# MECHANICAL PROPERTY EVALUATION OF RESIN-IN-CEMENT SYSTEMS FOR IMPROVED WELLBORE INTEGRITY

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## ABSTRACT

The Resin-in-Cement (RIC) system is a hybrid technology that merges thermosetting epoxy resin emulsions with traditional Portland cement systems, creating a stable emulsion for superior wellbore sealing and bond-adhesion in oil and gas wells. It solves key integrity issues like micro-annuli, and debonding in harsh downhole conditions. Conventional resin-cement mixes often fail due to density-driven separation, causing incompatibility and a non-homogeneous slurry. RIC counters this with proprietary chemistry of dry and liquid additives, ensuring uniform resin dispersion, additive compatibility, and strong adhesion to casing and formations.

RIC excels over traditional cement in flexibility and durability. Portland cement is economical but rigid—high Young's modulus, low toughness, moderate bonds, and permeable set cement sheath—leading to stress-induced cracks. RIC cuts Young's modulus while boosting flexibility against temperature, pressure, and mechanical loads. The RIC system shows an increase in modulus of toughness against conventional cement blends, absorbing energy to resist fracture. In cyclic pressure wells such as injection wells, it adapts to expansions/contractions, preventing fatigue cracks and prolonging life. In mobile formations such as highly mobile salts, lower stiffness allows elastic deformation, easing shear stress and avoiding debonding or isolation failures. Shear bonding to casing and formation shows formidable adhesion, curbing migration; permeability falls, compressive strength rises, fluid loss drops, and free fluid is non-existent. Typical temperature profile of this system can range from Surface ambient to 200ºF+, and density of the systems can be run from a conventional 10 ppg up to a heavyweight 18 ppg slurry.

Economically, RIC delivers resin's premium traits—impermeability, resilience—through bulk cement, using 10-30% resin to cut costs dramatically versus pure resin. This system is ideal for P&A, HPHT wells, and injection applications.

Ultimately, RIC transforms zonal isolation: cement strength plus resin agility, affordably, for enduring well integrity.

## INTRODUCTION

Portland cement has been the default wellbore sealant for over a century. It is economical, widely available, and well understood. But it has real limitations. Set cement is a ceramic-like material—stiff, brittle, and weak in tension. It fails suddenly with little plastic deformation. This makes it a poor choice for wells that see cyclic thermal and pressure loads: injection wells, production wells undergoing stimulation, and wells drilled through mobile formations like salt. When the cement sheath cracks or debonds, it can create connected micro-annuli that serve as flow paths for unwanted fluid migration, leading to sustained casing pressure and zonal isolation failure.

Cement's particle size is another fundamental challenge. The solids in oilwell cement slurry are too large to penetrate small flow channels like formation porosity or an existing micro-annulus. Cement seals in these situations depend entirely on surface bonding. Jones and Watters (1998) estimate squeeze cementing success at 50% or less. Cowan (2007) analyzed a large data set in the Permian Basin and found a first-attempt squeeze success rate of only 34%, with many wells requiring two or more attempts. These numbers point to a basic mismatch between the sealant material and the job it is asked to do.

Epoxy resin is a fundamentally different material. It is a thermosetting polymer that behaves as a true fluid during its set reaction—meaning it can penetrate formation porosity, sand packs, and micro-annuli that cement cannot reach (Sabins and Watters, 2020). Once cured, resin exhibits high compressive and tensile strength, low stiffness, higher adhesion strength, and substantially greater energy absorption than cement. Previous laboratory testing has shown that resin provides a 400% increase in shear bond strength compared to conventional cement (Arroyave et al., 2021). Resin shrinkage during curing concludes at least seven hours before the onset of adhesion, which means the material bonds to pipe and formation only after dimensional changes have stopped. The set resin is impermeable to gas, non-shrinking, corrosion resistance and can be drilled out with standard tools.

The drawback of pure resin is higher cost relative to cement. At roughly 9.3 ppg base density and premium pricing, a full resin system is economically impractical for large-volume applications. The RIC system solves this by incorporating 10–30% resin by volume into a cement slurry, delivering the mechanical benefits of resin with an increase in volume for the application. The resin component forms a cross-linked matrix within the cement that adds ductility, energy absorption, and bond strength to the overall system (Al-Yami et al., 2023). This paper quantifies those improvements across multiple cement blend families.

## TEST METHODOLOGY

### *System Designs*

Three families of cement blends were tested: neat Class-C cement, pozzolan-extended cement (Poz:C), and RIC systems at 10%, 20%, and 30% resin by volume. Each was tested at 13.7 ppg and 14.8 ppg where applicable. All blends used API Class-C cement as the base. The RIC systems incorporated an epoxy resin component with a stoichiometric hardener, and fluid loss stabilizing emulsifier. Table 1 summarizes the test matrix.

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**Commented [MS2R1]:** Yes I will include that.

**Table 1 - System Designs Tested**

| System | Density (ppg) | Temperature (°F) | Resin (%) |
|---|---|---|---|
| Neat Class C | 13.7 | 99 | 0 |
| Neat Class C | 14.8 | 99 | 0 |
| Poz:C | 13.7 | 99 | 0 |
| C + 10% RIC | 13.7 | 99 | 10 |
| C + 20% RIC | 13.7 | 99 | 20 |
| C + 30% RIC | 13.7 | 99 | 30 |
| Poz:C + 10% RIC | 13.7 | 99 | 10 |
| Poz:C + 20% RIC | 13.7 | 99 | 20 |
| Poz:C + 30% RIC | 13.7 | 99 | 30 |
| C + 10% RIC | 14.8 | 99 | 10 |
| C + 20% RIC | 14.8 | 99 | 20 |
| C + 30% RIC | 14.8 | 99 | 30 |

### *Testing Procedures*

All slurry preparation and testing followed API Recommended Practice 10B-2. Slurry-state properties measured included rheology at 80°F, 99°F, fluid loss, free fluid, and thickening time. Samples were cured at a downhole temperature of 99ºF and tested for 24-hour crush strength using 2”x2”x2” cubes under load of a hydraulic press.

Samples are cured in 2 in. × 4.1 in. cylindrical molds, demolded, and trimmed to a final length of 4.0 in. Each sample is fitted with Epsilon Diametral and Averaging Axial Extensometers and tested in a Chandler 4207D at the API Slow load rate of 4,000 lbf/min until failure. Raw data (Time, Load, Diametral Displacement, Axial Displacement) is trimmed to the active loading window, then used to calculate axial stress and strain. Young's modulus and Poisson's ratio are derived from the slope and lateral-to-longitudinal strain ratio over the most linear pre-yield region of the stress-strain curve, respectively, and toughness is calculated as the area under the curve using the trapezoidal rule.

## RESULTS AND DISCUSSION

### *Slurry-State Properties*

Table 2 summarizes the slurry-state properties. The most notable finding is that every RIC system tested showed zero free fluid, compared to measurable free fluid in the neat cement baselines. Free fluid in a cement sheath can create channels and/or voids that compromise isolation, and eliminating it entirely is a meaningful purpose. Fluid loss values for RIC systems were also generally lower than their neat counterparts. This is a result of the addition of the emulsifying additive introduced into the system. Low fluid loss in squeeze and remedial applications allow for the slurry to properly penetrate the void space without prematurely dehydrating and creating a node on the injection point and limiting the level of penetration to the treatment zone.

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Thickening times remained workable across all blends, though the higher resin concentrations resulted in a decrease of working time on the mixture. The general idea of the thickening times is that they are based on the cement itself, as the percentage of resin increases it is removing water from the system creating a shorter thickening time. The 20% systems, by contrast, maintained 8+ hour thickening times with manageable rheology across all blends and the resin portion of the mixture can be accelerated with a resin activator if required.

**Table 2 - Slurry-State Properties Summary**

| System | Density (ppg) | Free Fluid (mL / %) | Fluid Loss (mL) | Thickening Time (70bc) | 24-hr Crush (psi) | PV/YP (80°F) |
|---|---|---|---|---|---|---|
| Neat Class C | 13.7 | 22 / 8.8 | 626 | 7:15 | 953 | 14 / 11 |
| PozC | 13.7 | 20 / 8.0 | 854 | 11:01 | 272 | 15 / 8 |
| Neat Class C | 14.8 | 0 / 0 | 745 | 3:52 | 1,733 | 33 / 26 |
| C + 10% RIC | 13.7 | 0 / 0 | 67 | 8:37 | 1,201 | 67 / 19 |
| C + 20% RIC | 13.7 | 0 / 0 | 199 | 8:19 | 1,270 | 83 / 41 |
| C + 30% RIC | 13.7 | 0 / 0 | 226 | 6:27 | 2,155 | 190 / 134 |
| PozC + 10% RIC | 13.7 | 0 / 0 | 30 | 9:45 | 895 | 83 / 19 |
| PozC + 20% RIC | 13.7 | 0 / 0 | 136 | 8:37 | 753 | 216 / 39 |
| PozC + 30% RIC | 13.7 | 0 / 0 | 282 | 1:26 | 774 | 363 / 131 |
| C + 10% RIC | 14.8 | 0 / 0 | 105 | 4:23 | 1,974 | 220 / 82 |
| C + 20% RIC | 14.8 | 0 / 0 | 52 | 4:29 | 2,922 | 307 / 94 |

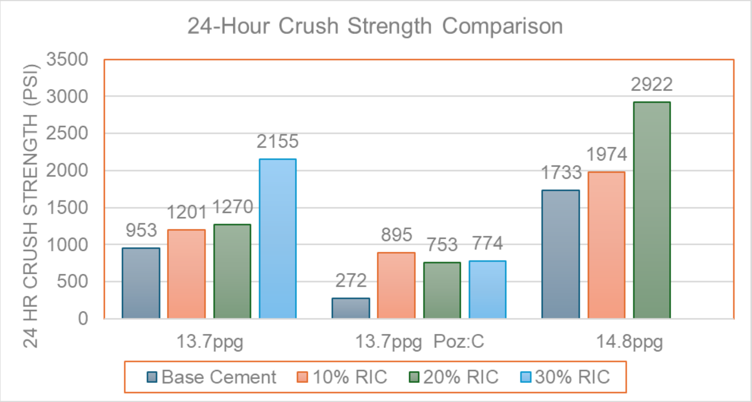

Figure 1 - 24-Hour Crush Strength Comparison

24-hour crush strength increased proportionally with resin concentration across both densities. C + 20% RIC at 14.8 ppg hit 2,922 psi—a 69% increase over the 1,733 psi baseline. At 13.7 ppg, C + 30% RIC reached 2,155 psi versus 953 psi for neat cement, a 126% improvement. Even at 13.7 ppg, C + 20% RIC delivered 1,270 psi, a 33% gain that indicates the resin is contributing measurable strength even at lower concentrations and lighter densities.

### *Compressive Strength*

The mechanical testing is unmistakable evidence of a higher quality, more robust, tougher and resilient slurry system. Table 3 presents the average results for all systems.

**Table 3 - Average Mechanical Properties (3-Sample Average)**

| System | Density (ppg) | Avg UCS (psi) | Avg YM (psi) | Avg Poisson’s Ratio | Avg Toughness (BTU/$ft^3$) |
|---|---|---|---|---|---|
| Neat Class C | 13.7 | 1,535 | 1.03E+06 | 0.204 | 0.44 |
| C + 10% RIC | 13.7 | 1,597 | 9.33E+05 | 0.227 | 0.46 |
| C + 20% RIC | 13.7 | 1,689 | 9.04E+05 | 0.273 | 1.05 |
| C + 30% RIC | 13.7 | 3,502 | 1.03E+06 | 0.296 | 1.66 |
| Poz:C | 13.7 | 1,081 | 1.12E+06 | 0.169 | 0.22 |
| Poz:C + 10% RIC | 13.7 | 1,362 | 8.32E+05 | 0.184 | 0.29 |
| Poz:C + 20% RIC | 13.7 | 1,939 | 8.98E+05 | 0.217 | 0.55 |
| Poz:C + 30% RIC | 13.7 | 2,861 | 8.69E+05 | 0.255 | 1.54 |
| Neat Class C | 14.8 | 3,041 | 1.42E+06 | 0.232 | 0.94 |
| C + 10% RIC | 14.8 | 4,039 | 1.31E+06 | 0.217 | 2.39 |
| C + 20% RIC | 14.8 | 7,194 | 1.58E+06 | 0.255 | 6.43 |
| C + 30% RIC | 14.8 | 5,864 | 1.64E+06 | 0.307 | 4.02 |
| **Pure Resin* | *9.3* | *8898* | *3.72E+05* | *0.48* | *8.2* |

**Pure resin property data was historical data from Riteks at 190°F for illustrative comparison. Compressive strength defined here as the maximum load before significant deformation.*

The standout result is the C + 20% RIC at 14.8 ppg: 7,194 psi average Unconfined Compressive Strength (UCS), a 137% increase over the 3,041 psi base cement. The Poz:C blends followed a similar trend—Poz:C + 20% RIC hit 1,939 psi versus 1,081 psi for the base Poz:C, a 79% gain. At 30% resin, the Poz:C blend reached 2,861 psi (165% improvement), but at the cost of a PV/YP of 363/132 and a potential of adding retarder if the job design required a longer working time.

The telling data point is what happened in the 14.8 ppg blends at 30% resin. UCS decreased to 5,864 psi—well below the 20% system’s 7,194 psi. And the 30% formulation at 14.8 ppg had to be removed from the test program entirely because it could not be mixed. This signals that 20% is the practical ceiling for resin loading in this system. Beyond 20%, the slurry becomes difficult to mix and the mechanical returns diminish at increasing density.

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**Commented [LA7]:** We likely don’t have the data, but do you think if we pre-weighted the resin we could resolve this issue? Just a thought to increase the operation envelope.

**Commented [MS8R7]:** Potentially. I think for the purposes of this as a straight comparison it leaves room for further investigation into other loading efficiencies.

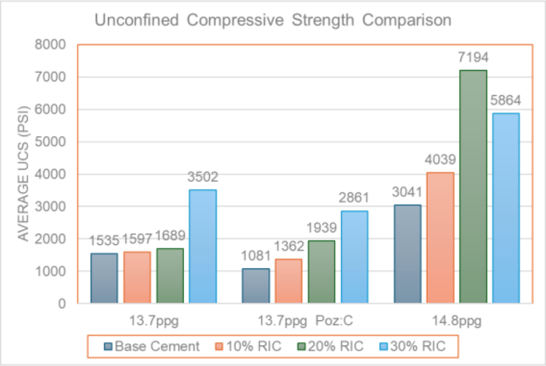

Figure 2 - Ultimate Compressive Strength Comparison

*Young's Modulus and Flexibility*

A lower Young's modulus means a more flexible, resilient cement sheath—one that can be exposed to strain without breaking. In injection wells, that flexibility lets the sheath accommodate repeated thermal and pressure cycles without developing fatigue cracks. As a barrier over salt formations, it allows elastic deformation under formation loading instead of brittle failure at the casing-cement interface.

The 13.7 ppg Neat Class C blends showed consistent young's modulus reductions with resin addition: C + 10% RIC was 9.4% lower (933,263 psi versus. 1,029,996 psi), and C + 20% RIC was 12.2% lower (904,268 psi). The Poz:C blends showed sizable improvement—Poz:C + 10% RIC achieved a 25.7% young's modulus reduction versus base Poz:C (832,026 psi vs. 1,120,385 psi). The C + 20% RIC again shows this is the optimal loading level: meaningful stiffness reduction with no slurry stability concerns. The 30% systems show comparable flexibility in some blends, but the rheological tradeoff may not justify the marginal gain.

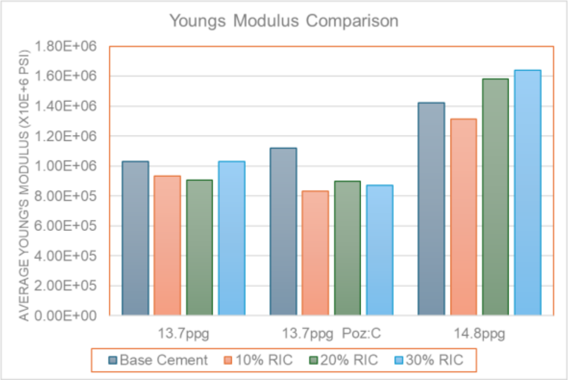

Figure 3 - Young's Modulus Comparison

*Modulus of Toughness*

Toughness is the total energy a material absorbs before it fails. It is the area under the entire stress-strain curve (Figure 7). For a cement sheath that must survive decades of well operations, it is arguably the most important property of the set.

The data shows the undeniable benefits of the RIC systems. C + 20% RIC at 14.8 ppg delivered 6.43 BTU/ft³—the highest value in the entire test program—compared to 0.94 BTU/ft³ for the base cement. That is a 587% improvement, more than half an order of magnitude gain. The C + 30% RIC at 14.8 ppg came in lower at 4.02 BTU/ft³, again confirming that 20% is the optimal solution. The Poz:C blends showed a similar pattern: Poz:C + 30% RIC reached 1.54 BTU/ft³ versus 0.22 BTU/ft³ for base Poz:C (593% gain), while Poz:C + 20% RIC delivered a solid 147% increase with much more manageable slurry properties.

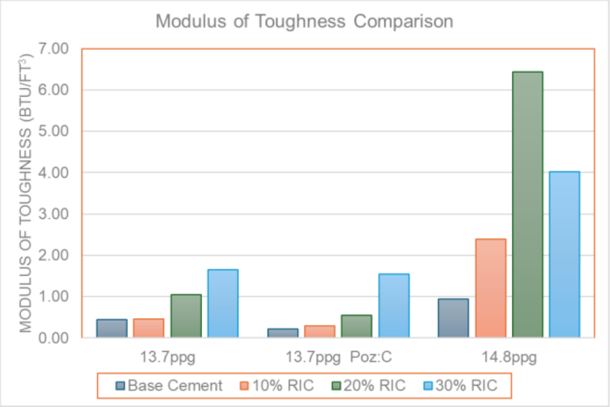

Figure 4 - Modulus of Toughness Comparison

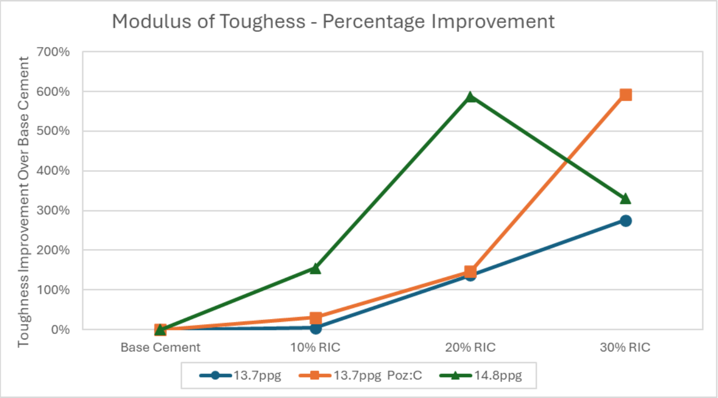

Figure 5 - Toughness: Percentage Improvement Over Base Cement

*Poisson's Ratio*

Poisson's ratio increased with resin content across all blends. In the 13.7 ppg Neat Class C systems, it went from 0.204 for base cement to 0.273 at 20% RIC (34% increase) and 0.296 at 30% RIC (45%). At 14.8 ppg, it rose from 0.232 to 0.255 at 20% and 0.307 at 30%. Higher Poisson's ratio means the material distributes stress laterally under axial load rather than concentrating it at failure-prone interfaces. For a cement sheath, this translates to better load sharing between the casing, cement, and formation.

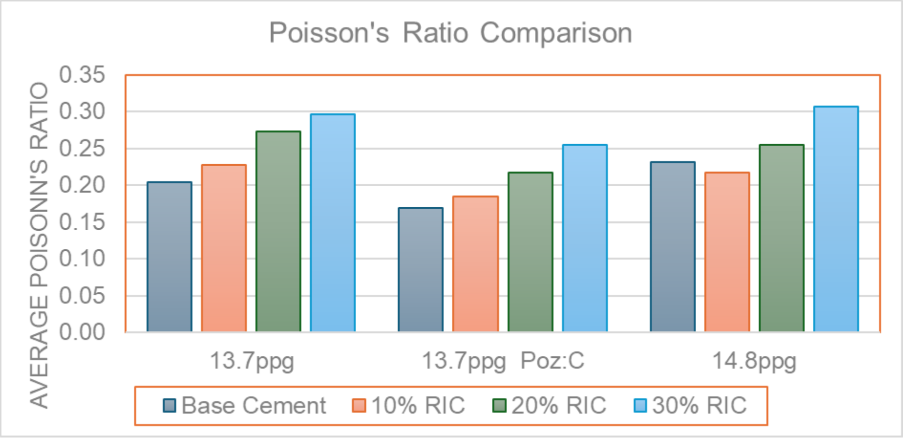

Figure 6 - Poisson's Ratio Comparison

*Bond Adhesion Considerations*

While this test program focused on bulk mechanical properties rather than bond adhesion testing, the contribution of epoxy resin to bond strength is well documented in the literature and warrants discussion. The resin component of the RIC system bonds to steel and formation surfaces through both chemical adhesion and mechanical interlock. Unlike Portland cement—which relies on surface contact of hydrated particles—epoxy resin wets and penetrates the substrate surface as a true fluid before cross-linking into a rigid thermoset. This produces a fundamentally stronger bond at both the casing-cement and cement-formation interfaces.

Previous laboratory testing on comparable epoxy resin systems has demonstrated a 400% increase in shear bond strength to casing compared to conventional cement (Arroyave et al., 2021). Al-Yami et al. (2023) reported that resin-cement blends provide increased shear bond strength and ductility that help prevent sustained casing pressure by creating a more reliable barrier at the casing interface. Jadhav et al. (2017) showed that thermosetting resin coatings on casing enhanced shear bond strength compared to uncoated controls, and Sabins and Watters (2020) documented the resin's ability to flow into sand packs, gravel packs, and formation porosity under gravity alone creating a seal through mechanical interlock in areas that cement slurry physically cannot enter.

The practical implication is that the RIC system benefits from both mechanisms: the cement matrix provides bulk fill and structural support, while the resin component delivers superior adhesion at the interfaces where micro-annuli form and zonal isolation is lost. Bond adhesion testing of the RIC system specifically is planned as a follow-up to this study.

## FIELD APPLICATION RELEVANCE

### *Remedial Squeeze and Zonal Isolation*

RIC is well suited for squeeze operations. The resin component's fluid-state behavior means the slurry can penetrate micro-annuli and formation porosity where conventional cement bridges off at the surface. The cement matrix provides bulk fill. Combined with zero free fluid, improved compressive strength, and the resin's adhesion characteristics, RIC offers a path to higher squeeze success rates—a meaningful improvement over the 34–50% success rates documented for cement squeeze (Jones and Watters, 1998; Cowan, 2007).

### *Mobile Formations*

Salt zones and other mobile formations impose significant external loading on the cement sheath. Conventional cement is too stiff to accommodate this—it can potentially crack or debonds if the stress environment exceeds the mechanical properties of the system. RIC's lower Young's modulus lets the sheath deform elastically under load, and the higher Poisson's ratio distributes stress laterally instead of concentrating it at the casing-cement interface. The increased toughness provides margin—the sheath absorbs more energy before reaching failure.

### *Injection Well Cyclic Pressures*

Injection wells see repeated pressurization and depressurization cycles with corresponding thermal swings. Each cycle imposes alternating tensile and compressive stresses on the cement sheath. Conventional cement, with its higher young's modulus and low toughness, can accumulate fatigue damage over time. RIC's flexibility and dramatically higher energy absorption capacity let the sheath absorb these cycles without cracking. That translates directly to longer well life and fewer remedial interventions.

### *Plug and Abandonment*

For P&A, the RIC system provides a more durable, impermeable barrier. Zero free fluid mitigates the risk of channel formation within the plug. The enhanced mechanical properties ensure the plug holds up over the long term under geological stresses and pressure differentials. The system's temperature range (surface ambient to 200°F+) and density flexibility (10 to 18 ppg) make it adaptable to a wide range of P&A scenarios.

## CONCLUSIONS

1. The C + 20% RIC formulation is the recommended concentration, delivering peak mechanical performance with field-practical slurry properties. The 30% in high density systems showed diminishing returns in strength and toughness and, in one case, proved unmixable. In lower density systems the 30% improve mechanical properties.

2. UCS improvements of up to 137% (C + 20% RIC at 14.8 ppg) were achieved. In the Poz:C blends, improvements reached 165% at 30% resin loading.

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3. Modulus of toughness—the material's total energy absorption capacity—improved by up to 587% (C + 20% RIC at 14.8 ppg). This was the highest value in the test program and represents a near order-of-magnitude increase in fracture resistance.

4. Young's modulus reductions of up to 25.7% were observed in the Poz:C RIC blends, indicating a more flexible/resilient cement sheath capable of surviving cyclic loading and mobile formation stresses.

5. All RIC systems exhibited zero free fluid and maintained operationally viable thickening times. The 20% concentration maintained manageable rheology across all blend families.

6. Published literature supports a 400% increase in shear bond strength for epoxy resin versus conventional cement. Bond adhesion testing of the RIC system is recommended as follow-on work.

These results support the use of RIC in applications where conventional cement has historically struggled to effectively meet downhole challenges experienced through the life of the well: remedial squeeze, zonal isolation in mobile formations, injection well cyclic service, and P&A. The system delivers resin-class mechanical performance at a fraction of pure resin cost. Field trials, engineering modeling and long-term durability testing are recommended to validate these lab results under downhole conditions.

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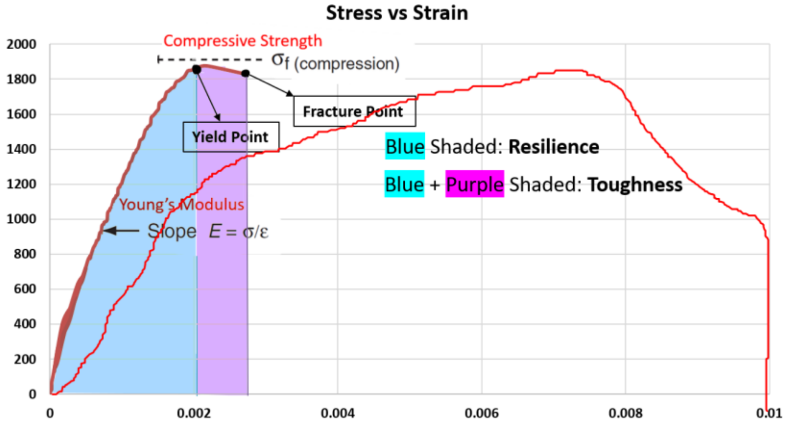

Figure 7 - Stress vs. Strain Curve Illustrating Mechanical Property Relationships

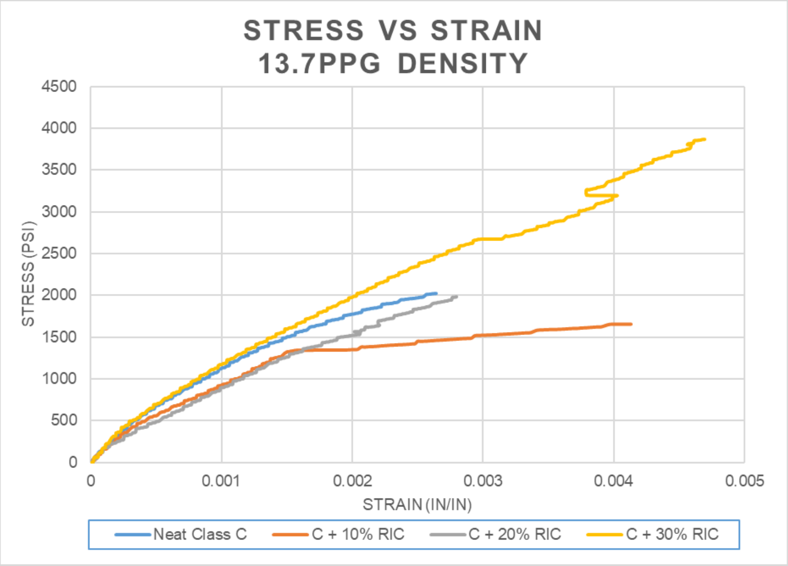

Figure 8 - Stress vs. Strain Curve Neat C with RIC Concentrations

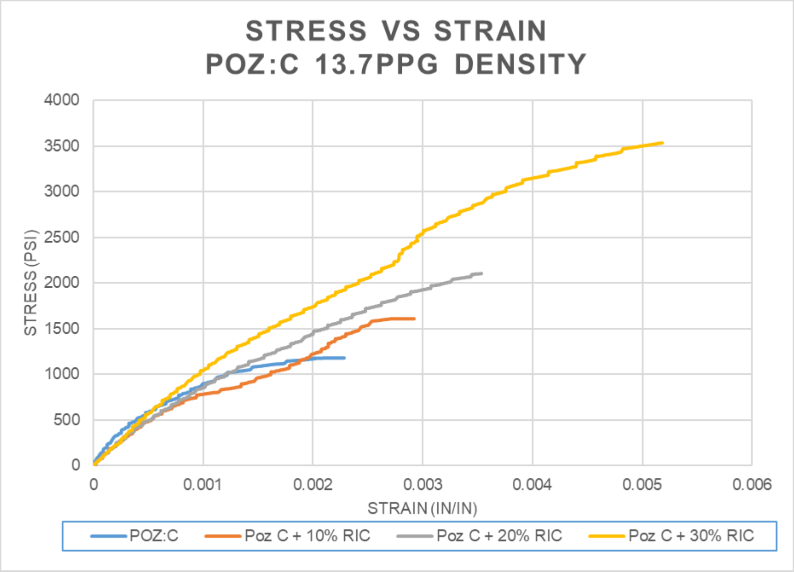

Figure 9 - Stress vs. Strain Curve Poz:C with RIC Concentrations

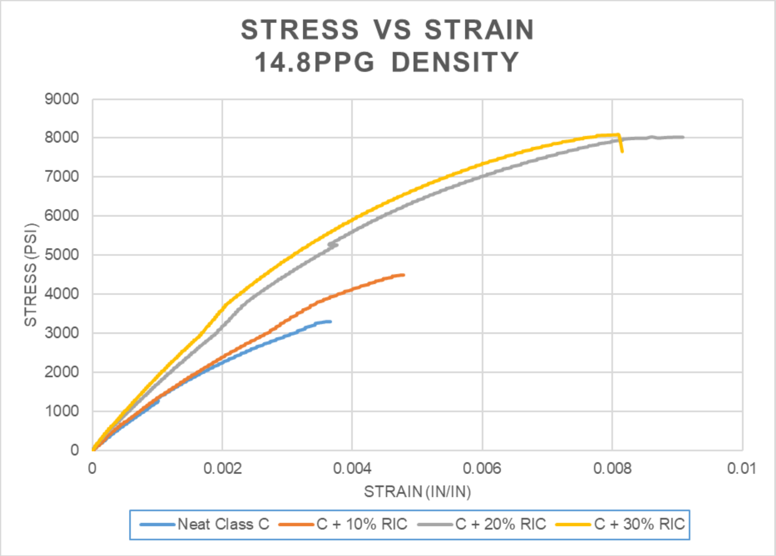

Figure 10 - Stress vs. Strain Curve Poz:C with RIC Concentrations

Figure 11 - Uniaxial Compression Test Setup with Epsilon Extensometer for Stress-Strain Measurement

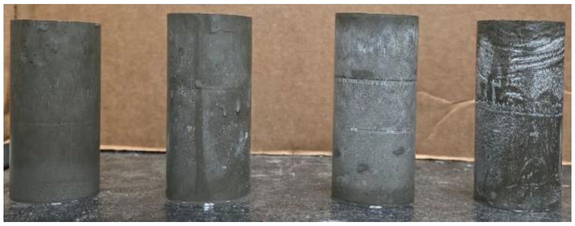

Figure 12 - 13.7 ppg Neat Class C Specimens (Left to Right: 0%,10%,20%,30% Resin)

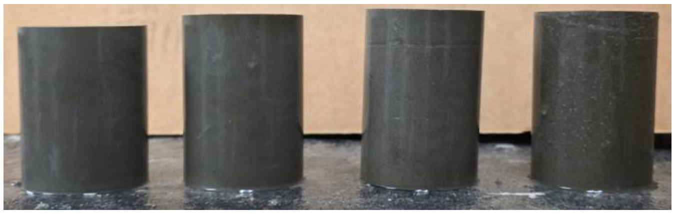

Figure 13 - 13.7 ppg Poz:C Test Specimens (Left to Right: 0%,10%,20%,30% Resin)

Figure 14 - 14.8 ppg Neat Class C Specimens (Left to Right: 0%,10%,20%,30% Resin)