either measure it twice or measure it seven times. If they want to reduce cycling of the curing chamber (and significant time/labor), they will-

- Pour the cement in the ring mold, put it in a curing chamber, and bring it to temperature/pressure.
- After 24 hours (or an alternate time when the cement is hardened) they will cool down the curing chamber and remove the mold.
- The spacer block is removed (to allow for shrinkage) and the initial measurement is made.
- Then the mold is put back in the curing chamber and brought back to test temperature.
- Seven days later (or some other final time interval) the curing chamber is cooled down again, the mold removed, and the final measurement is made.

Alternatively, this process can be repeated each day for seven days to get daily readings. This is a very time-consuming process, and each cycle will induce errors in the test. Both the cement and the circular expansion mold are affected by the temperature variations. The procedures and equipment detailed in this paper are an attempt to eliminate the errors inherent with current methods. It will also help to save time and produce more reliable results.

Figure 1: Expansion Mold inside Curing Chamber



Equipment

A curing chamber is specifically designed to expose Oil Well Cements to down hole temperatures and pressures, which can be extremely high. The expansion tester uses an automated curing chamber and upgrades it with a Hi-Pressure LVDT sensor assembly and a specifically designed mold. This curing chamber and LVDT probe assembly have a max temperature of 400°F (204.4°C) and max pressure of 5000 psi (34.5 mPa). Volumetric change and other parameters can be displayed and recorded for the entire test from slurry to hardened cement at any frequency (1 second to 1 hour intervals).

The mold is made from Stainless Steel so that it will not react with the high PH cement. It will fit inside of a standard curing chamber with a spring loaded arm to keep the mold securely positioned inside the cell. This allows most existing curing chambers to be upgraded with the Expansion Apparatus Kit. When the mold is secure in the curing vessel and one side of the mold is fixed (unable to move), the other side of the mold is free to move in one direction. While a thin layer of grease (mold release agent) is applied to all sides of the mold, the cement still bonds to the surfaces. To ensure the cement shrinkage is measured, we also use an removable anchor in the cement that is threaded into the mold.

After the cement is poured into the mold, the mold is placed inside the curing chamber. Temperature and pressure are applied, and the cement is allowed to harden. While this hydration process is taking place, the mold translates any expansion or shrinkage to the LVDT system which graphs and records the data. This Mold/LVDT system can be installed on existing curing chambers to provide additional functionality to older curing chambers.

Procedures

Mixing of the cement slurry was done in accordance with API Recommended Practice 10B2 (API - American Petroleum Institute 2024). The slurry was poured directly into the mold, although if necessary, the slurry could have been conditioned to test temperature and the curing chamber preheated to the appropriate temperature. A puddling rod was used to remove any trapped air pockets and then the cover plate was installed. The cement filled mold was placed into the curing chamber and the test started. All cement testing took the initial point at four hours into the test as the baseline from which to judge shrinkage or expansion.

Testing done on a fast-acting polyester resin system provided significant shrinkage within hours instead of days. This 'slurry' was mixed by hand according to resin manufacturer recommendations. This resin system demonstrated shrinkage rapidly, too fast for any temperature/pressure stabilization. All resin testing took the initial point immediately after starting test as the baseline from which to judge shrinkage or expansion.

Cement test data was collected every ten seconds and reported in increments of initial, 12-hour, and then daily until the test was terminated 4 or 7 days later. Resin test data was collected every minute and reported in 30-minute increments for approximately 4-hours. Results in the table below (Table 1) show the displacement (in inches) at these intervals as well as the final volumetric change percentage.

Each slurry tested in the expansion tester was also poured in the annular expansion mold for general comparison. To get a result that would compare with the tests run in the expansion tester, the slurry was not conditioned to test temperature prior to pouring in the mold as recommended by API RP 10B5. And the curing method was in a pressurized curing chamber instead of a water bath as recommended by API RP 10B5.

Results

The tests below show several examples of tests demonstrating shrinkage and expansion at various temperatures and pressures. As well as results from expansion ring mold tests.

Table 1: Summary of Results

Description	Temperature	Expansion Tester Results		Annular Exp-Ring Results
Test 1 - Resin	70 °F (21.1 °C)	-0.44% (0.0054" (0.137mm))	Repeat	- n/a -
Test 2 - Resin	70 °F	-0.55% (0.0067" (0.170mm))		- n/a -
Test 3 – 2% EA Slurry	125 °F (51.7 °C)	+0.15% (0.0018" (0.045mm))	Repeat	0.21% (0.0023" (0.058mm))
Test 4 – 2% EA Slurry	125 °F	+0.11% (0.0014" (0.036mm))		0.3% (0.0033" (0.084mm))
Test 5 – 5% EA Slurry	250 °F (121.1 °C)	+0.2% (0.0024" (0.061mm))		0.13% (0.0014" (0.036mm))
Test 6 – Neat Slurry	250 °F	-0.07% (0.0009" (0.023mm))	w/o EA	0.04% (0.0004" (0.010mm))
Test 7 – Neat Slurry	350°F (176.7 °C)	-0.03% (0.0004" (0.010 mm))	w/o EA	-0.16% (0.0018" (0.046mm))

Both resin tests (shown in Figures 2 and 3) demonstrated shrinkage of approximately half a percent (0.44 and 0.55 for tests 1 and 2 respectively). This slurry was too thick to get into an Annular Ring Mold so no comparison was run.

Figure 2- Resin system (-0.44%) at room temperature

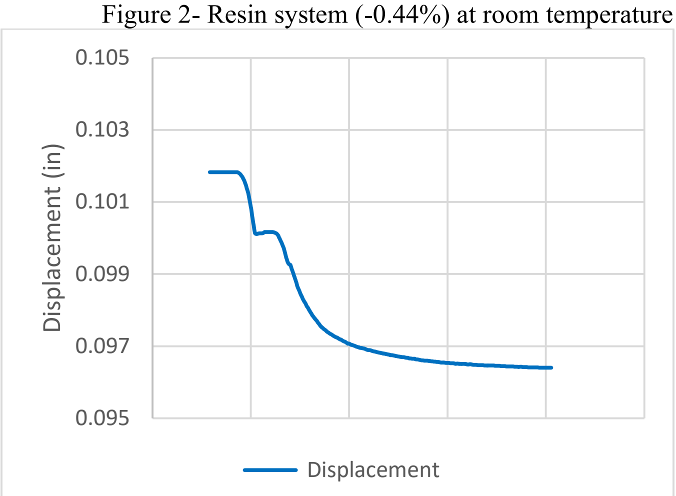
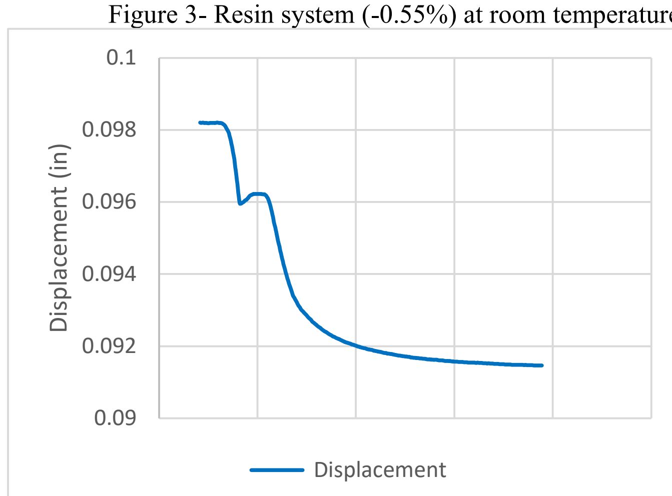


Figure 3- Resin system (-0.55%) at room temperature



The next two tests were run under the same conditions to determine repeatability. While Cement can behave differently from slurry to slurry the machine measured very similar movement. Both slurries had 2% EA added to the 16.6 ppg Class H cement slurry and were tested at 125°F for longer than 4 days. Test 1 (figure 4) showed expansion of 0.15% and test 2 (figure 5) showed expansion of 0.11%.

Figure 4- w/2%EA (+0.15%) (RingMold- +0.21%)

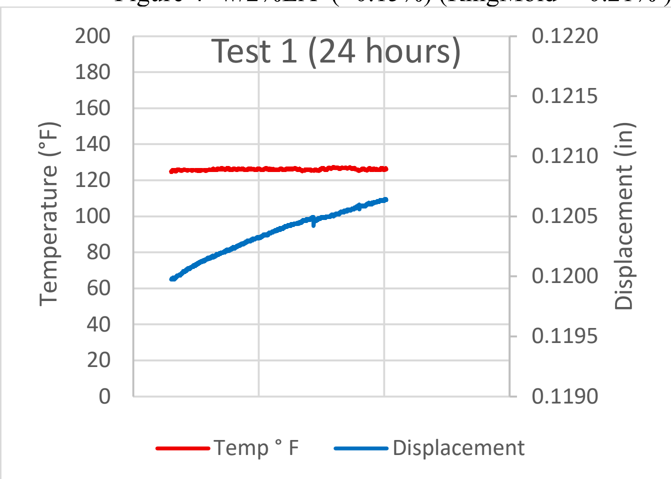
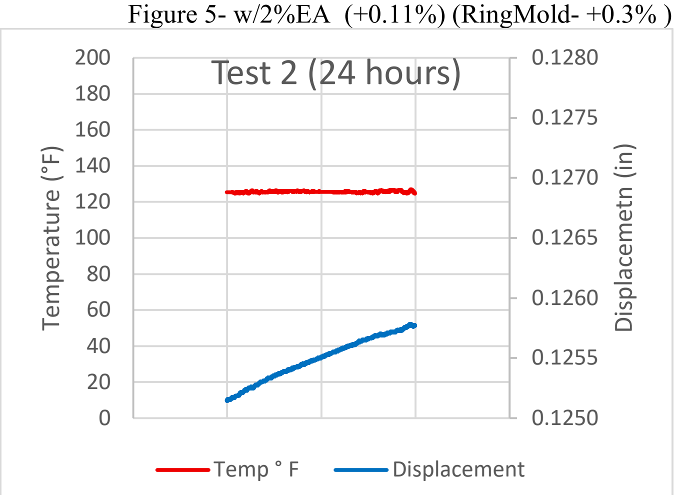


Figure 5- w/2%EA (+0.11%) (RingMold- +0.3%)



The next two tests were run at 250 °F, one slurry with 5% EA and the other slurry without EA. The slurry with EA added (figure 6) showed expansion of 0.2% and the slurry without (figure 7) showed a slight shrinkage of -0.07%.

The final test (figure 8) was run at 350 °F, on a neat cement slurry to track shrinkage. This slurry showed slight shrinkage of -0.03%.

Figure 6- w/5%EA (+0.2%) (RingMold- +0.13%)

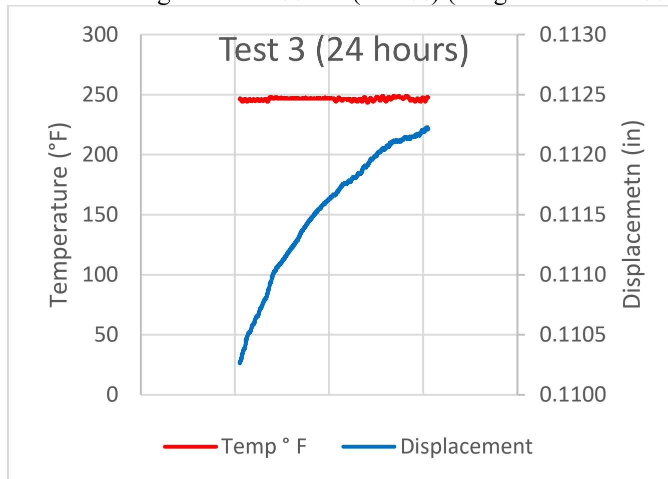


Figure 7- w/o EA (-0.07%) (RingMold- +0.04%)

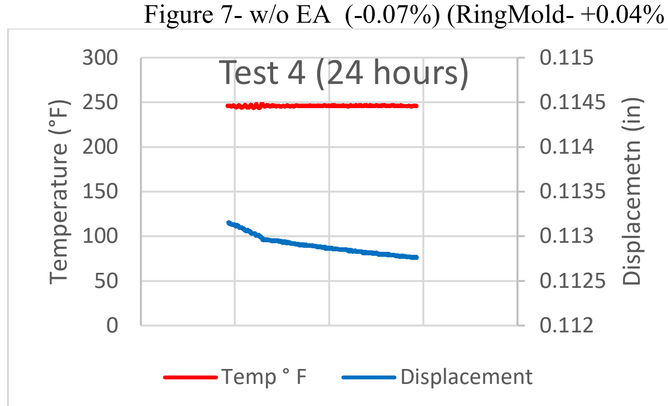


Figure 8- w/o EA (-0.03%) (RingMold- -0.16%)

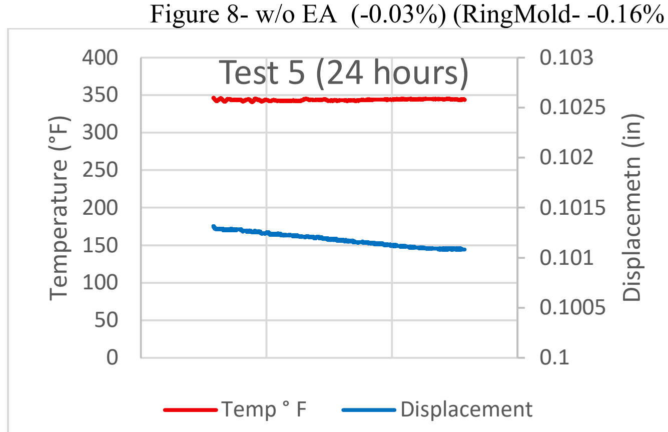
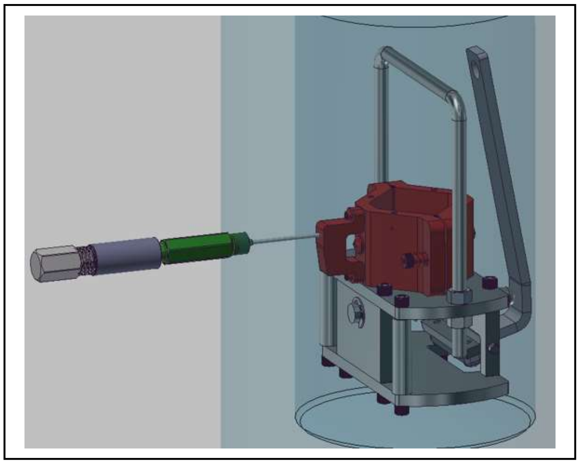


Figure 9: Expansion Mold Assy w/ LVDT



Conclusions

Laboratory testing of cement expansion under simulated downhole temperature and pressure has shown that both expansion and shrinkage behavior are significantly influenced by test conditions. Results demonstrate that evaluating volumetric deformation only at atmospheric conditions can lead to incomplete or misleading interpretations of additive performance. The experimental setup described—featuring a pressure-rated curing vessel, a displacement-measuring LVDT probe, and a one-directional expansion mold—provides a practical and repeatable means of quantifying cement expansion or shrinkage under realistic wellbore environments.

Testing confirmed that expansion additives can produce positive volumetric changes that vary with both temperature and additive concentration. In particular, systems designed for lower-temperature service showed excessive expansion when tested above 250 °F, suggesting that additive dosage and type must be calibrated for the expected well conditions. Conversely, systems without expansion additives exhibited consistent minor shrinkage at all test conditions, establishing a reliable baseline for comparison.

The method also highlighted that repeated thermal and pressure cycling introduces measurable artifacts and data scatter, emphasizing the importance of minimizing curing chamber cycling when long-term expansion monitoring is required. Controlling these operational variables was key to obtaining consistent deformation data.

Overall, the developed test methodology delivers more field-representative results than conventional atmospheric expansion ring tests and enables more accurate optimization of expanding additive concentrations for zonal isolation assurance. Future work should include correlation of these laboratory expansion data with mechanical properties, annular stress development models, and field performance results to strengthen design reliability for expanding cement systems.

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Nomenclature

HPHT = High Pressure High Temperature
LVDT = Linear Variable Differential Transformer
EA = Expanding additive
PPG = Pounds per Gallon

References

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