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**Annex C on 10TR7**
**Procedure and Test Results from Work Group 9 Cooperative Testing**

## C.1 General Scope

Our Work Group (WG9) was charged with investigating and developing a standardized test procedure for determining Triaxial Elastic Mechanical Properties of cement under confining pressures. This report presents the outcome of that effort. The procedure described here is derived from several methods already in use within the industry, consolidated into a single, agreed-upon approach.

We conducted two rounds of cooperative testing, with more than six laboratories participating. In the first round, we tested aluminum cylinder specimens 1" and 2" (25 mm and 50 mm) in diameter. In the second round, cement cylinders of the same sizes were used. Testing variables included specimen size and material, loading rate and control feedback, confined versus unconfined conditions, and differences in laboratory, personnel, and equipment. The cement specimens underwent a long curing period (90+ days), and the Labs ran their tests according to the agreed upon procedure. Furthermore, a single calculation method for calculating elastic properties was applied across all labs. As a result, the cooperative testing produced results within 3% of the group average for round one, and within 25% of the group average for round two. These results demonstrate the benefits of standardizing procedures as well as the variance still seen within labs.

## C.2 Test Procedure for determining triaxial elastic mechanical properties of cement under confining pressures

### C.2.1 Overview:

This procedure was used for both rounds of testing with minor variation for aluminum and cement specimens. The first set of tests were run without confining pressure (or Unconfined). Then several tests were run with confining pressure (6.9 MPa (1000 psi)) applied. Each specimen was tested in two stages (or dual-stage) with the first stage applying axial stress up to 50% of expected UCS (Unconfined Compressive Strength). Then relieving the stress to below 3.5 MPa (500 psi) and in the second stage stress was applied until specimen failure.

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For the first round with aluminum specimens, some tests were run using deviator stress feedback control (adjusting the strain to maintain a constant stress rate) and the rest of the tests were run using axial strain feedback control (adjusting the stress to maintain a constant strain rate). Since there was little difference between the two methods of control feedback, we used just strain control in the second round. However, this should not be taken to infer preference of strain over stress control as both methods are acceptable.

For the second round with Cement, a class C mixed at 15.4ppg (1845.3 kg/m$^3$) was used. The slurry was mixed, and specimens cured, in one lab for the entire group. Each lab prepared their specimen and ran the tests according to the procedure detailed below.

There are three factors that will significantly affect the results from mechanical properties testing including- Specimen, Testing, and Calculation. Procedures for producing cement Specimens cover mixing, curing, specimen QC, specimen preparation, and building the platen assembly. Procedures for Testing cover setting up the test program and running the test. Procedures for Calculating results cover data to extract and share, a method for calculating Youngs and Poisson's, and what information should be shared about testing.

## C.2.2 SPECIMEN

Cement slurries should be tested to ensure stability and free water control prior to being used for mechanical property testing. Mixing of the cement slurry should be done according to API RP 10B-2. Any deviations to that procedure should be documented in the report. Once mixed, the slurry should be poured in the prepared mold and cured following the recommendations from section 7 of API RP 10 B-2.

Molds should be capable of producing specimens of the appropriate diameter- 1", 1 ½ ", or 2" (25mm, 38mm, and 51mm respectively). The length of the specimen when tested should twice the diameter (ASTM D7012, section 8.2, suggests a ratio of 2:1 or 2.5:1 length:diameter). Since both ends of the specimen need to be cut off and the surfaces grinded, the mold length should be 0.5 inches (13mm) longer than the desired specimen length.

After curing is completed, the specimen should be kept wet when not being tested. Specimens from the mold should be cleaned of any residue. Both ends should be cut off and a grinder used to surface the ends until they are parallel to each other. Then the

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specimen diameter, length, weight, and density should be measured and reported. Other QC procedures may be helpful including photographs and CT-Scan if available.

## C.2.3 Testing

### C.2.3.1 Generalized Equipment Setup

Approximately 10 different models of Load Frames were used with slightly different methods of programing and operation. The information below were guidelines that each lab implemented for their specific equipment. Each lab also ensured their equipment was calibrated before each round of testing. This includes primarily the pressure transducer (used to measure axial stress and confining stress) and all strain sensors (axial and radial). Temperature control systems were calibrated if applicable.

### C.2.3.2 Test Parameters

The Load-Frames were programed with the following steps:

1) Bring platens into contact with Load Frame Arm and apply a seating load of 0.34 to 0.68 MPa (50 to 100 psi).

2) Apply deviatoric axial stress up to 50% of Unconfined Compressive Strength. -or 69 MPa (or 10,000 psi) for aluminum in Round 1

~approximately 13.79 to 20.68 MPa (or 2000 to 3000 psi) for cement in Round 2

3) Feedback control for Strain should be set to a rate of 0.01% /minute. If set to Stress Control, it should be set to 4.13 MPa/min (600 psi/min).

4) End condition for cement failure should be at Peak Reversal of 2.1 to 3.5 MPa (300-500 psi).

5) Relieve Axial Stress to 1.4 MPa (200 psi). (just enough to maintain contact)

6) Apply deviatoric axial stress until failure (or 68.95 MPa (15,000 psi) for aluminum specimen) at same rates as first cycle.

7) Return ‘head’ to the original position (or slightly above original position)

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### C.2.3.3 Test steps

Install the Specimen Assembly into the load frame and measure the Axial Gage Length. This measurement should be recorded and reported. Then the Deformation sensors (2 axial and the radial sensor(s) installed. If running the confined tests, bring the pressure vessel up (or install it if separate) and fill the vessel with Oil. Following the manufacturer's instructions- bring the cell pressure up to 6.9 MPa (1000 psi) and zero out the deformation sensors. Start the tests and repeat until finished with all specimens.

### C.2.3.4 Note on Test Conditions

Two factors that play a significant role in how cement will behave (or deform) when stress is applied are- the rate that stress is applied and whether, or not, the pore fluid is allowed to escape (or flow).

There is a wide range of stress application rates that laboratories can use in their mechanical property testing. There are also several methods of controlling that rate through different feedback sensors- including LVDT's, transducers, and calculated values. It is important to consider these factors when comparing results between tests run under different conditions. Especially when comparing tests run under Drained conditions versus Undrained conditions.

All tests were conducted in a Drained-state, although one lab did run a test in undrained condition. The state of 'Drained' or 'Undrained' refers to the fluid in the pore space of the specimen, whether this pore-fluid is allowed to escape during the test (drained) or if it is trapped (or not allowed) in the specimen (undrained). In a drained test, the fluid flows out of (or in) the specimen as stress is applied. In an undrained test, the fluid is prevented from flowing as stress is applied.

The selection of drained or undrained testing conditions should be based on the anticipated service environment and the objectives of the analysis. Drained test conditions are generally appropriate when simulating scenarios involving highly permeable formations or situations where long-term equilibrium is expected, as these allow pore fluids to escape during loading. Conversely, undrained test conditions should be selected for analyses representing low-permeability (impermeable) formations, cased-hole in-situ environments, or scenarios involving rapid, short-term loading, where pore fluids are effectively trapped within the specimen. The rationale for the chosen test condition must be documented for each test.

Pore-fluids are made up of mostly mix-water in cement specimens, and this water is nearly incompressible. When stress (compressive load or confining pressure) is applied,

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both the cements solid 'skeleton' and the pore-fluid compress together. If the pore-fluid is prevented from escaping it will add to the overall stiffness of the specimen and results in a higher bulk modulus than when the fluid is allowed to escape.

## C.2.4 Calculations Used For Analysis

Refer to section 4.4.3 in this report for formulas, definitions, and descriptions of calculating elastic properties.

Results from the cooperative testing were all calculated with a simple slope method with strains and stresses. Axial strain ($\varepsilon_a$) was determined by dividing the average displacement measured by both axial sensors by the axial gauge length (original length covered by the sensors). $\varepsilon_a = \Delta L / L_0$

Radial strain ($\varepsilon_r$) was measured with different types of sensors but calculated as the change in radius divided by the original radius. $\varepsilon_r = \Delta r / r_0$

Elastic moduli were determined over a stress range of 25 to 50% of the unconfined compressive strength (UCS). Within this range, initial and final stress-strain points were identified to calculate the incremental changes in stress ($\Delta\sigma$) and strain ($\Delta\varepsilon$). Young's Modulus (E) was then calculated as: $E = \Delta\sigma / \Delta\varepsilon_a$

Poisson's Ratio (v) was determined from the ratio of lateral to axial strain: $v = -\Delta\varepsilon_r / \Delta\varepsilon_a$

## C.2.5 Results that Should Be Reported

In addition to elastic property results, the following information from each test should be included in reporting:

1) **Specimen characteristics:** length, diameter, mass, end planeness tolerance, and density
2) **Axial gauge length** used for strain measurements
3) **Test deviations:** documentation of any departures from standard procedures
4) **Software output data:** The data acquisition system should record the following parameters at each time step:
    - Axial stress, Confining pressure, Temperature

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- Axial Displacement Sensor 1, Axial Displacement Sensor 2, Average 1&2, and Circumferential Deformation Sensor(s).

## C.3 TEST RESULTS

Our first round of testing on both Aluminum Cylinders was conducted in 2023. A member of our API Work Group was able to produce several each of both size cylinders from the same Aluminum 6061 stock (# 409 6-154). These samples were sent to each lab where the lab technicians verified the dimensions of each specimen were within 0.005" (or 0.127mm) of the requirements.

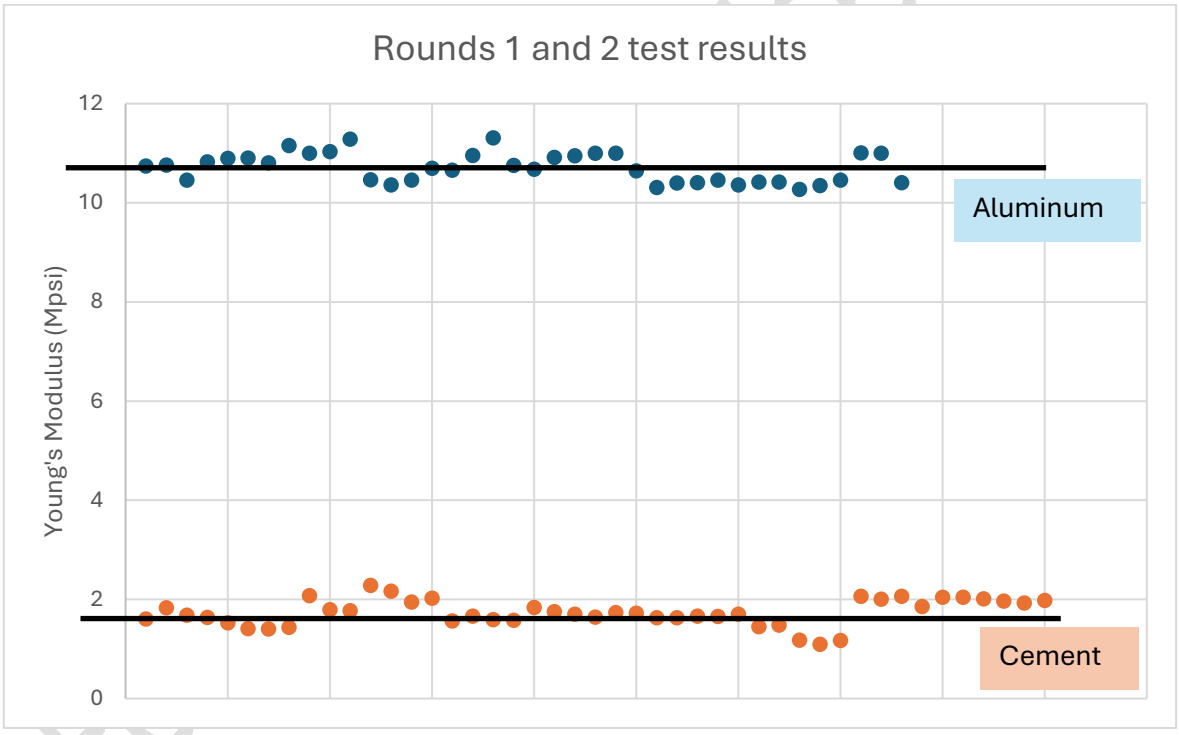



Figure C.1 Summary Test Results

Results from the first round are below:

Table C.1- Round 1 Young's Modulus

| Round 1 – Aluminum – Young's Modulus (MPa) |
|---|

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| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 |
|---|---|---|---|---|---|---|---|
| Lab A 1” | 74,063 | 74,229 | 72,112 | 74,670 | 75,153 | 75,180 | 74,532 |
| Lab B 1" | 76,939 | 75,849 | 76,091 | 77,800 | 72,167 | 71,457 | 72,099 |
| Lab B 2" | 73,774 | 73,512 | 75,539 | 77,973 | 74,174 | 73,608 | 75,263 |
| Lab C 2” | 75,491 | 75,863 | 75,877 | 73,429 | - | - | - |
| | 71,071 | 71,733 | 71,754 | 72,126 | - | - | - |
| Lab E 2" | 71,430 | 71,843 | 71,843 | 70,809 | 71,361 | - | - |
| Lab F 1" | 72,133 | 75,884 | 75,870 | 71,754 | - | - | - |

Table C.2- Round 1 Young’s Modulus

| Round 1 – Aluminum – Young's Modulus (Mpsi) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 |
| Lab A 1” | 10.742 | 10.766 | 10.459 | 10.83 | 10.9 | 10.904 | 10.81 |
| Lab B 1" | 11.159 | 11.001 | 11.036 | 11.284 | 10.467 | 10.364 | 10.457 |
| Lab B 2" | 10.7000 | 10.6620 | 10.9560 | 11.3090 | 10.7580 | 10.6760 | 10.9160 |
| Lab C 2” | 10.949 | 11.003 | 11.005 | 10.65 | - | - | - |
| | 10.308 | 10.404 | 10.407 | 10.461 | - | - | - |
| Lab E 2" | 10.36 | 10.42 | 10.42 | 10.27 | 10.35 | - | - |
| Lab F 1" | 10.462 | 11.006 | 11.004 | 10.407 | - | - | - |

Table C.3- Round 1 Poisson's Ratio

| Round 1 – Aluminum – Poisson's Ratio | | | | | | | |
|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 |

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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Lab A 1" | - | - | - | - | - | - | - |
| Lab B 1" | 0.29 | 0.29 | 0.31 | 0.20 | 0.29 | 0.24 | 0.23 |
| Lab B 2" | 0.33 | 0.32 | 0.34 | 0.34 | 0.33 | 0.33 | 0.33 |
| Lab C 2” | 0.33 | 0.33 | 0.33 | 0.30 | - | - | - |
| | 0.30 | 0.30 | 0.32 | 0.32 | - | - | - |
| Lab E 2" | - | - | - | - | - | - | - |
| Lab F 1" | - | - | - | - | - | - | - |

Average Young's Modulus for Round 1 (on Aluminum) was **73,854 MPa** (**10.7116 Mpsi**). Five out of the six labs achieved results within 1% of the average, and the other lab averaged within 3%. The measured average for each laboratory are as follows:

Average Individual Labs: LabA- 74,277 MPa (10.773 Mpsi), LabB1- 74,629 (10.824), LabB2- 74,836 (10.854), LabC- 73,415 (10.648), LabE- 71,457 (10.364), LabF- 73,912 (10.720).

Results from the second round are below:

Table C.4- Round 2 Young’s Modulus

| Round 2 – Cement – Young's Modulus (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 | Sp.8 |
| Lab A 1" | 11,086 | 12,631 | 11,607 | 11,322 | 10,561 | 9,746 | 9,708 | 9,906 |
| Lab B 2" | 14,311 | 12,367 | 12,233 | - | - | - | - | - |
| Lab B 1” | 15,751 | 14,951 | 13,442 | 13,970 | - | - | - | - |
| Lab C 1" | 10,792 | 11,487 | 11,006 | 10,881 | 12,668 | 12,120 | 11,745 | - |
| Lab D2" | 11,348 | 11,973 | 11,864 | 11,274 | 11,239 | 11,499 | 11,429 | 11,766 |
| Lab E 1" | 10,019 | 10,249 | 8,130 | 7,547 | 8,103 | - | - | - |
| Lab F 1" | 14,250 | 13,821 | 14,238 | 12,805 | 14,087 | - | - | - |
| Lab F 2" | 14,087 | 13,890 | 13,570 | 13,316 | 13,662 | - | - | - |

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Table C.5- Round 2 Young's Modulus

| Round 2 – Cement – Young's Modulus (Mpsi) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 | Sp.8 |
| Lab A 1" | 1.6079 | 1.8319 | 1.6835 | 1.6421 | 1.5317 | 1.4135 | 1.408 | 1.4368 |
| Lab B 2" | 2.0756 | 1.7937 | 1.7743 | - | - | - | - | - |
| Lab B 1" | 2.2845 | 2.1685 | 1.9496 | 2.0262 | - | - | - | - |
| Lab C 1" | 1.5652 | 1.666 | 1.5963 | 1.5781 | 1.8373 | 1.7579 | 1.7034 | - |
| Lab D2" | 1.6459 | 1.7366 | 1.7207 | 1.6352 | 1.6301 | 1.6678 | 1.6576 | 1.7065 |
| Lab E 1" | 1.4532 | 1.4865 | 1.1792 | 1.0946 | 1.1752 | - | - | - |
| Lab F 1" | 2.0668 | 2.0045 | 2.0651 | 1.8572 | 2.0431 | - | - | - |
| Lab F 2" | 2.0431 | 2.0146 | 1.9682 | 1.9313 | 1.9815 | - | - | - |

Table C.6- Round 2 Compressive Strength

| Round 2 – Cement– Compressive Strength (MPa) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 | Sp.8 |
| Lab A 1" | 42.56 | 41.13 | 50.20 | 60.32 | 63.26 | 64.91 | 66.05 | 50.72 |
| Lab B 2" | 40.09 | 48.27 | 48.27 | - | - | - | - | - |
| Lab B 1" | 48.28 | 38.49 | 44.64 | 45.67 | - | - | - | - |
| Lab C 1" | - | - | - | - | 57.45 | 58.90 | 61.38 | 0.00 |
| Lab D2" | 50.04 | 54.04 | 45.64 | 53.92 | 55.44 | 54.00 | 55.02 | 53.55 |
| Lab E 1" | 44.22 | 53.44 | 39.75 | 46.89 | 51.98 | - | - | - |
| Lab F 1" | 49.99 | 55.19 | 50.94 | 56.97 | 52.33 | - | - | - |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lab F 2" | 51.57 | 50.93 | 55.91 | 56.60 | 57.32 | - | - | - |

Table C.7- Round 2 Compressive Strength

| Round 2 – Cement– Compressive Strength (PSI) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 | Sp.8 |
| Lab A 1" | 6,173 | 5,965 | 7,281 | 8,749 | 9,175 | 9,414 | 9,580 | 7,356 |
| Lab B 2" | 5,815 | 7,001 | 7,001 | - | - | - | - | - |
| Lab B 1” | 7,002 | 5,582 | 6,475 | 6,624 | - | - | - | - |
| Lab C 1" | - | - | - | - | 8,332 | 8,543 | 8,902 | - |
| Lab D2" | 7,258 | 7,838 | 6,620 | 7,820 | 8,041 | 7,832 | 7,980 | 7,767 |
| Lab E 1" | 6414 | 7751 | 5765 | 6801 | 7539 | - | - | - |
| Lab F 1" | 7,250 | 8,005 | 7,388 | 8,263 | 7,590 | - | - | - |
| Lab F 2" | 7,480 | 7,387 | 8,109 | 8,209 | 8,313 | - | - | - |

Table C.8- Round 2 Poisson’s Ratio

| Round 2 – Cement – Poisson's Ratio | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Description | Sp.1 | Sp.2 | Sp.3 | Sp.4 | Sp.5 | Sp.6 | Sp.7 | Sp.8 |
| Lab A 1" | 0.313 | 0.221 | 0.186 | 0.625 | 0.202 | 0.181 | 0.168 | 0.212 |
| Lab B 2" | 0.281 | 0.264 | 0.261 | - | - | - | - | - |
| Lab B 1” | 0.493 | 0.442 | - | - | - | - | - | - |
| Lab C 1" | 0.194 | 0.175 | 0.188 | 0.155 | 0.297 | 0.330 | 0.2839 | - |
| Lab D2" | 0.152 | 0.140 | 0.134 | 0.139 | 0.143 | 0.144 | 0.171 | 0.124 |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lab E 1" | - | 0.254 | 0.149 | 0.166 | 0.196 | - | - | - |
| Lab F 1" | 0.313 | 0.312 | 0.322 | - | - | - | - | - |
| Lab F 2" | 0.298 | 0.307 | 0.298 | - | - | - | - | - |

Average Young's Modulus for Round 2 (on Cement) was **11,966 MPa** (**1.7355 Mpsi**). Two labs out of the five labs achieved results within 4% of the average, and the other labs averaged 15% to 26%. The measured average for each laboratory are as follows:

Average Individual Labs: LabA- 10,818 MPa (1.569 Mpsi), LabB1- 13,858 (2.010), LabC- 11,528 (1.672), LabD- 11,549 (1.675), LabE- 8,812 (1.278), LabF- 13,776 (1.998).

### C.3.1 Variable Comparison of Young's Modulus

The Table shows the combined average Young's Modulus for each variable tested in rounds 1 and 2, and the percentage-range-of-results (+% to -%) to that combined variable average. While the ranges were much wider for the cement testing, this value includes the outliers. More than half the results were within 10% of the combined variable average. And more than 80% of the results were within 20% of the combined variable average.

Variable effects on the aluminum specimen tests were minor when comparing a combined average across all labs with the average Young's Modulus for Round 1. The difference between the 1" and 2" diameter test results were within 1% (0.132 Mpsi or 900 MPa) of each other. The difference between the unconfined and confined test results were within 0.2% (0.022 Mpsi or 115 MPa) of each other. The difference between the control rate test results were within 2% (1064 MPa (0.217 Mpsi)) of each other. The average Young's Modulus for each variable was within 1% of the Round 1 average value.

Table C.8- Variable Average Comparison

| Round's 1 & 2 Average | Young's Modulus Combined Averages | |
|---|---|---|
| Round 1<br>73,854 MPa (10.7116Mpsi) | 1" Diameter | 2" Diameter |
| | 74,332 MPa (10.781Mpsi) | 73,422 MPa (10.649Mpsi) |
| | +5% to -3% | +6 % to -4% |
| | Unconfined | Confined |
| | 73,891 MPa (10.717Mpsi) | 73,739 MPa (10.695Mpsi) |

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| | | |
|---|---|---|
| | +6% to -4% | +2% to -3% |
| | Strain | Stress |
| | 73,422 MPa (10.649Mpsi) | 74,918 MPa (10.866Mpsi) |
| | +5% to -4% | +4% to -5% |
| Round 2<br>11,966 MPa (1.7355Mpsi) | 1" Diameter | 2" Diameter |
| | 11,680 MPa (1.694Mpsi) | 12,486 MPa (1.811 Mpsi) |
| | +35% to -35% | +15 % to -10% |
| | Unconfined | Confined |
| | 12,348 MPa (1.791Mpsi) | 11,197 MPa (1.624 Mpsi) |
| | +28% to -34% | +26% to -33% |

The variable effects on cement testing were more noticeable than they were on the aluminum. The difference between the 1" and 2" diameter test results were within 7% (806 MPa (0.117 Mpsi) of each other. The difference between the unconfined and confined test results were within 10% (1151 MPa (0.167 Mpsi) of each other. The average Young's Modulus from the 1" specimens was within 2% of the round average, while for the 2" specimen, the deviation went to 4%. The average Young's Modulus from the unconfined was within 3% of the round average, while for the confined, the deviation went to 6%.

### C.3.2 Round 1- Lab Results

Lab A tested 1" diameter specimens at both confined and unconfined conditions, and under both stress/strain control methods. Average Young's Modulus for all tests was 74,227 MPa (10.773 Mpsi) (with 1 out of 7 results outside of 1 standard deviation of 0.151 or 1.4%). Average results for confined 74,953 MPa (10.871 Mpsi) and for the unconfined, it was 73,767 MPa (10.699 Mpsi). Average results for specimens tested under strain control was 74,146 MPa (10.754 Mpsi) and for stress control was 74,601 MPa (10.820 Mpsi).

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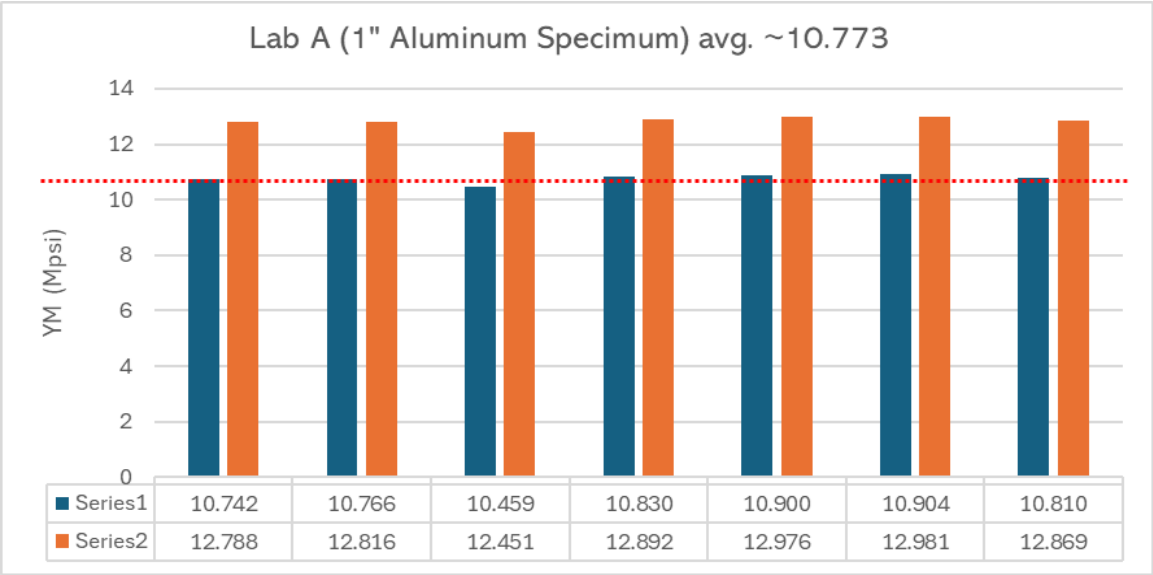



Figure C.2 Lab A Results

The second set of results on this graph has two sets of results to demonstrate the effects of accurately measuring the Axial Gage length. The much higher set of results come from including the platen material in the distance and deformation in the calculations. This axial gage distance was corrected in the formula and after this correction, the results were well within the 5% deviation of the combined average. This dimension is critical to measure accurately so that it includes the total length that is measured by the deformation sensors. This effect is more pronounced when testing cement, which has a relatively low Young's Modulus compared with aluminum.

Lab B tested both 1" and 2" diameter specimens at confined and unconfined conditions, and under both stress and strain control methods. Average Young's Modulus for all tests was 74,732MPa (10.839 Mpsi) (with 6 out of 14 results outside of 1 standard deviation of 0.304 or 2.8%). Average results for confined 74,953 MPa (10.871 Mpsi) and for the unconfined it was 73,767 MPa (10.699 Mpsi). Average results for 1" diameter specimen was 74,629 MPa (10.824 Mpsi) and for the 2" was 74,836 MPa (10.854 Mpsi). Average results for specimens tested under strain control was 74,312 MPa (10.778 Mpsi) and for stress control was 75,787 MPa (10.992 Mpsi).

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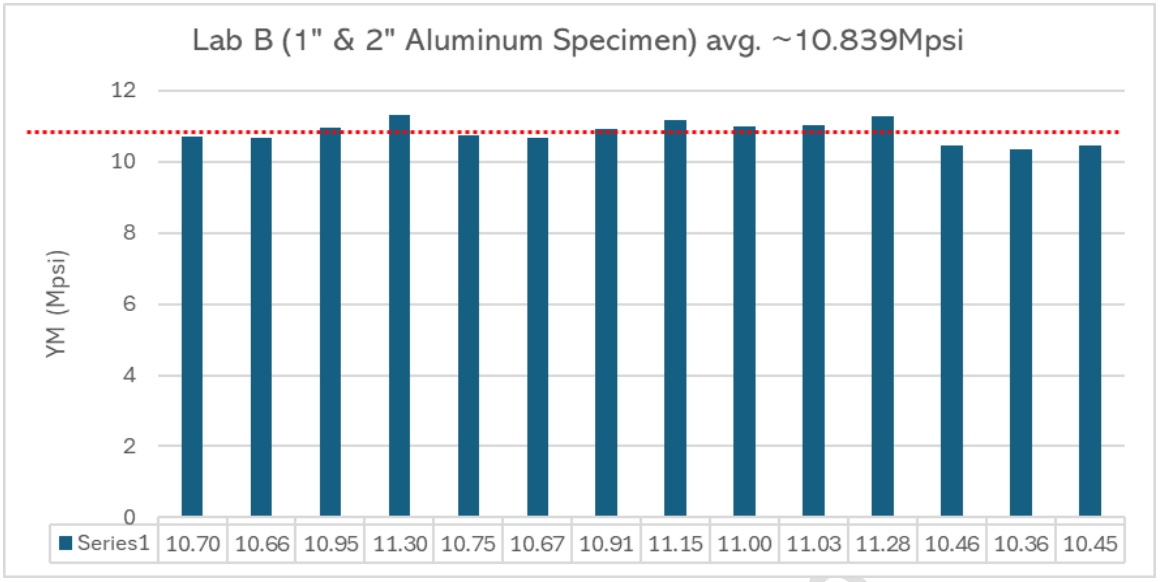



Figure C.3 Lab B Results

Lab C tested 2” diameter specimens at unconfined conditions, and under both stress/strain control methods. Average Young's Modulus for all tests was 73,415 MPa (10.648 Mpsi) (with 3 out of 8 results outside of 1 standard deviation of 0.296 or 2.8%). Average results for specimens tested under strain control was 71,871 MPa (10.424 Mpsi) and for stress control was 73,356 MPa (10.783 Mpsi).

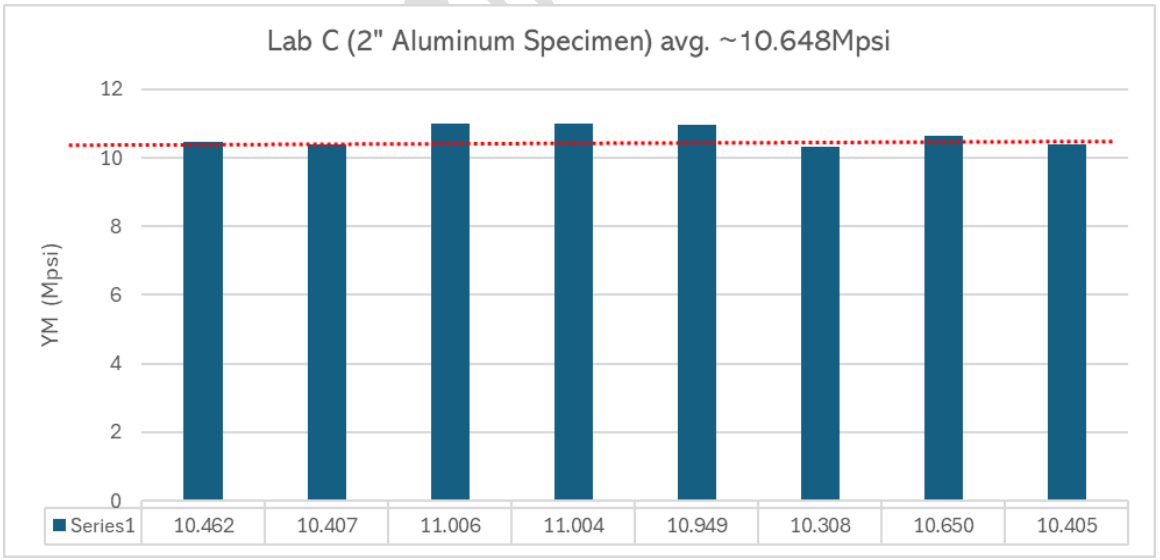



Figure C.3 Lab C Results

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Lab E tested 2" diameter specimens at unconfined conditions, and under stress control. Average Young's Modulus for all tests was 71,457MPa (10.364 Mpsi) (with 1 out of 4 results outside of 1 standard deviation of 0.062 or 0.6%). Laboratory E also ran the results though their model to come up with Elastic Properties very similar to the model used by the work group for this project. Laboratory E produced results that were remarkably close (within 1%) to each other (Very Precise) and within 5% of the combined average (Less Accurate). The charts for Labs E and F have two sets of results, showing the differences when 2 people analyze the same data.

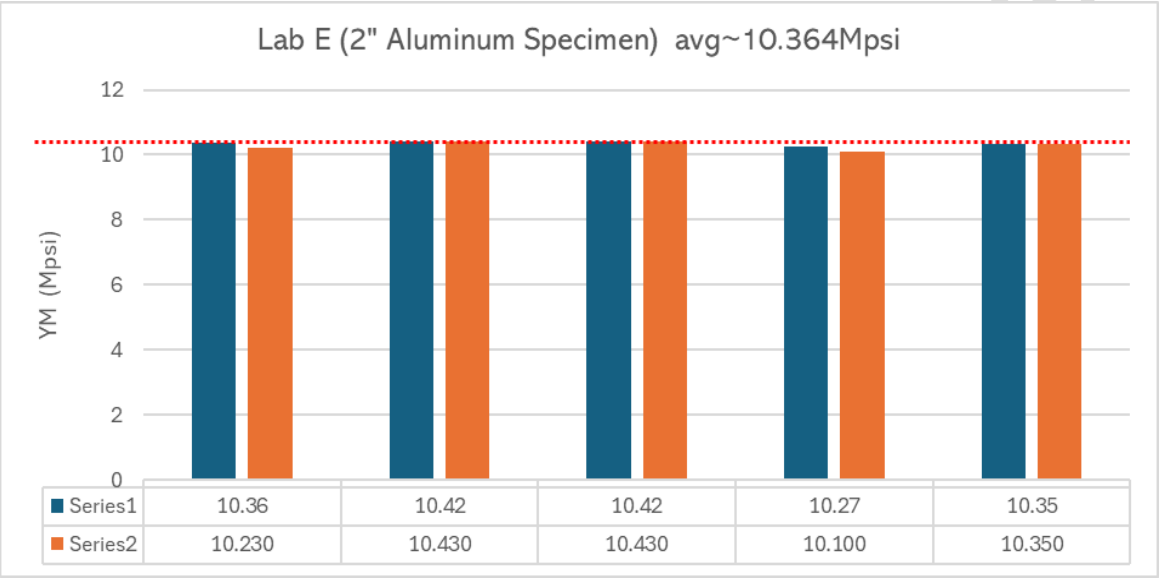



Figure C.4 Lab E Results

Lab F tested 1" diameter specimens at unconfined conditions, and under strain control. Average Young's Modulus for all tests was 73,912 MPa (10.720 Mpsi) (with no results outside of 1 standard deviation of 0.330 or 3.1%). Laboratory F also ran the results though their model to come up with Elastic Properties very similar to the model used by the work group for this project.

For Comment

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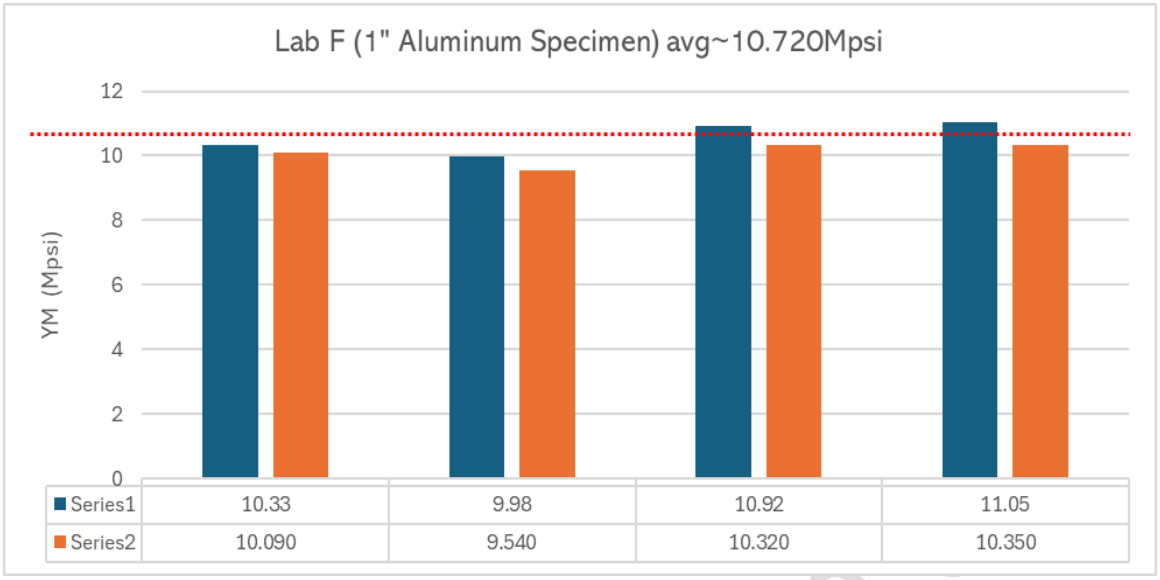



Figure C.5 Lab F Results

## C.3.3 Round 2 Lab Results

Lab A tested 1" diameter specimens at both confined and unconfined conditions, and under strain control methods. Average Young's Modulus for all tests was 11,004 MPa (1.596 Mpsi) (with half the results outside of 1 standard deviation of 0.153 or 9.6%). Average results for confined was 10,259 MPa (1.448 Mpsi) and for the unconfined it was 11,659 MPa (1.691 Mpsi). Average Compressive strength was 54.89MPa (7,962psi).

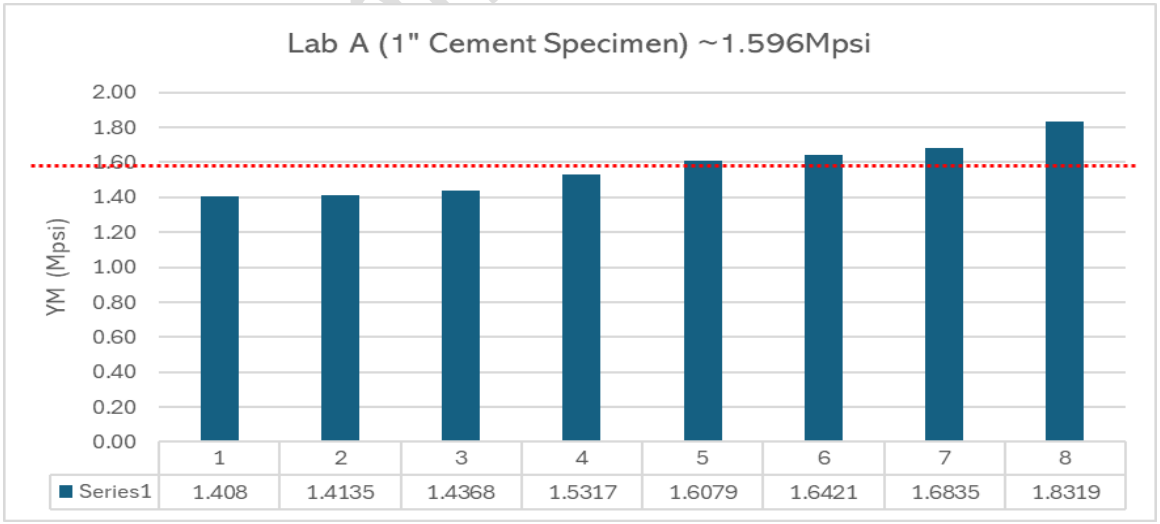



Figure C.6 Lab A Results

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Lab B tested both 1" and 2" diameter specimens at unconfined conditions, and under strain control methods. Average Young's Modulus for all tests was 14,478 MPa (2.01 Mpsi) (with 3 out of 7 results outside of 1 standard deviation of 0.187 or 9.3%). Average results for 1" diameter specimen was 14,527 MPa (2.107 Mpsi) and for the 2" was 12,969 MPa (1.881 Mpsi). Average Compressive strength was 44.82 MPa (6,500 psi).

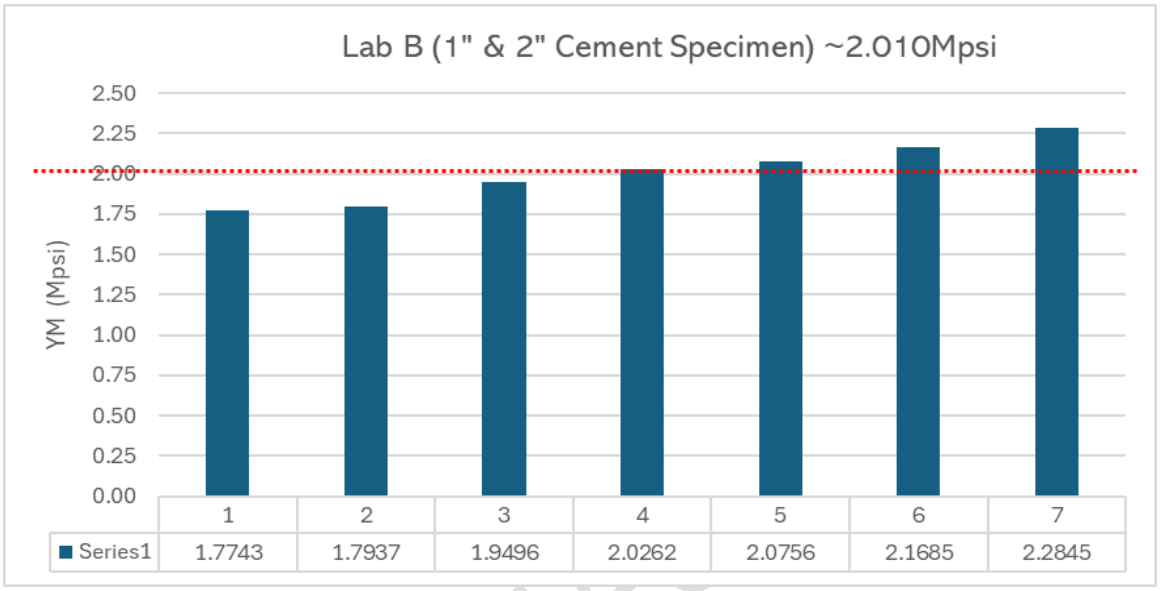



Figure C.7 Lab B Results

Lab C tested 1" diameter specimens at both confined and unconfined conditions, and under strain control methods. Average Young's Modulus for all tests was 11,528 MPa (1.672 Mpsi) (with 2 out of 7 results outside of 1 standard deviation of 0.101 or 6.1%). Average results for confined was 11,935 MPa (1.731 Mpsi) and for the unconfined it was 11,369 MPa (1.649 Mpsi). Average Compressive strength was 59.24MPa (8,592 psi).

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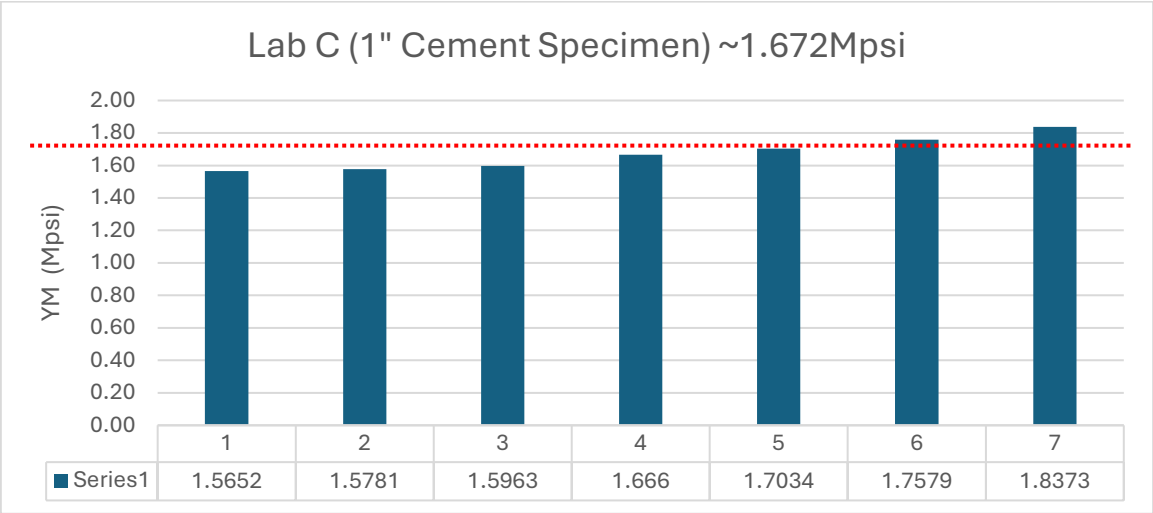



Figure C.8 Lab C Results

Lab D tested 2” diameter specimens at both confined and unconfined conditions, and under strain control methods. Average Young's Modulus for all tests was 11,549 MPa (1.6751 Mpsi) (with 3 out of 8 results outside of 1 standard deviation of 0.041 or 2.4%). Average results for confined was 11,563 MPa (1.677 Mpsi) and for the unconfined it was 11,542 MPa (1.674 Mpsi). Average Compressive strength was 52.71MPa (7,645 psi).

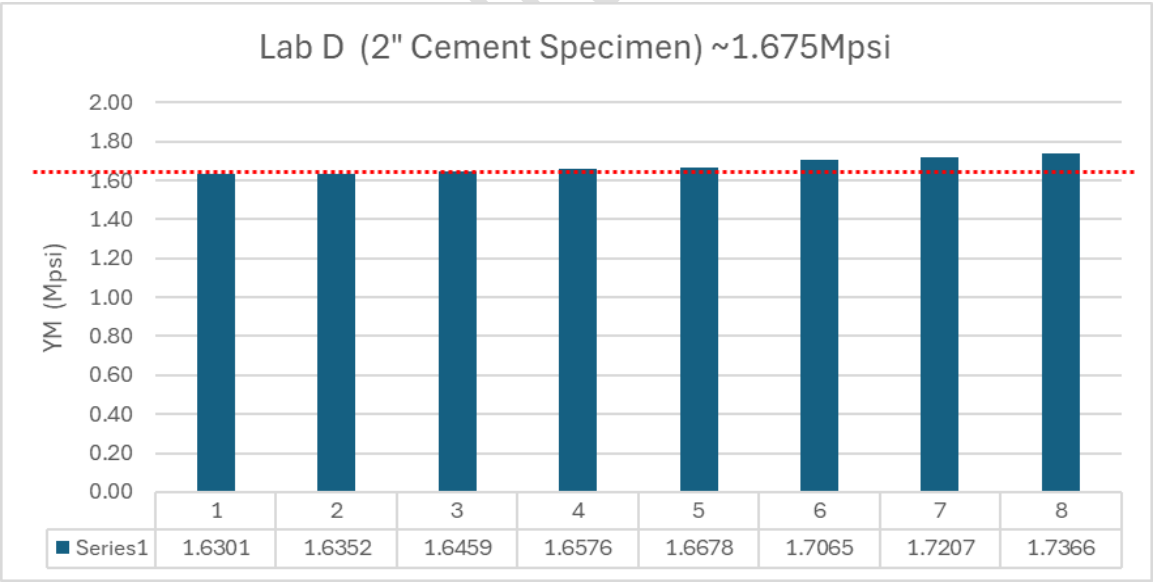



Figure C.9 Lab D Results

Lab E tested 1” diameter specimens at both confined and unconfined conditions, and under strain control methods. Average Young's Modulus for all tests was 8,811 MPa

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(1.278 Mpsi) (with 1 out of 10 results outside of 1 standard deviation of 0.179 or 14%). Average results for confined was 7,826 MPa (1.135 Mpsi) and for the unconfined it was 9,467 MPa (1.373 Mpsi). Average Compressive strength was 47.26 MPa (6,854 psi).

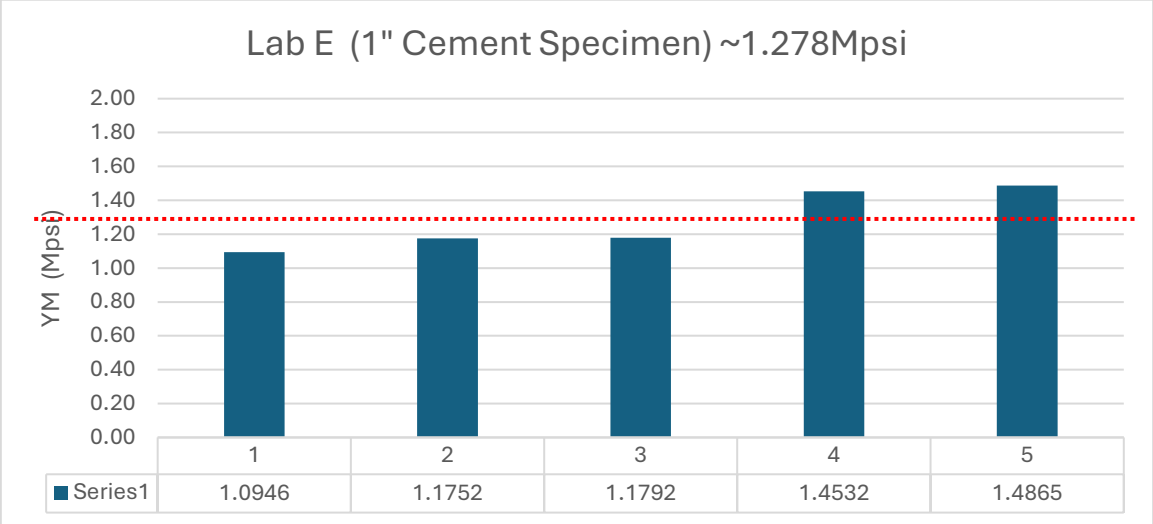



Figure C.10 Lab E Results

Lab F tested both 1" and 2" diameter specimens at both confined and unconfined conditions, and under strain control methods. Average Young's Modulus for all tests was 13,776 MPa (1.998 Mpsi) (with 2 out of 11 results outside of 1 standard deviation of 0.066 or 3.3%). Average results for 1" diameter specimen was 14,527 MPa (2.007 Mpsi) and for the 2" was 13,707 MPa (1.988 Mpsi). Average results for confined was 1.953Mpsi (13,465 MPa) and for the unconfined it was 13,976 MPa (2.027 Mpsi). Average Compressive strength was 53.77 MPa (7,799 psi).

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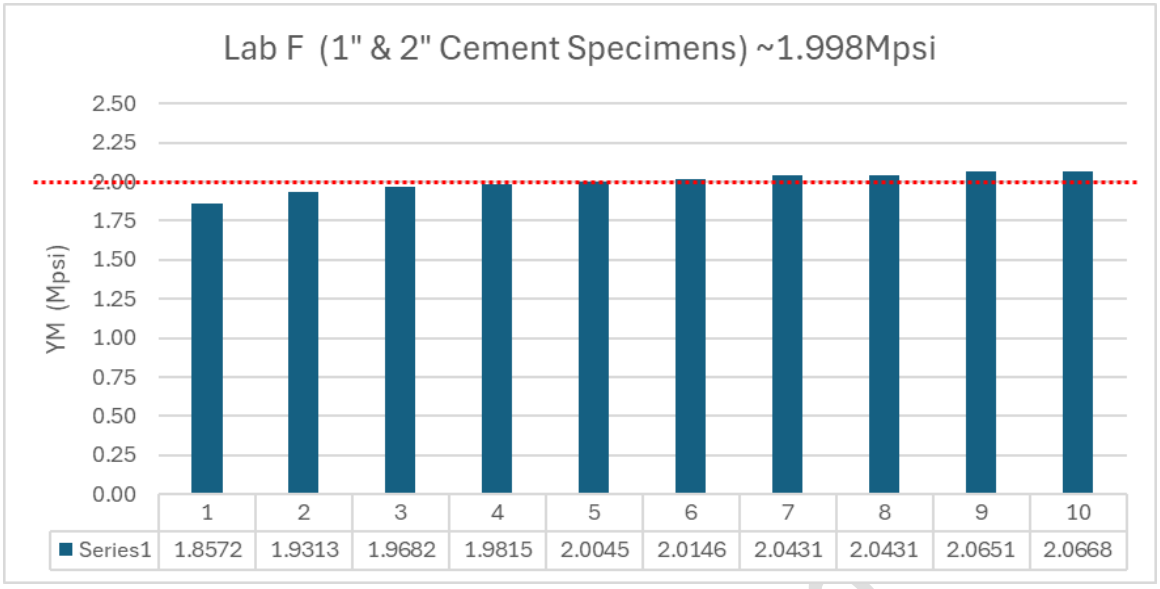



Figure C.10 Lab F Results

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