# ENVIRONMENTAL AND REINFORCEMENT EFFECTS ON CONCRETE EXPANSION UNDERGOING ACCELERATED ALKALI SILICA REACTION

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# ORGANIZATION

1. Motivations & Objectives
2. Background Information
3. Specimen Casting
4. Specimen Curing
5. Expansion Monitoring
6. Results & Discussion
7. Conclusions

# MOTIVATIONS & OBJECTIVES

# MOTIVATIONS

- The alkali-silica reaction (ASR) was identified by Stanton in 1940
- Observed in dams, bridge piers, and nuclear power plants worldwide
- Understand how structures are effected on a global scale
- First, understand how they react on a material level
- Compare variations in reinforcement and temperature to understand the effect on ASR expansion

# OBJECTIVES

- Cast a variety of reactive and non-reactive specimens
- Rapidly develop alkali-silica reaction in reactive specimens
- Collect expansion, strain, and temperature data
- Analyze data to study the effects of reinforcement and temperature on expansion

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# BACKGROUND INFORMATION

# ASR FORMATION

- ASR occurs when alkalinity in cement reacts with silica in aggregates

$$Silica + Alkali \rightarrow Gel$$
$$xSiO_2 + yNa(K)OH \rightarrow Na(K)_ySi_xO_z,$$

- Product is silica gel, which expands when hydrated

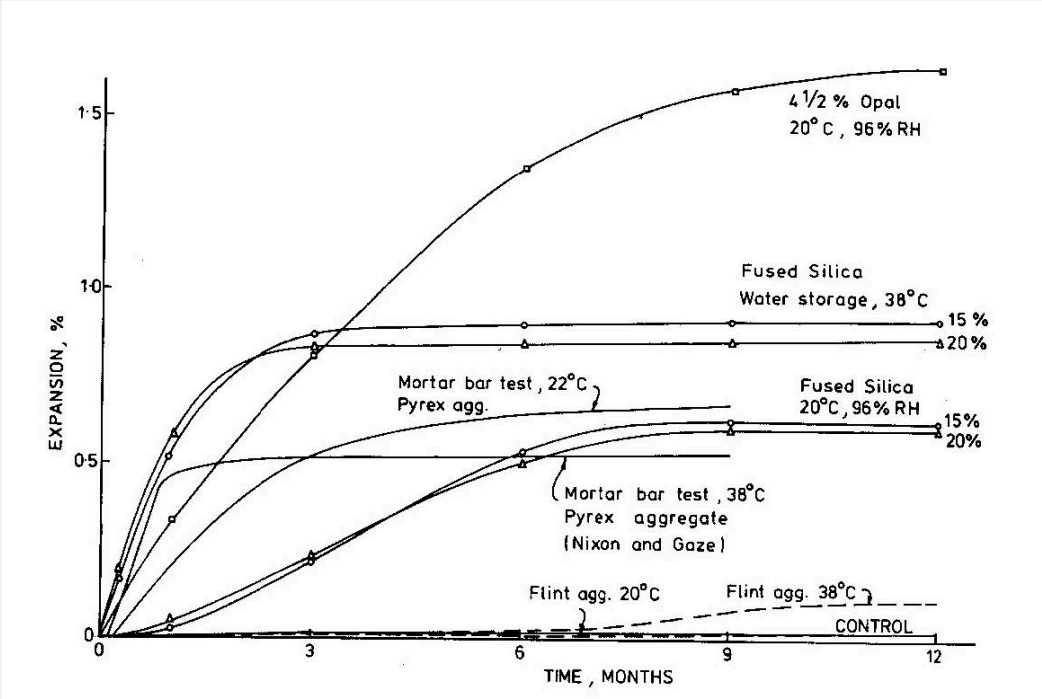
$$Gel + Water \rightarrow Hydrated\ gel$$
$$Na(K)_ySi_xO_z + wH_2O \rightarrow Na(K)_ySi_xO_z \cdot wH_2O$$

# CONDITIONS EFFECTING ASR EXPANSION *(LINDGÅRD, ET AL., 2012)*

1. Internal moisture condition
2. Alkali leaching
3. Specimen wrapping
4. Externally added alkalis
5. Storage Temperature

# EFFECTS OF TEMPERATURE ON ASR EXPANSION

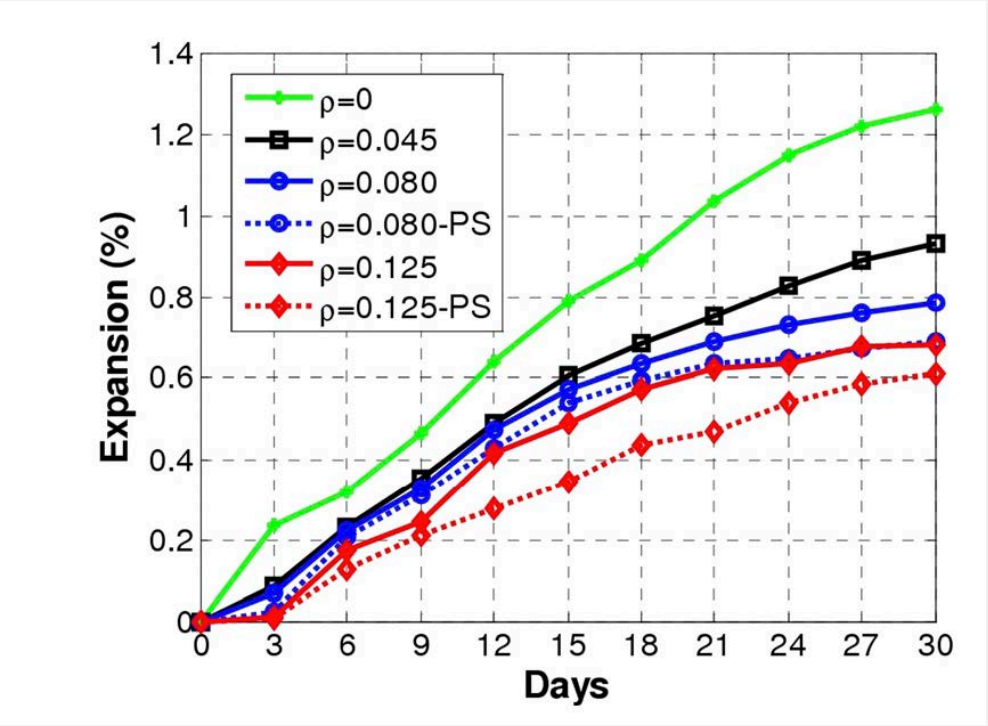
- Thermodynamically driven reaction (Larive, 1998)
- Elevated temperatures show rapid initial expansion and higher ultimate expansion than those stored at room temperature (Swamy and Al-Asali, 1988)
- Temperature increase causes solubility of $SiO_2$ increase which accelerates the reaction rate *(Lindgård, et al., 2012)*




(Swamy and Al-Asali, 1988)

# EFFECTS OF REINFORCEMENT ON ASR EXPANSION

- Reinforcement ratio increase causes expansion decreased in mortar bars
- Further expansion reduction with prestressing (Musaoglu, Turanli, and Saritas, 2014)
- Strain reduction in reinforcement direction can increase strain in orthogonal direction (Morenon et al.,2017)
- ASR expansion in real life structures experience less expansion in direction of reinforcement (Bérubé et al., 2005)
- Confinement also restricts expansion (Dunant and Scrivener, 2012), (Gautam et al., 2017), (Multon and Toutlemonde, 2006)




(Musaoglu, Turanli, and Saritas, 2014)

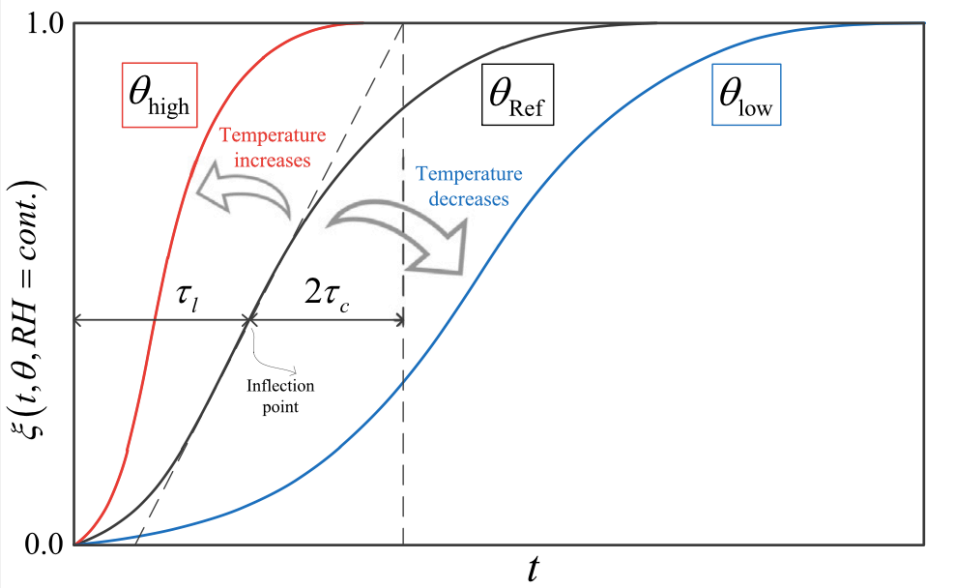
# LARIVE'S EXPANSION EQUATION

- Equation predicts ASR expansion at given time and temperature

$$\xi(t,\theta) = \frac{1 - e^{-\frac{t}{\tau_c(\theta)}}}{1 + e^{-\frac{(t-\tau_l(\theta))}{\tau_c(\theta)}}}$$

$$\begin{cases} \tau_c(\theta) = \tau_c(\theta_0)\exp\left[U_C\left(\frac{1}{\theta} - \frac{1}{\theta_0}\right)\right]; \ U_C = 5,400 \pm 500K \\ \tau_L(\theta) = \tau_L(\theta_0)\exp\left[U_L\left(\frac{1}{\theta} - \frac{1}{\theta_0}\right)\right]; \ U_L = 9,400 \pm 500K \end{cases}$$

- $\tau_l$ and $\tau_c$ are latency and characteristic times dependent on activation energies, $U_c$ and $U_L$
- Activation energy determined by performing tests at different temperatures to determine the corresponding latency or characteristic times.



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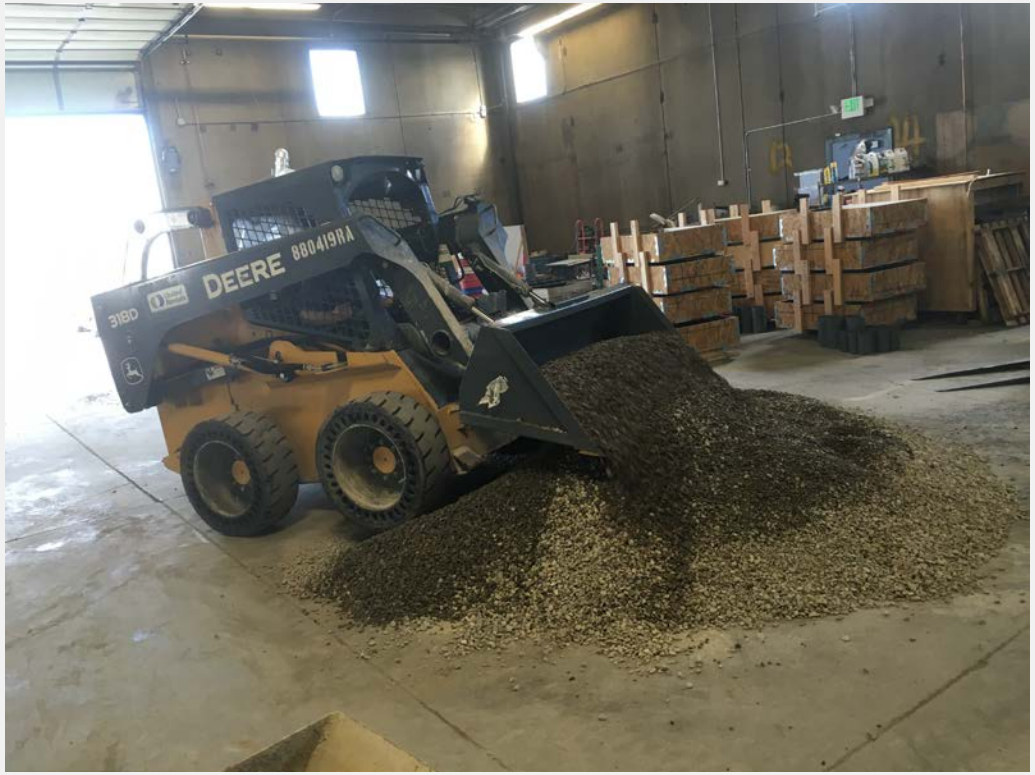
# SPECIMEN CASTING


Wood forms built, transported to casting location, and organized before casting





Mixing coarse and fine aggregate for consistent moisture content

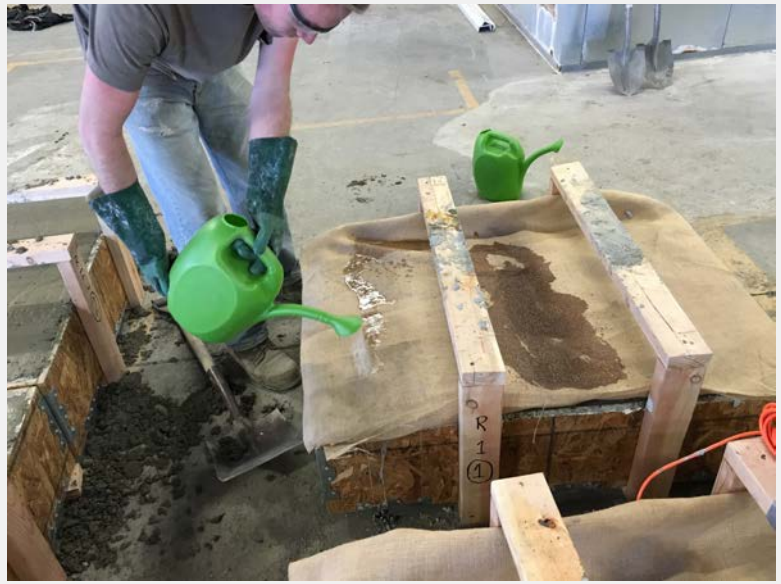


Loading aggregates in batcher which precisely dispenses desired aggregate weight

Adding water, aggregates, cement, and admixtures to mixer


Pouring mixed cement from mixer for testing and transportation to forms

Measuring concrete slump and air content


Filling forms, vibrating concrete, and covering filled forms with wetted burlap

Compression testing according to ASTM C39

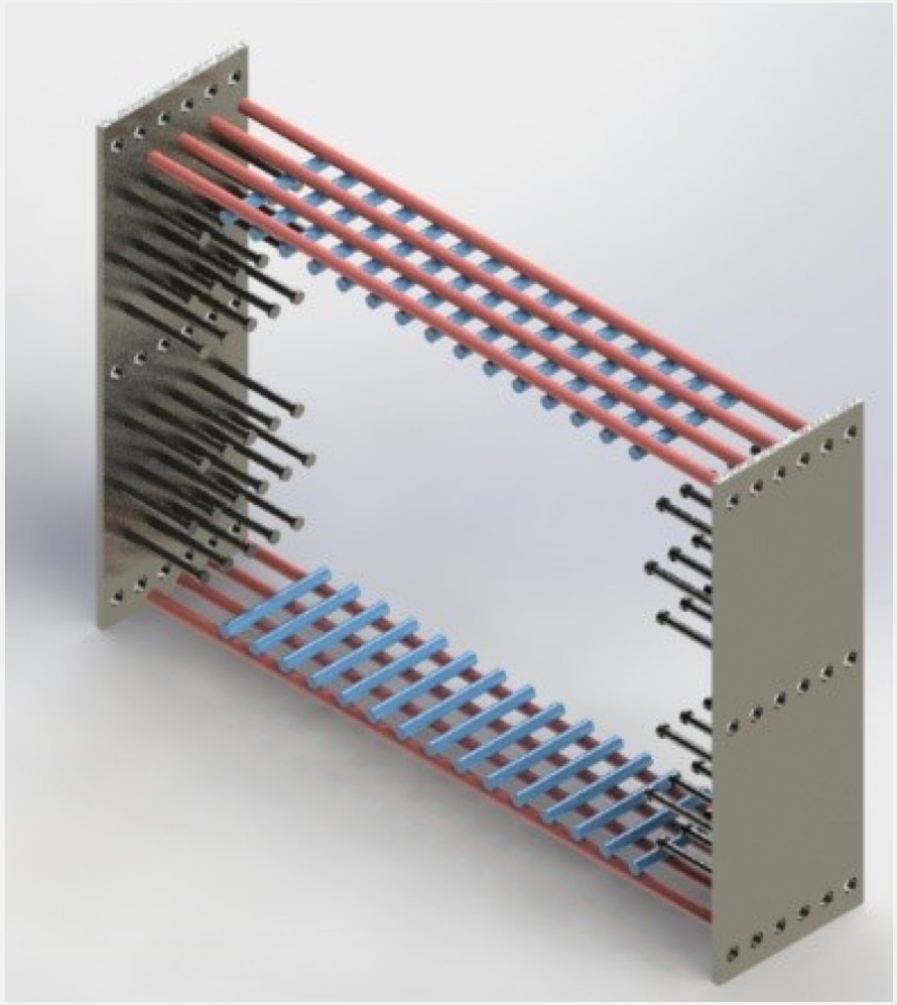
# SPECIMENS

- (16) Shear Specimens
  - (12) Reactive, (4) Non-Reactive
- (15) 14”x14”x14” Blocks – Varying reinforcements
- (12) 4”x4”x16” Prisms
- (10) 6”x6”x14” Prisms
- (9) Wedge Splitting Tests Specimens
- (48) 4”x8” Cylinders
- (12) 6”x12” Cylinders

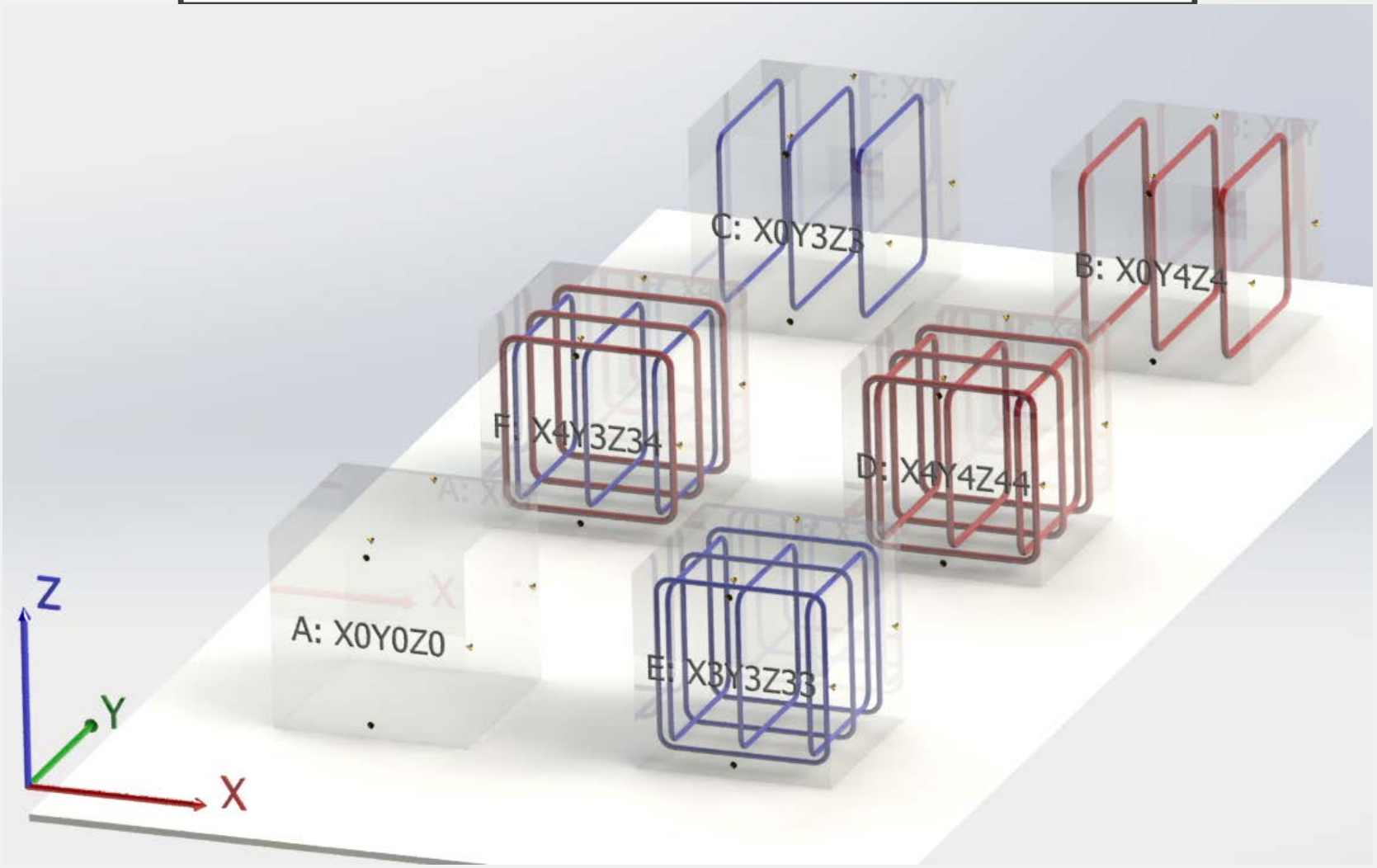
# DATA PROVIDED SPECIMENS

- Shear Specimens
  - Shear strength tests
- Blocks
  - Reinforced differently to study reinforcement effects and temperature effects
- Prisms
  - Tracks expansion, reinforcement and temperature effects
- Cylinders
  - Compression and Brazilian tests
- Wedge Splitting Tests
  - Determines fracture energy

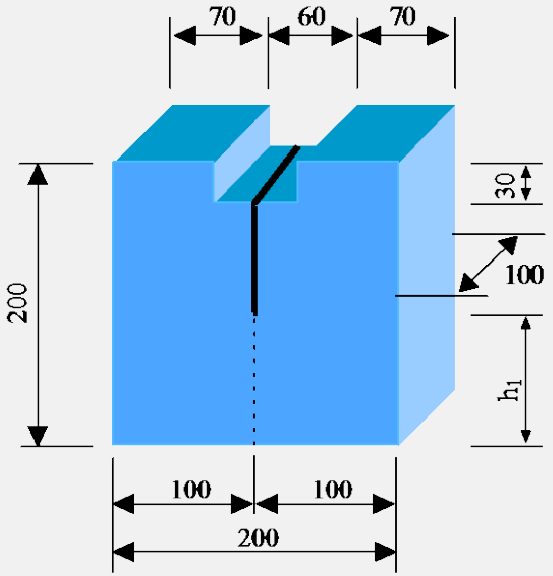
# SHEAR SPECIMEN



# BLOCKS



# CYLINDERS AND WEDGE SPLITTING TEST

# SPECIMEN INVENTORY

| S: Shear Specimens | | | | | | |
|---|---|---|---|---|---|---|
| Bat. | ID | Reac. | Rebars | Temp. ID | SG | Loc. |
| 1 | 1 | Y | Y | | | FR |
| | 2 | | Y | 1 | | |
| | 3 | | Y | | | |
| | 4 | | | | | |
| 2 | 5 | Y | Y | | | |
| | 6 | | Y | 2 | 9 | |
| | 7 | | Y | | | |
| | 8 | | | | | |
| 3 | 9 | Y | Y | | 10 | |
| | 10 | | Y | 3 | | |
| | 11 | | Y | | | |
| | 12 | | | | | |
| 4 | 13 | No | Y | | | |
| | 14 | No | Y | 4 | | |
| | 15 | No | | | | |
| | 16 | No | | | | |

| ID in the Lab | Rebars | | FR | Bat. | Reac. | Temp. | SG | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LAB | | | ID | X | Y | Z(UP) | A | B | C | D | E | F |
| 1 | A | A:X0Y0Z0 | FR | 1 | Yes | 5 | | | | 1 | | | | | |
| 2 | A | A:X0Y0Z0 | Lab | | | 6 | | | | 1 | | | | | |
| 3 | B | B:X0Y4Z4 | FR | | | | | | 1 | | 1 | | | | |
| 4 | B | B:X0Y4Z4 | Lab | | | | | | | | 1 | | | | |
| 5 | D | D:X4Y4Z44 | FR | | | | 2 | 3 | 4 | | | | 1 | | |
| 6 | A | A:X0Y0Z0 | FR | 2 | Yes | 7 | | | | 1 | | | | | |
| 7 | A | A:X0Y0Z0 | Lab | | | 8 | | | | 1 | | | | | |
| 8 | C | C:X0Y3Z3 | FR | | | | | | 5 | | | 1 | | | |
| 9 | C | C:X0Y3Z3 | Lab | | | | | | | | | 1 | | | |
| 10 | E | E:X3Y3Z33 | Lab | | | | | | | | | | | 1 | |
| 11 | A | A:X0Y0Z0 | FR | 3 | Yes | 9 | | | | 1 | | | | | |
| 12 | A | A:X0Y0Z0 | Lab | | | 10 | | | | 1 | | | | | |
| 13 | F | F:X4Y3Z34 | FR | | | | 6 | 7 | 8 | | | | | | 1 |
| 14 | F | F:X4Y3Z34 | Lab | | | | | | | | | | | | 1 |
| 15 | E | E:X3Y3Z33 | Lab | | | | | | | | | | | 1 | |
| | | | | | | | | | Sum | 6 | 2 | 2 | 1 | 2 | 2 |

# SPECIMEN INVENTORY

| PL: Prisms Large 6 x 6 x 14 inch (5 bars) | | | | | | |
|---|---|---|---|---|---|---|
| Bat. | ID | Reac. | Temp | Rebar | SG | Loc. |
| 1 | 1 | Yes | | | | FR |
| | 2 | | 11 | Y | 11 | |
| | 3 | | | | | LAB |
| | 4 | | | | | |
| 2 | 5 | Yes | | | | FR |
| | 6 | | | Y | 12 | |
| | 7 | | | | | LAB |
| | 8 | | 12 | | | |
| 3 | 9 | Yes | 13 | | | FR |
| | 10 | | | Y | 13 | |
| | 11 | | | | | LAB |
| | 12 | | | | | |

| PS: Prisms Small 4 x 4 x 16 inch (4 bars) | | | | | | |
|---|---|---|---|---|---|---|
| Bat. | ID | Reac. | Temp | Rebar | SG | Loc. |
| 1 | 1 | Yes | | | | FR |
| | 2 | | 14 | Y | 14 | |
| | 3 | | | | | LAB |
| | 4 | | 15 | | | |
| 2 | 5 | Yes | | | | FR |
| | 6 | | | Y | 15 | |
| | 7 | | | | | LAB |
| | 8 | | | | | |
| 3 | 9 | Yes | 16 | | | FR |
| | 10 | | | Y | 16 | |
| | 11 | | | | | LAB |
| | 12 | | | | | |

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# SPECIMEN CURING

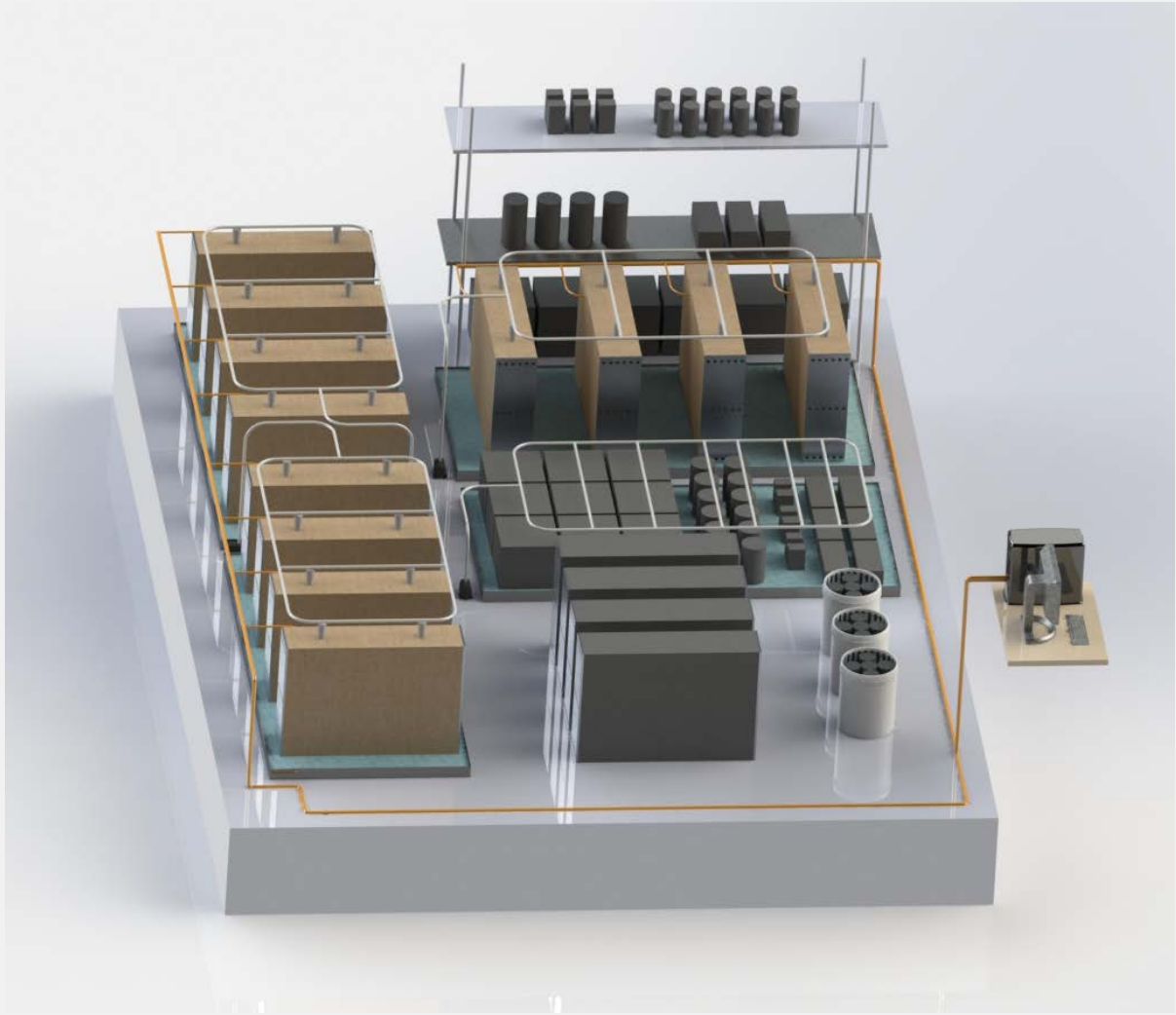
# FOG ROOM SPECIFICATIONS

- 100°F (38°C) Temperature
- 95% Relative Humidity

# SPRINKLER SYSTEM

- (4) 4’ x 8’ x 3” Steel Pans containing NaOH
- ¾” PVC Pipe Distribution System
- 1/6 HP Sump Pumps
- Turns on every 1.5 hours for 3 minutes

# FOG ROOM ARRANGEMENT



FOG ROOM

# FOG ROOM

# SPECIMEN INSTALLATION

# SPRINKLER SYSTEM

# LAB SPECIMENS

# SODIUM HYDROXIDE

- Aqueous NaOH
- 1.0 mol/liter concentration
- Each pan holds approximately 50 gallons of solution
- To achieve that volume, 16.69 lb. of solid NaOH is required for 50 galllons.

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# EXPANSION MONITORING

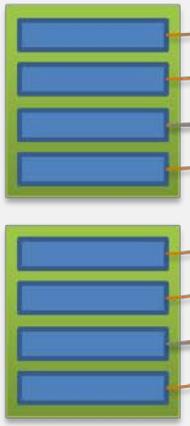
Specimen temperature sensor
MaturityCentral COMMAND 301006-X50

Specimen strain gauge
Tokyo Sokki Kenkyujo Co, YFLA-5-5LT, 5mm


Ambient room sensor
Omega OM-73

Laptop computer
Windows with USB interface and software from Omega and MaturityCentral

pH probe
Omega PHH-7011

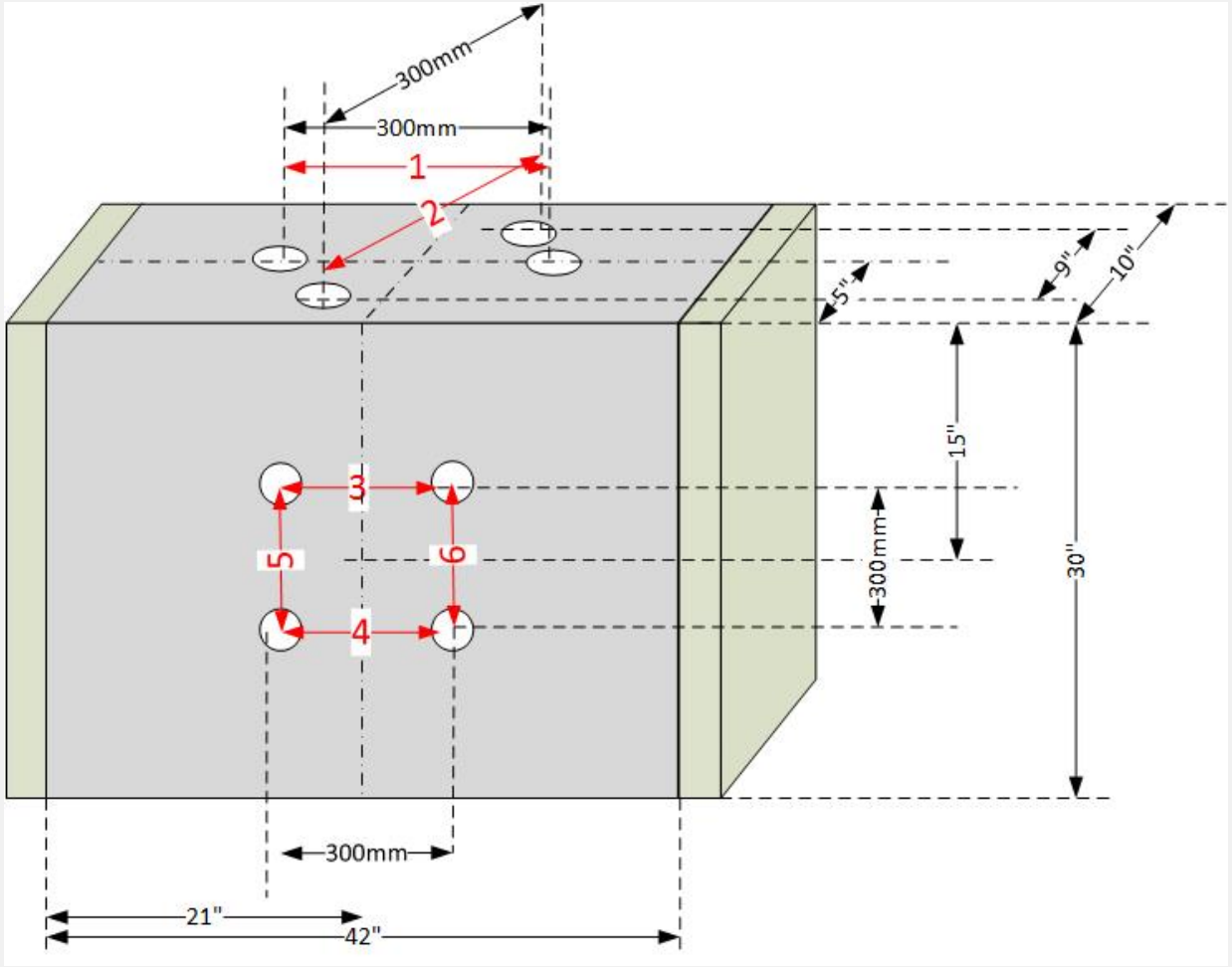


National Instruments DAQ
Windows and LabVIEW with PXI-6251 digitizer and SCXI-1520 strain conditioner

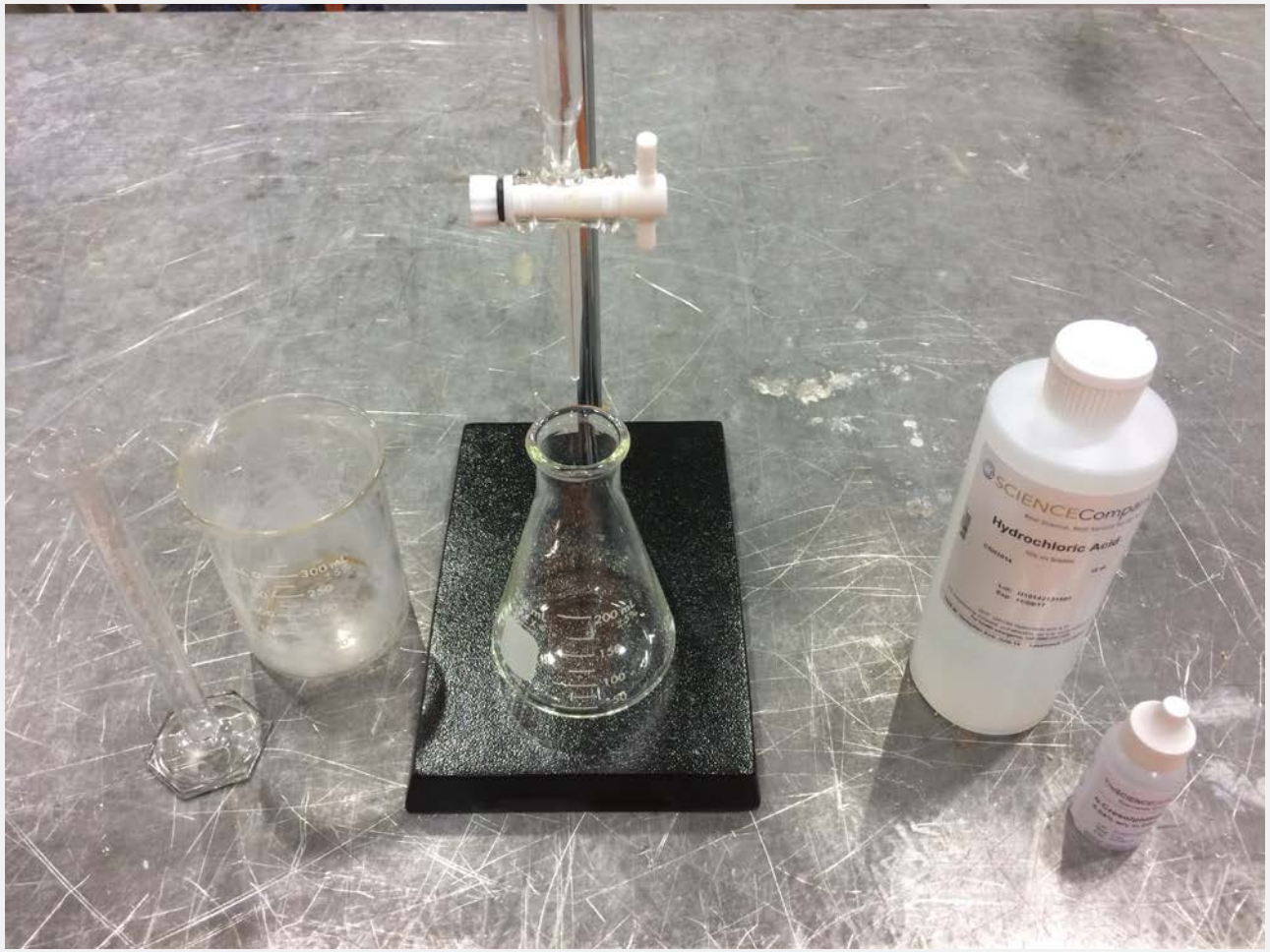
# DATUM DISC AND DEMEC


Chemical, temperature, and moisture resistant "brushable " ceramic epoxy used to attach discs to concrete surface.

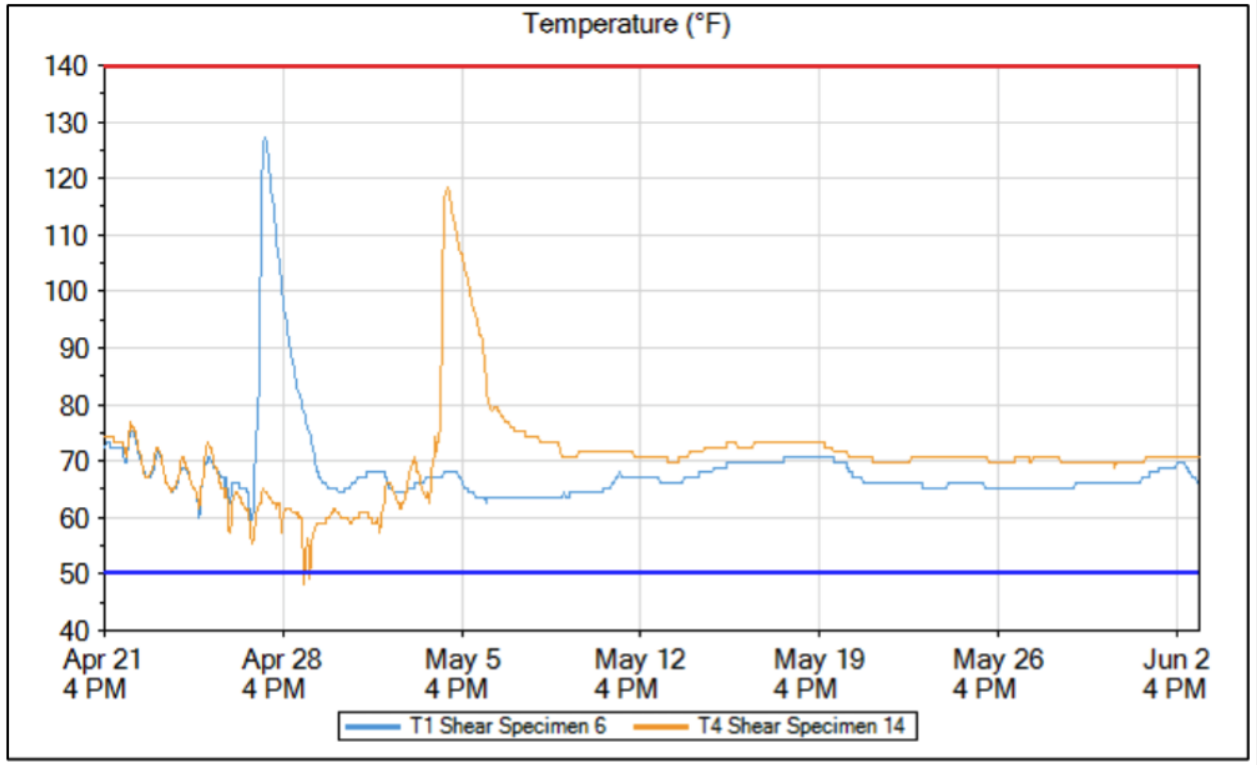
# DATUM DISC LOCATIONS



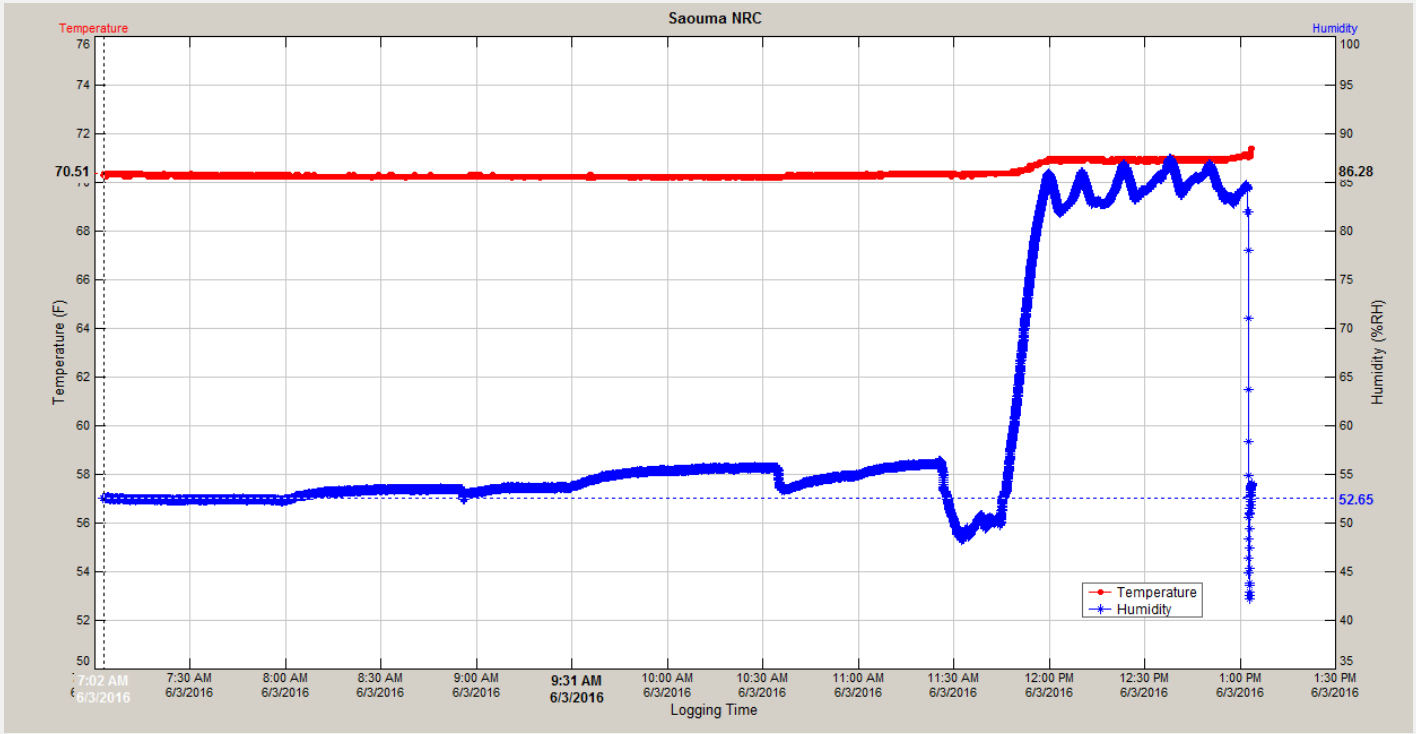
# PH MONITORING



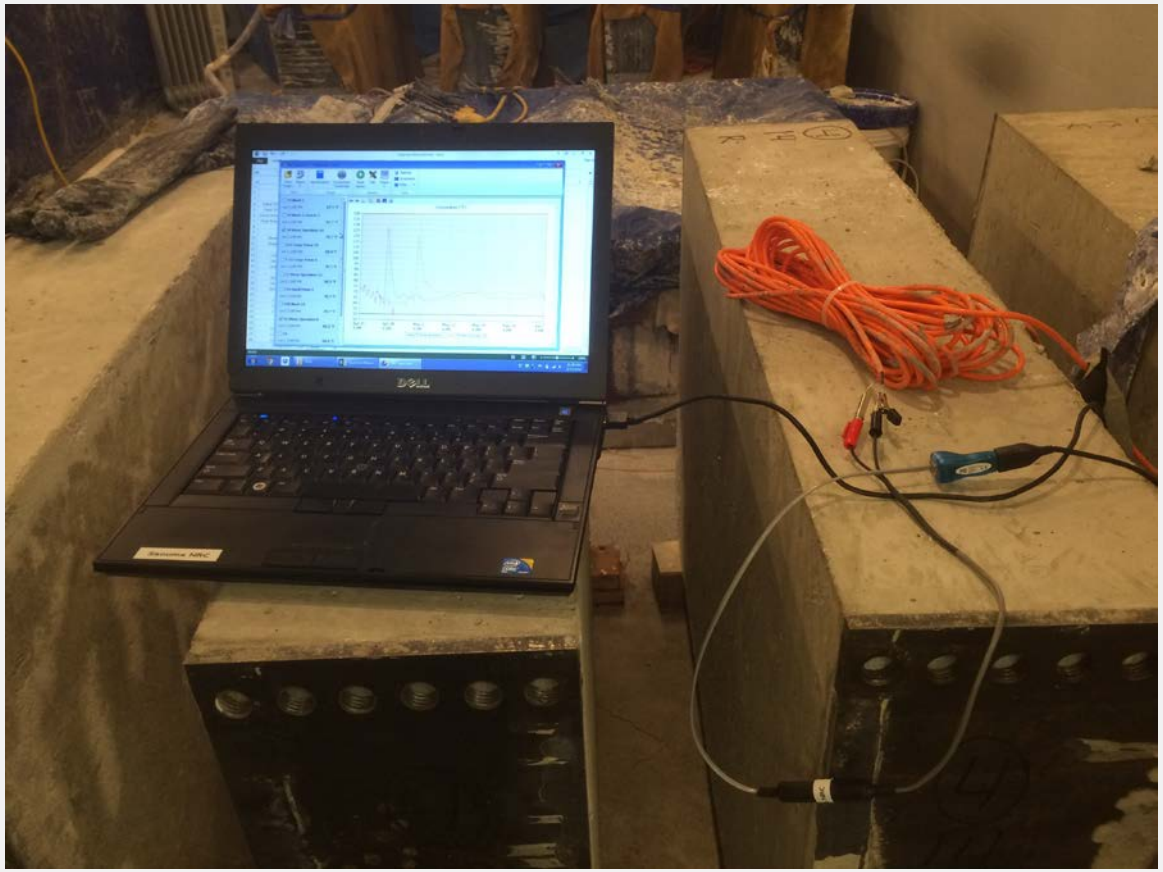

# INTERNAL TEMPERATURE MONITORING



# FOG ROOM TEMPERATURE & HUMIDITY

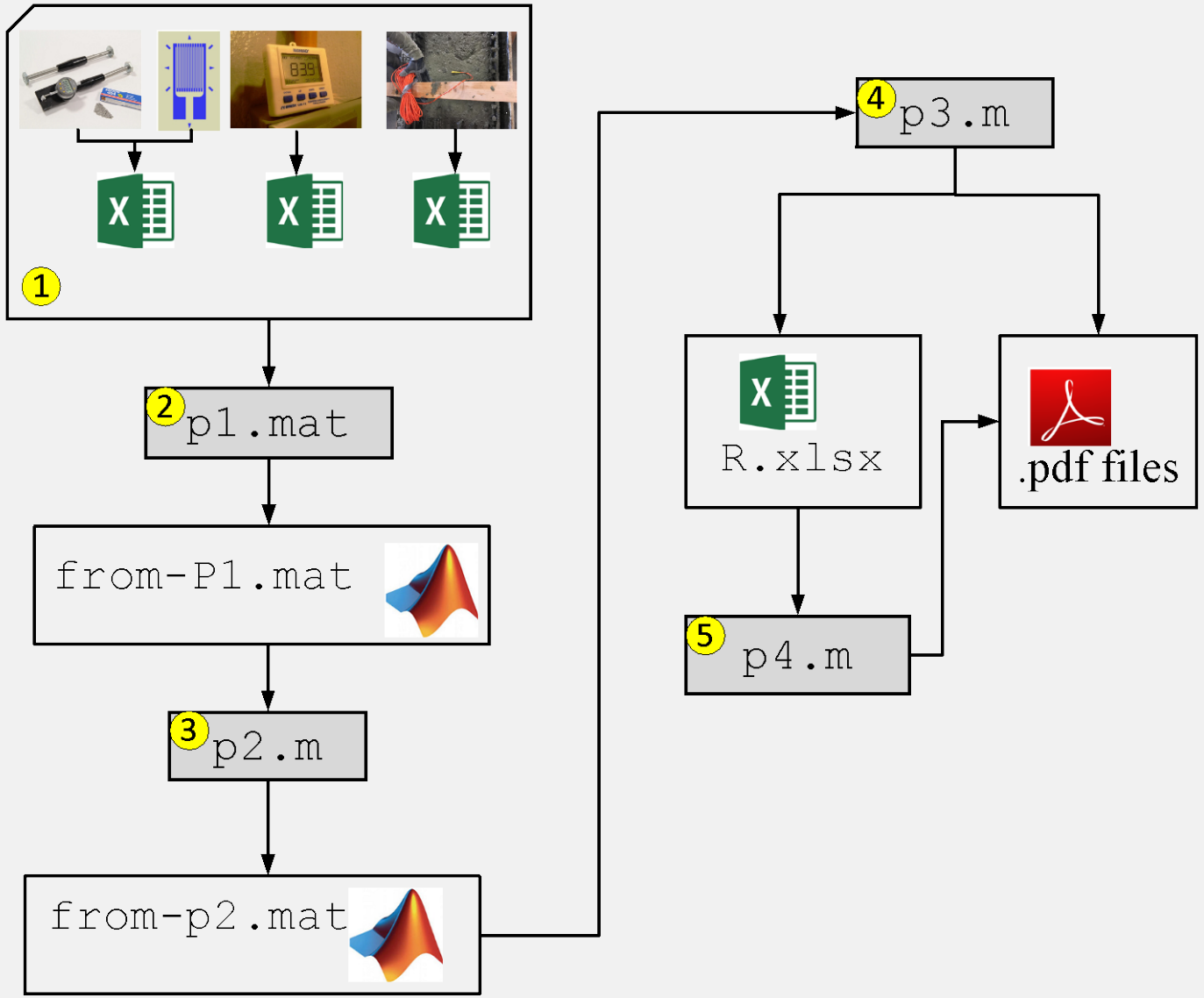
# STRAIN MONITORING



# SAFETY EQUIPMENT

# MEASUREMENTS

| | Expansion | | | Other | |
|---|---|---|---|---|---|
| Specimen Type | # of Specimens | # of Readings / Specimen | Total | Temperature | Strain |
| Reactive Shear Specimens | 12 | 6 | 72 | 3 | 2 |
| Non-Reactive Shear Specimens | 4 | 2 | 8 | 1 | - |
| 6 x 6 x 14 Inch Prisms | 10 | 1 | 10 | 3 | 3 |
| 4 x 4 x 16 Inch Prisms | 12 | 1 | 12 | 3 | 3 |
| 14 x 14 x 14 Inch Blocks | 15 | 3 | 45 | 6 | 8 |
| Total | 53 | - | 147 | 16 | 16 |
| | | | | **179** | |


1
2 p1.mat
from-P1.mat
3 p2.m
from-p2.mat
4 p3.m
R.xlsx
.pdf files
5 p4.m

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- Predictions
- Expansion Plots
- Reinforcement Effects
- Temperature Effects
- Other Observations

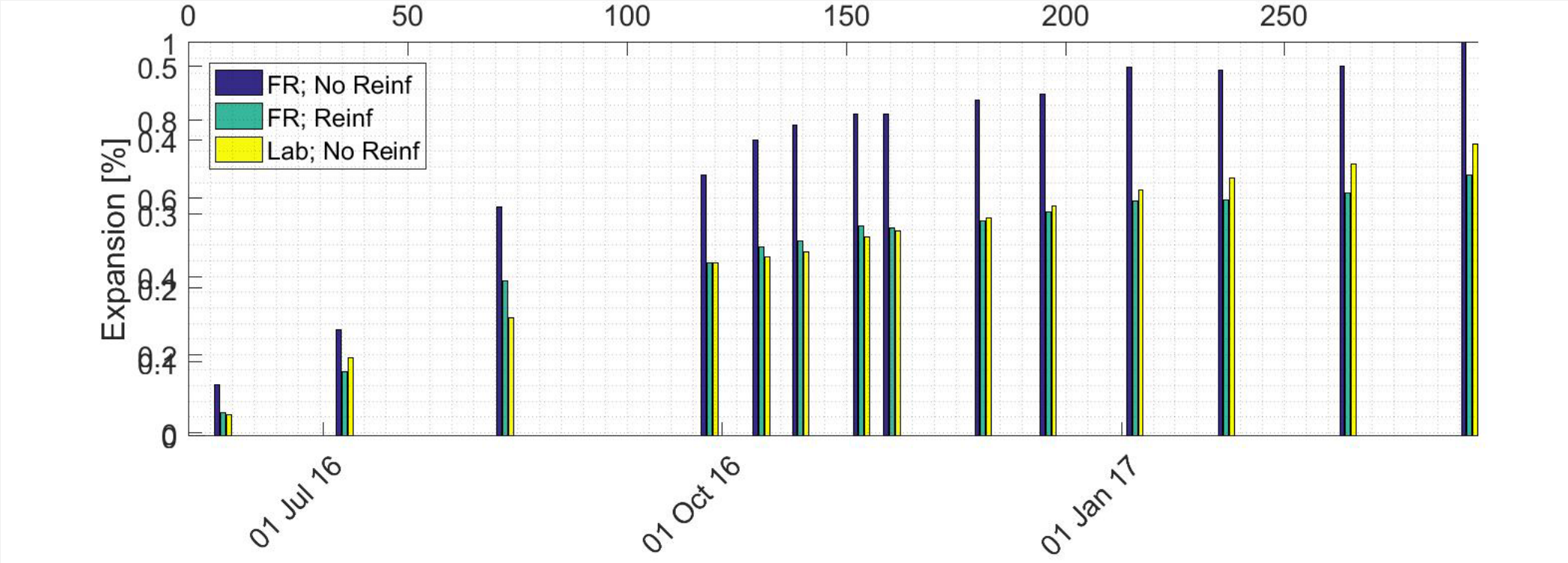
# RESULTS & DISCUSSION

# PREDICTIONS

- Reinforced specimens will have less expansion than unreinforced specimens
- Specimens stored in fog room will have greater expansion than specimens stored in the lab
- Blue indicates an expected result
- Red indicates an unexpected result
- Purple indicated an questionable or unclear result
- FR = Fog Room
- LB = Lab

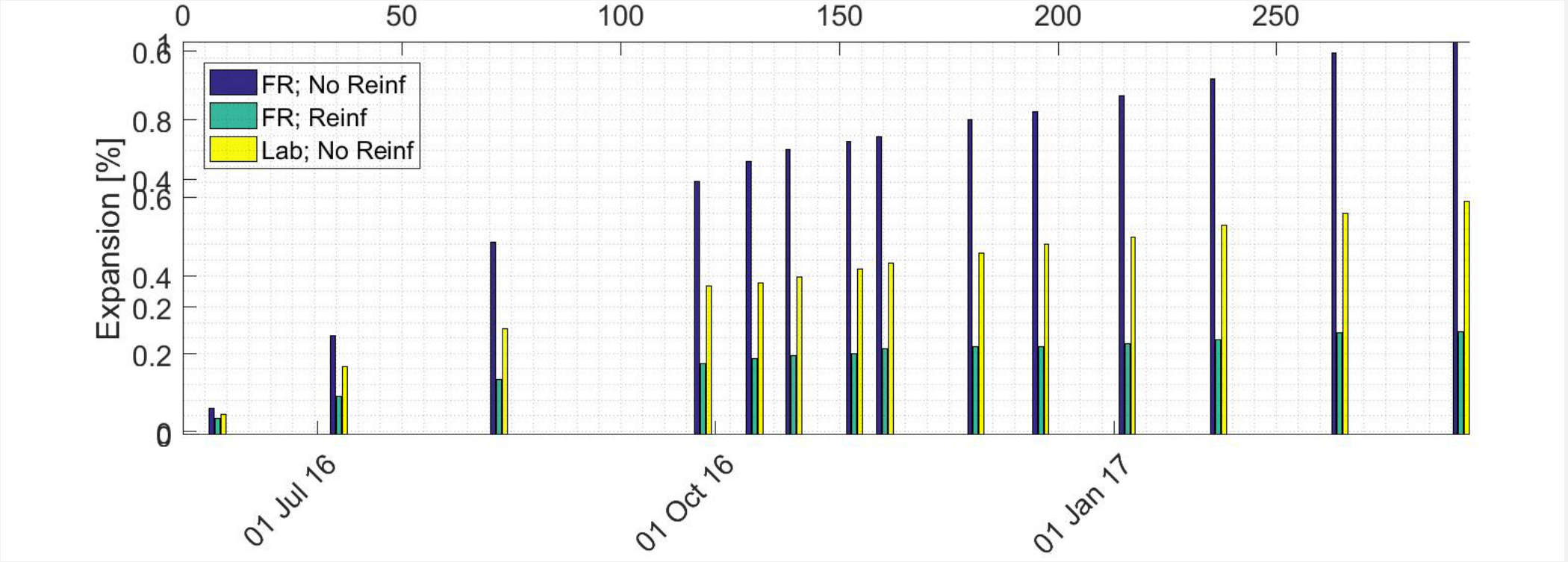
# EXPANSION PLOTS

# AVERAGE 6X6X14" PRISM EXPANSION



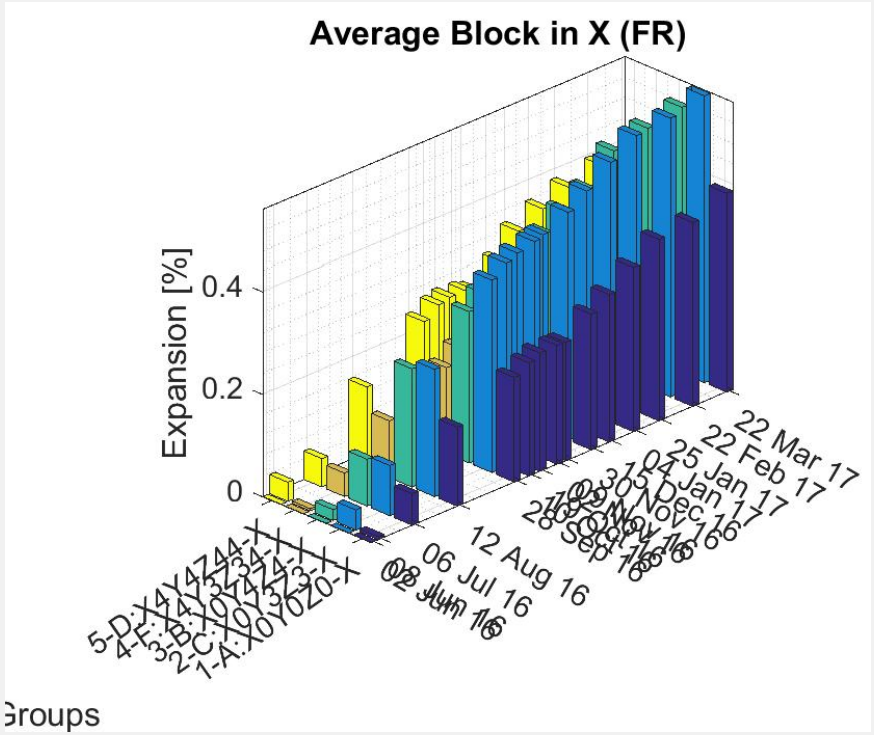

Unreinforced prisms in fog room have greatest expansion. Prisms are expanding as expected.

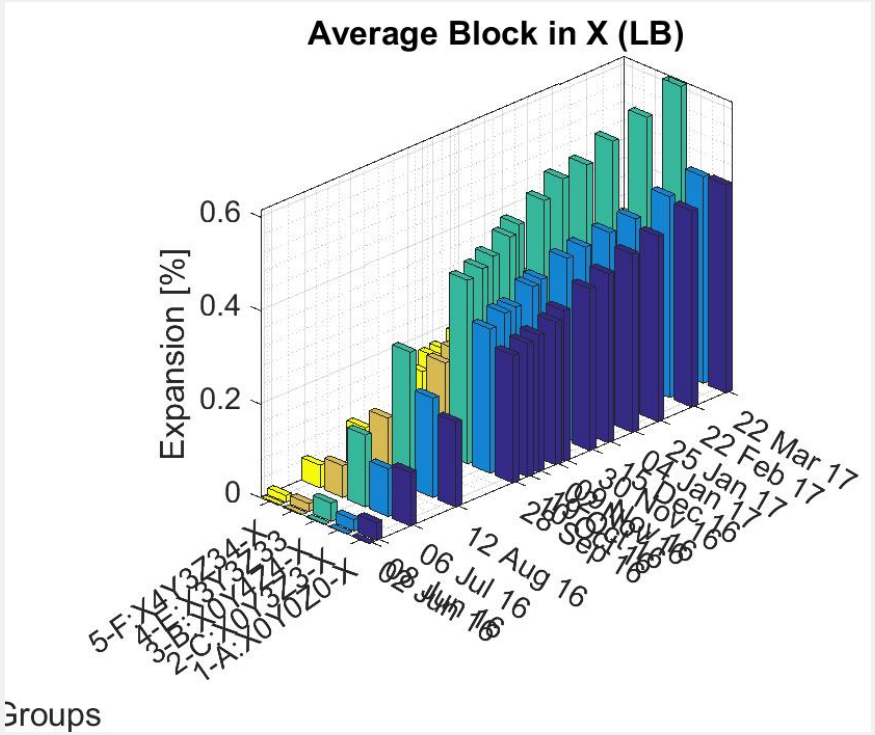
# AVERAGE 4X4X16" PRIMS EXPANSION




Unreinforced prisms in fog room have greatest expansion. Prisms are expanding as expected.

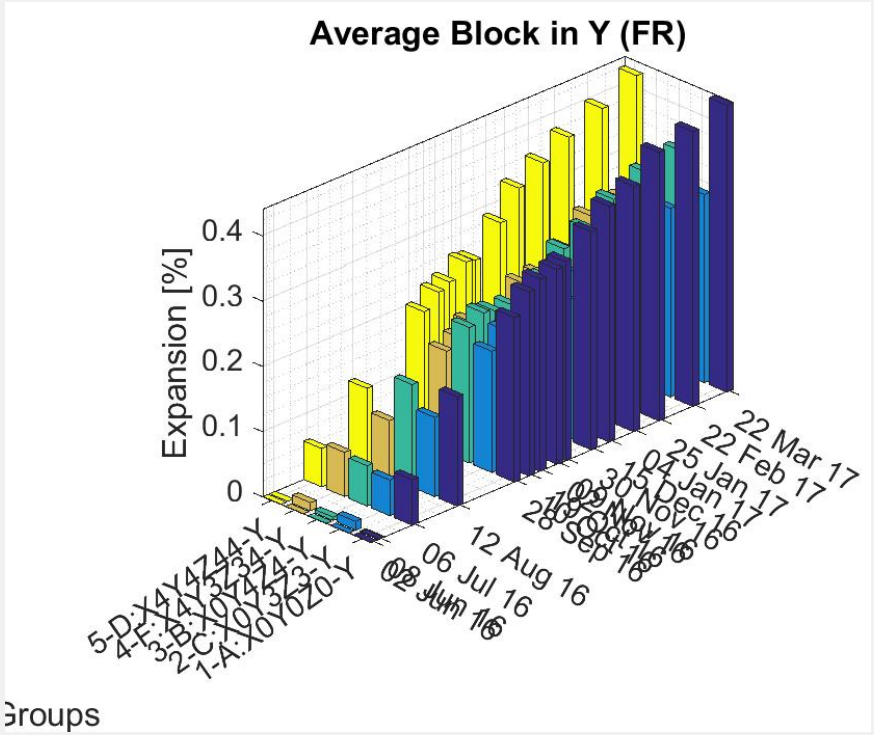
# BLOCK AVERAGE EXPANSION IN X DIRECTION (FOG ROOM AND LAB)

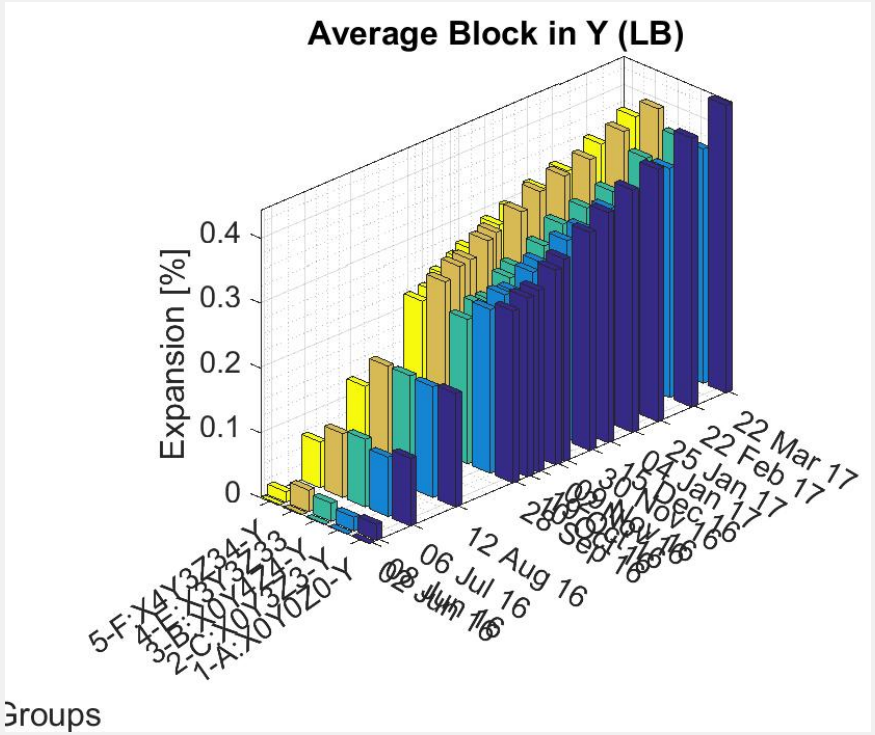



Some reinforced block with greater expansion than unreinforced blocks
Curious

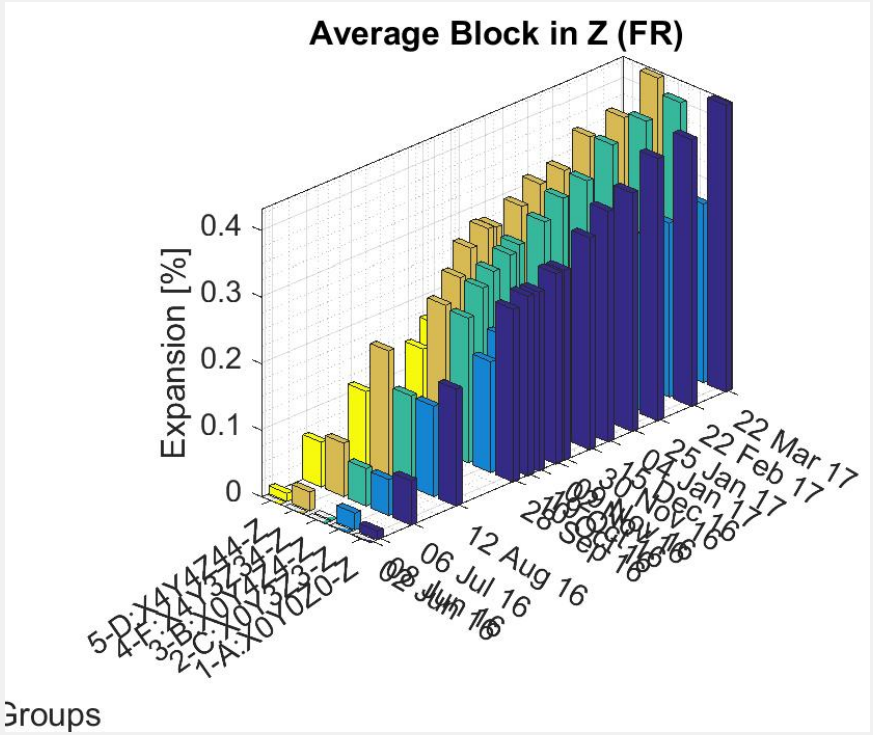
# BLOCK AVERAGE EXPANSION IN Y DIRECTION (FOG ROOM AND LAB)

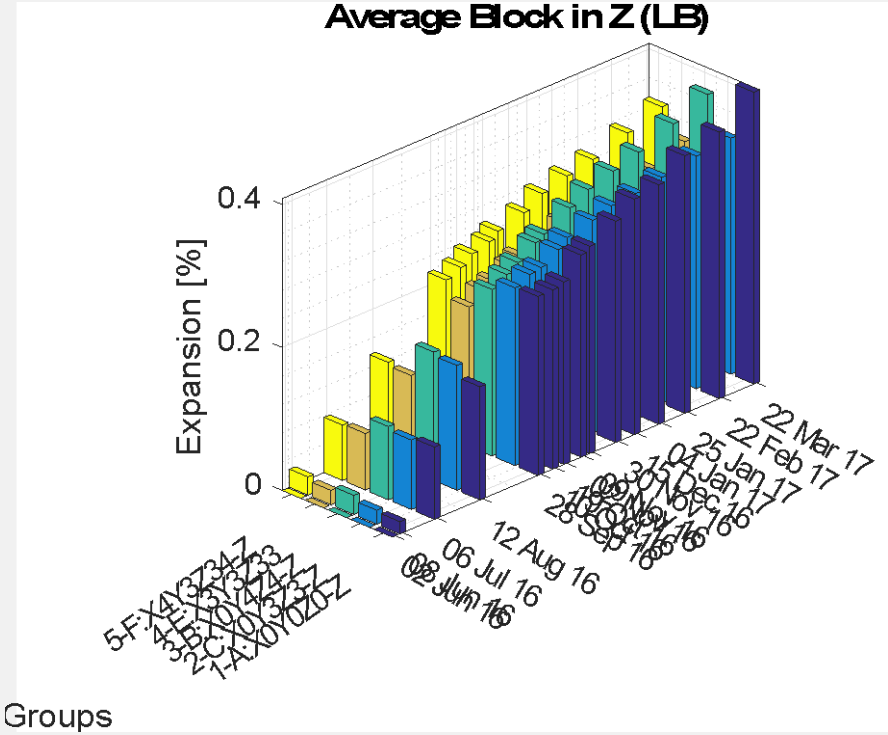



Unreinforced blocks have greatest expansion but reinforced blocks have similar expansion.

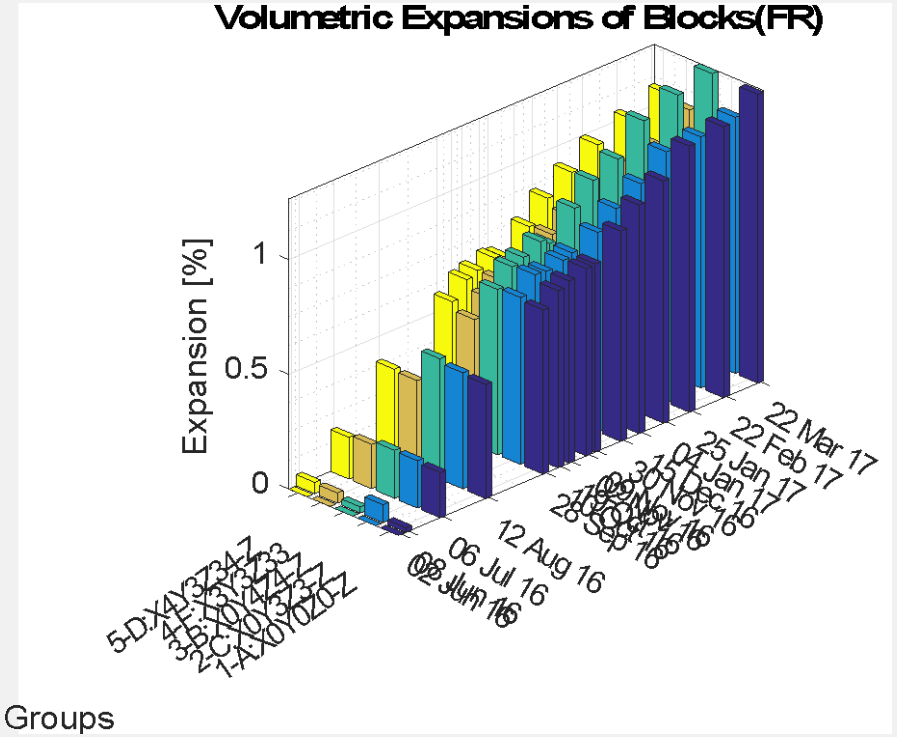
# BLOCK AVERAGE EXPANSION IN Z DIRECTION (FOG ROOM AND LAB)

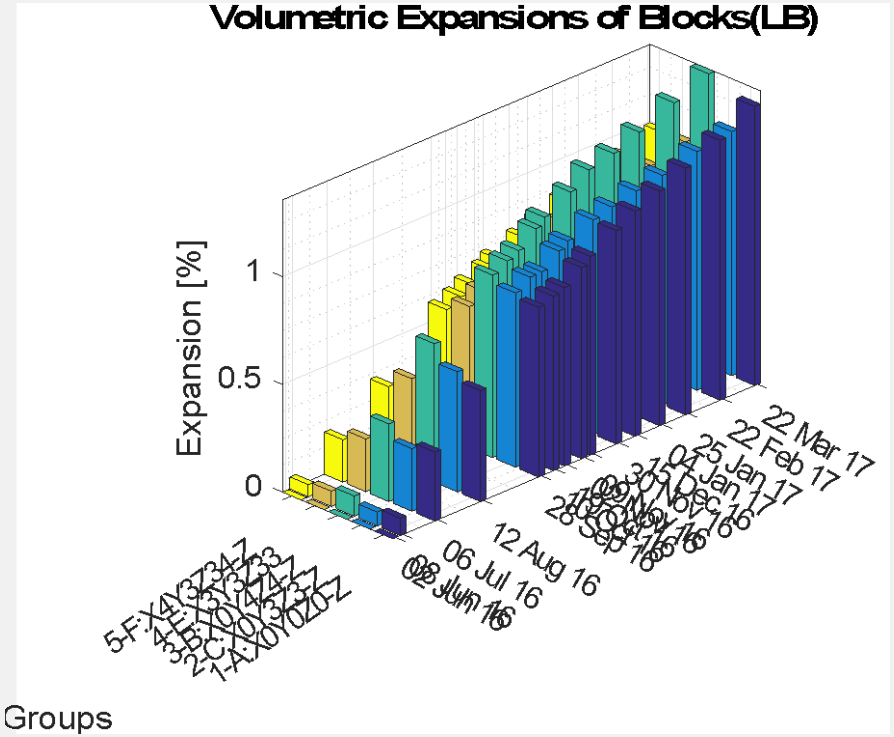



Some reinforced blocks expanding about the same as unreinforced.
Unexpected.

# BLOCK VOLUMETRIC EXPANSION (FOG ROOM AND LAB)

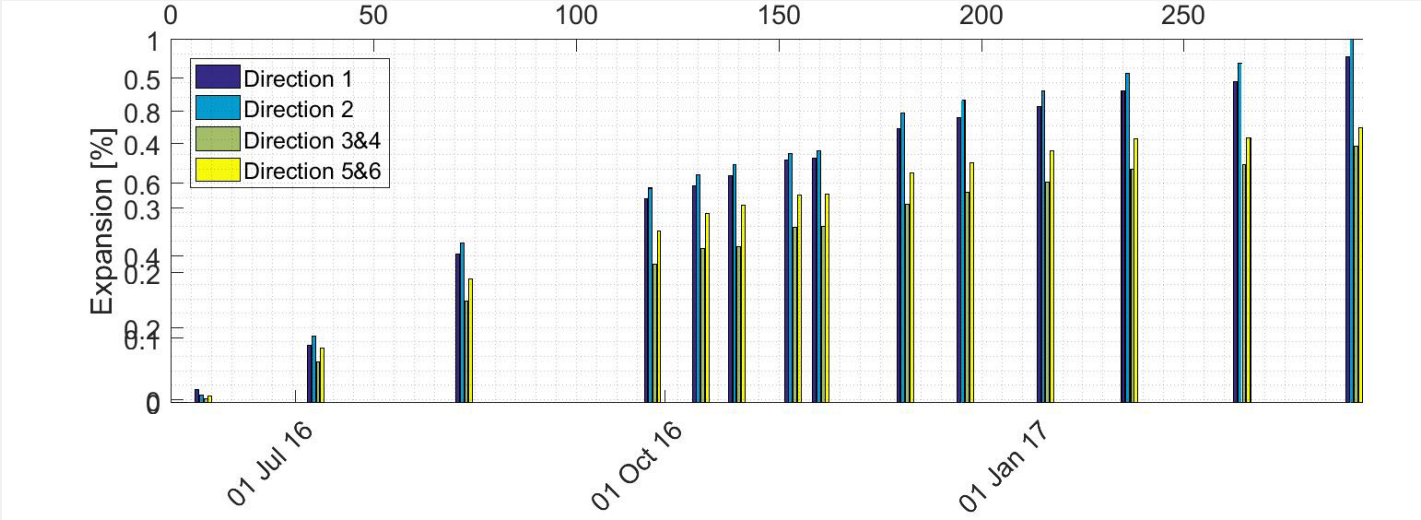


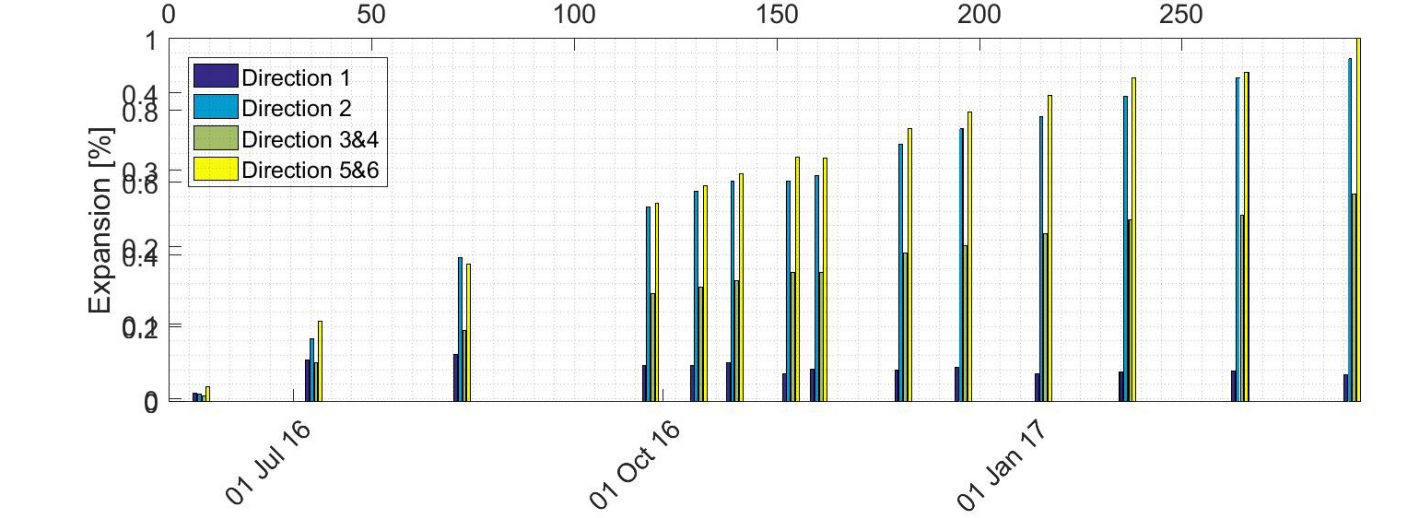




In both fog room and lab, volumetric expansions are similar, independent of reinforcement configuration. Indication of expansion redistribution.

## UNREINFORCED

- Longitudinal and transverse on specimen top show similar and greatest expansion.
- Vertical and longitudinal on specimen side show similar expansion.



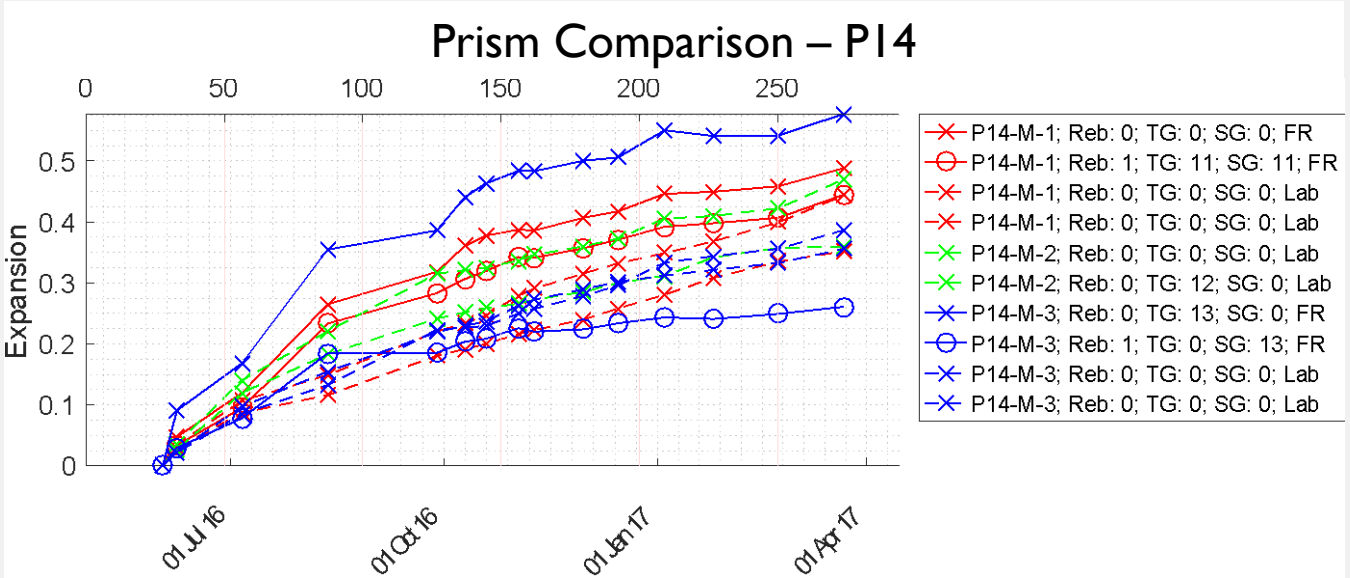

## REINFORCED

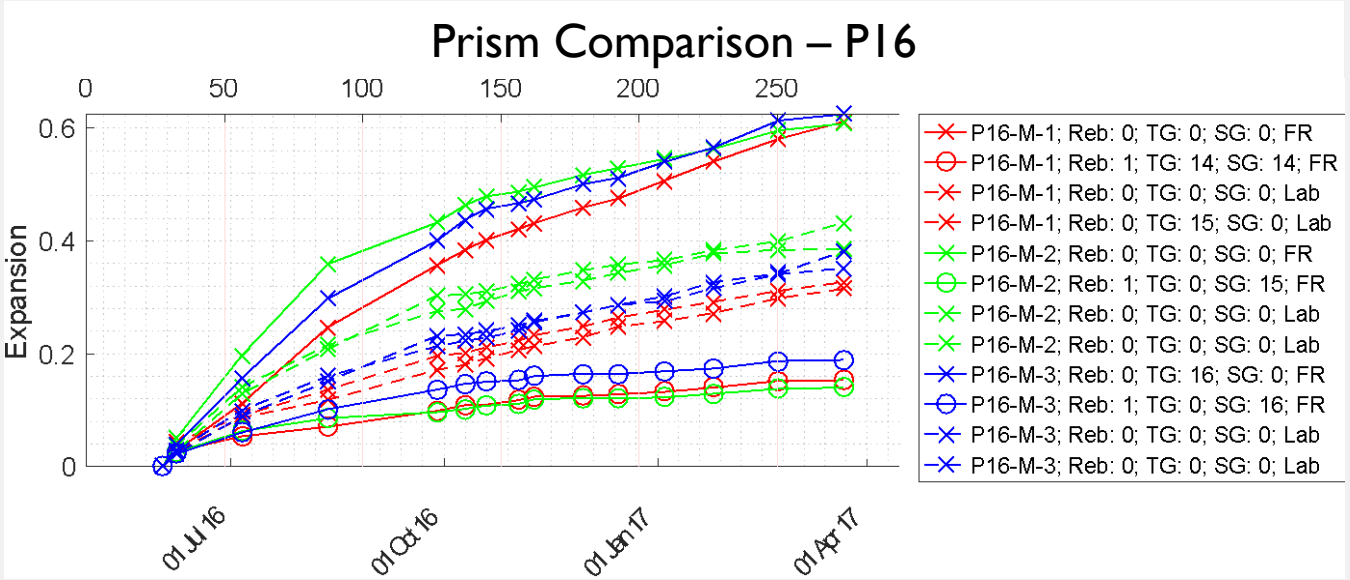
- Vertical side and transverse on specimen top show similar and greatest expansion.
- Longitudinal side has moderate expansion.
- Longitudinal top has very little expansion due to specimen cracking.

# PRISMS

- O = Reinforced
- X = Unreinforced
- - - - - = Lab
- —— = Fog Room
- Color corresponds to batch

- Unreinforced prisms in fog room have greatest expansion
- Reinforced prisms have least expansion



# BLOCKS

- O = Reinforced
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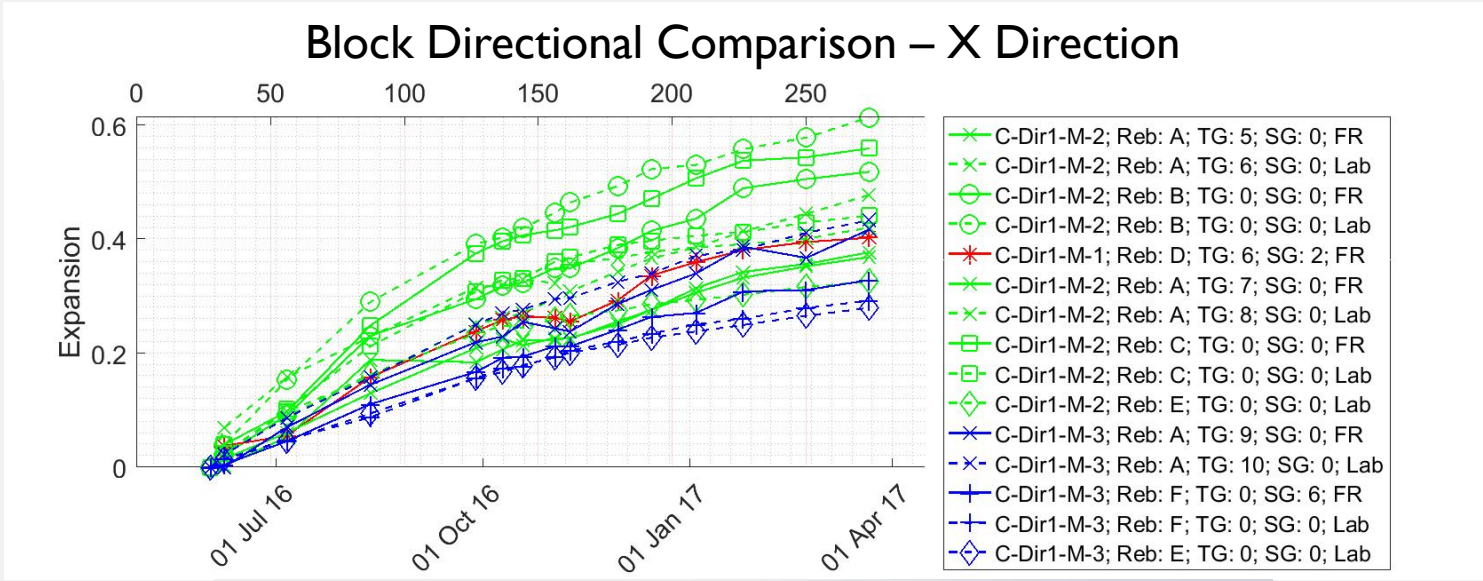
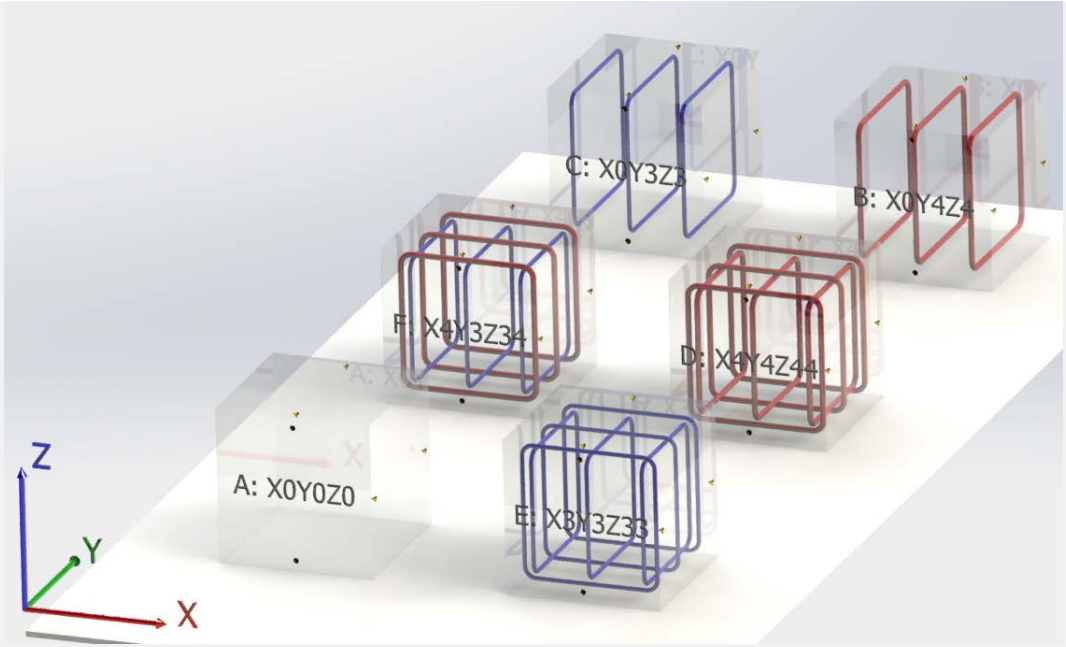
- - - - - = Lab
- ——— = Fog Room
- Color corresponds to batch



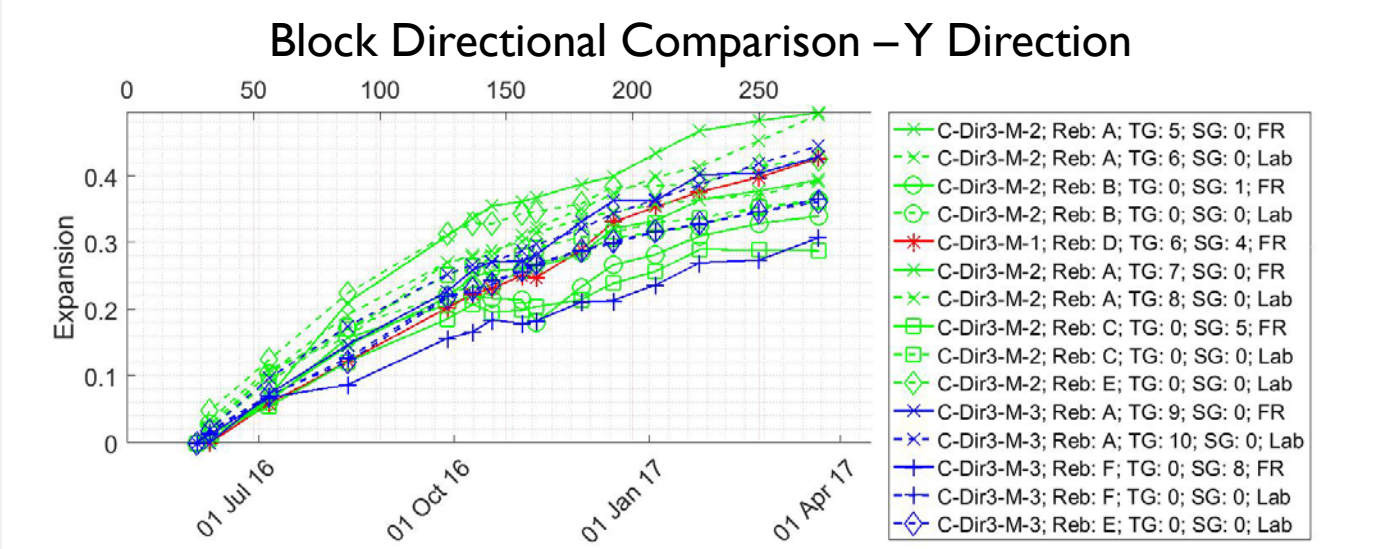



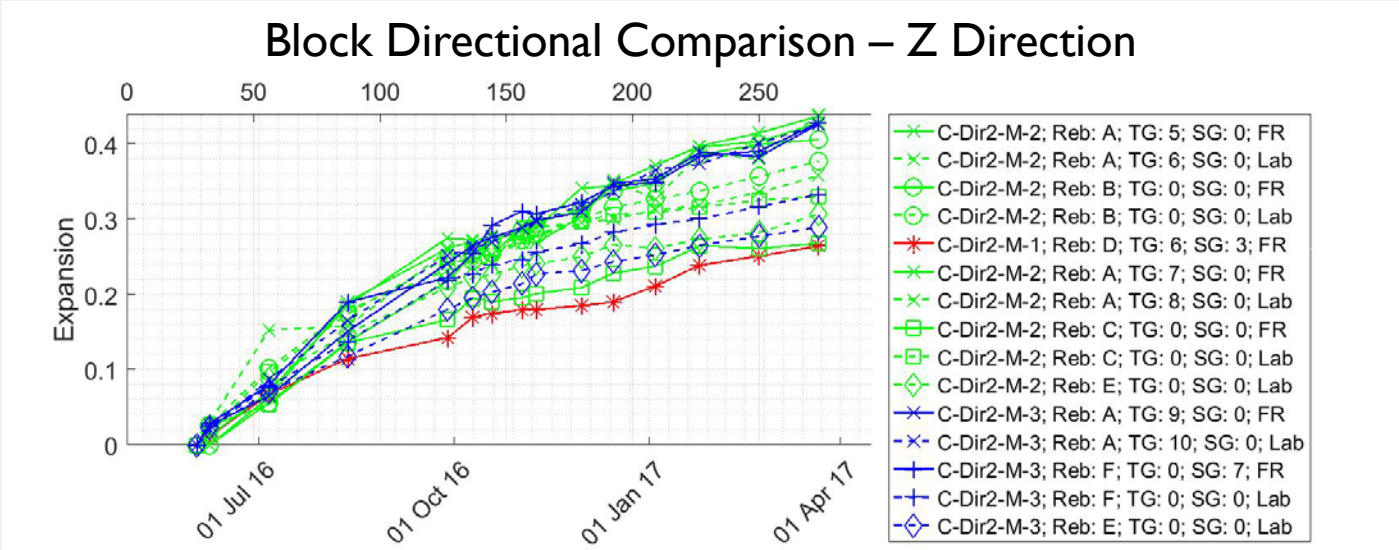
# BLOCKS

- O = Reinforced
- X = Unreinforced
- - - - - = Lab
- —— = Fog Room
- Color corresponds to batch

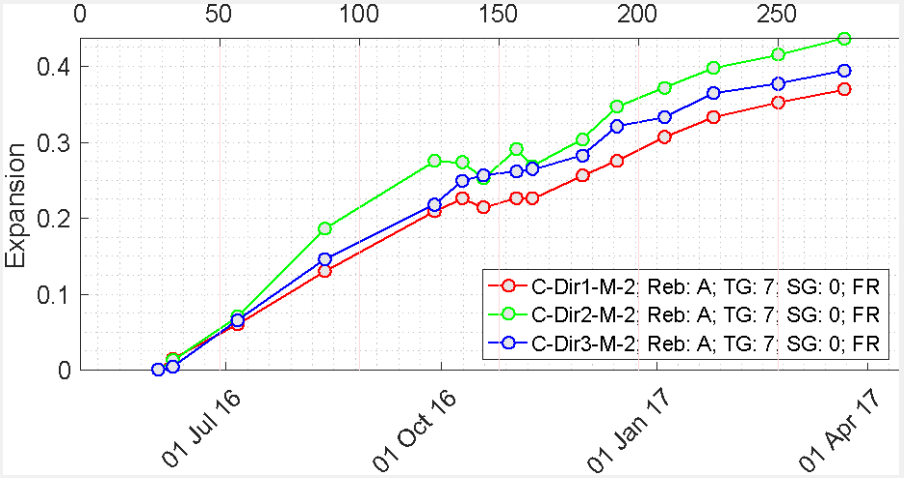
- Z Direction is the direction of pouring

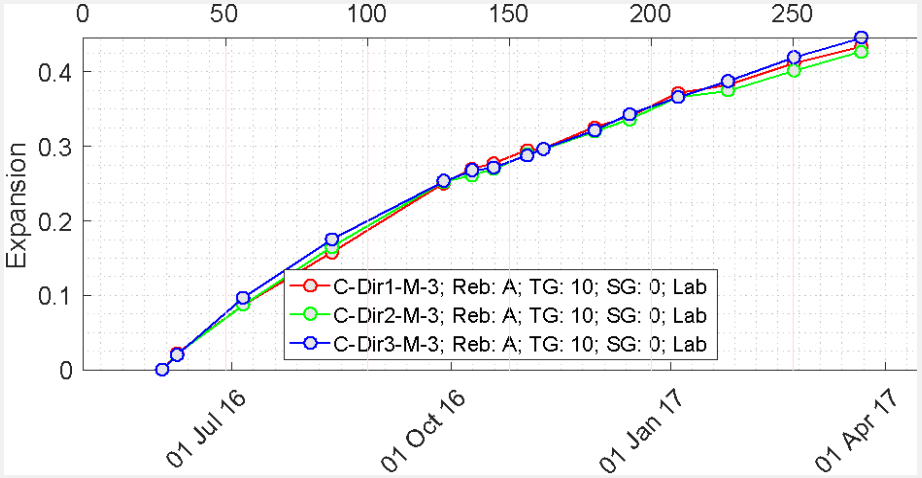
- No clear evidence that pouring direction effects expansion

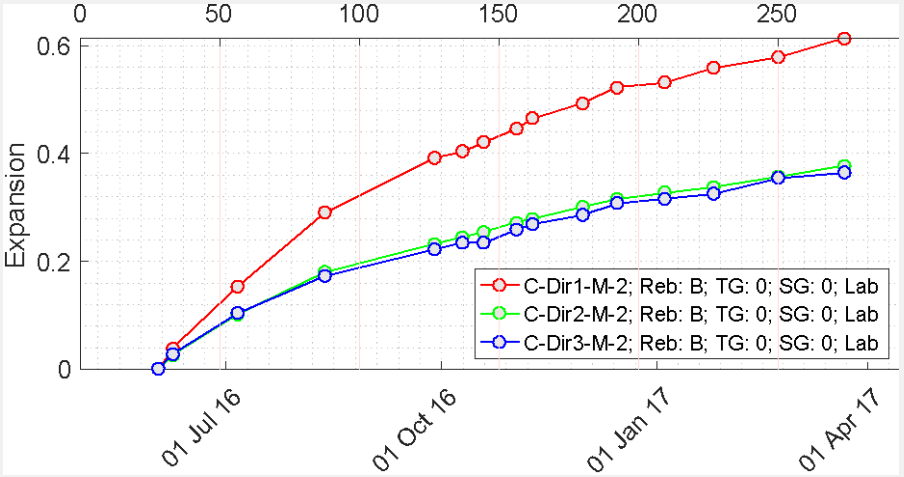


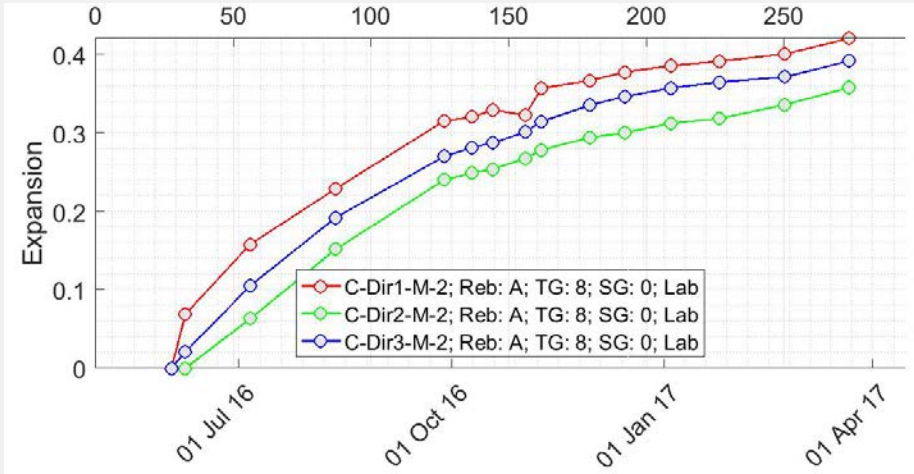



# INDIVIDUAL BLOCK EXPANSIONS (15 GRAPHS TOTAL)



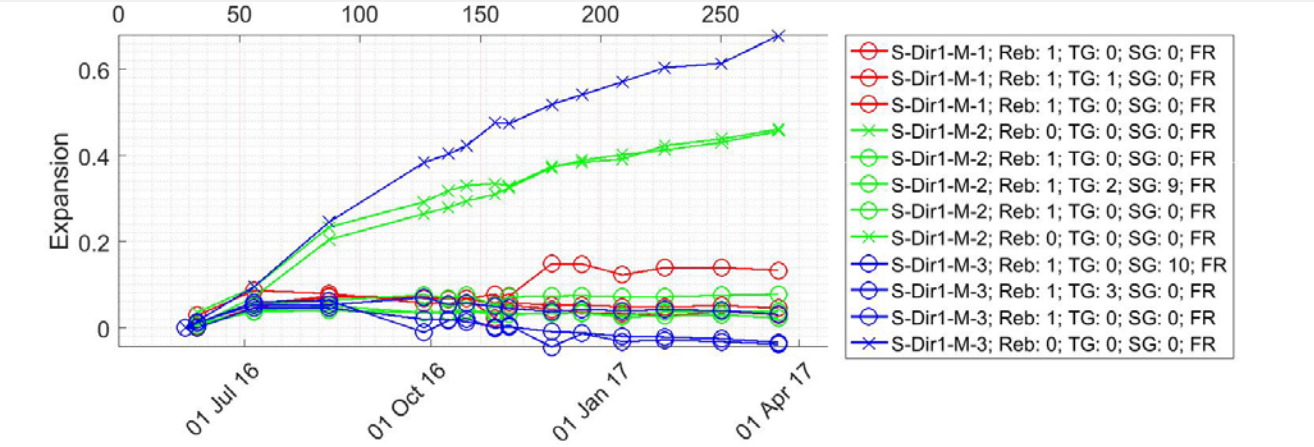



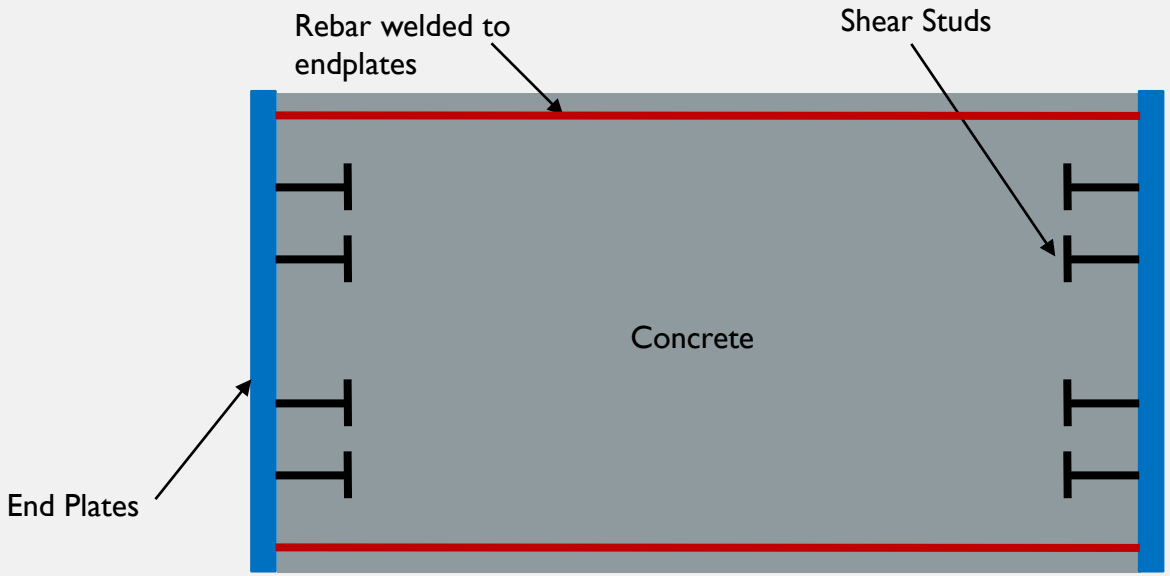

- Each graph shows expansion of each direction of one block
- Individual specimen graphs allowed location of outlier to be identified
- Easy to see how each block direction expanded in comparison to other directions

# INDIVIDUAL SHEAR SPECIMEN COMPARISON PER DIRECTION (6 TOTAL)

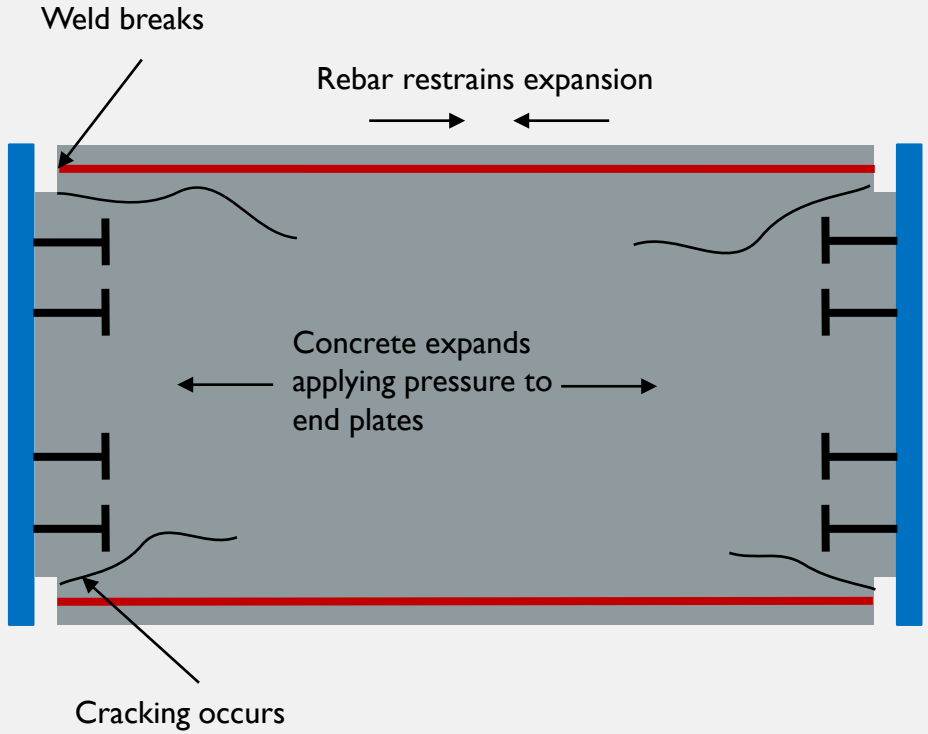



- For longitudinal top, unreinforced specimens have significantly more expansion than reinforced specimens due to cracking.
- Expansion caused rebar weld to end plate to break. Rebar restrains top specimen portion while middle continues to expand. Tension zone forms and cracking occurs.

# TENSION CRACKING

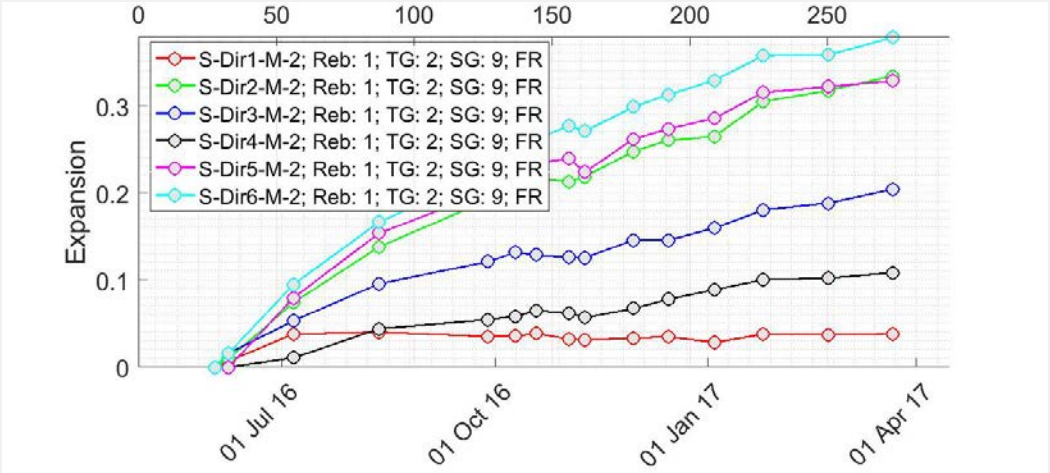


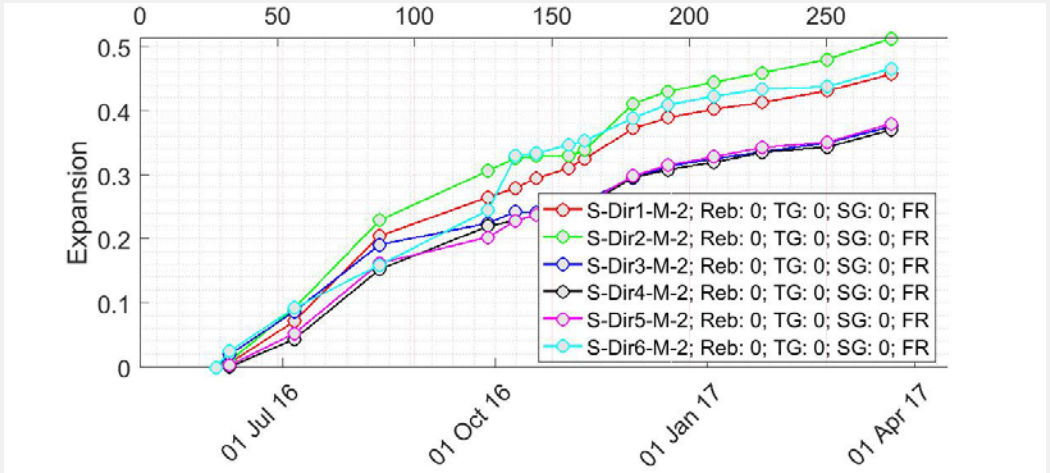

Before Expansion

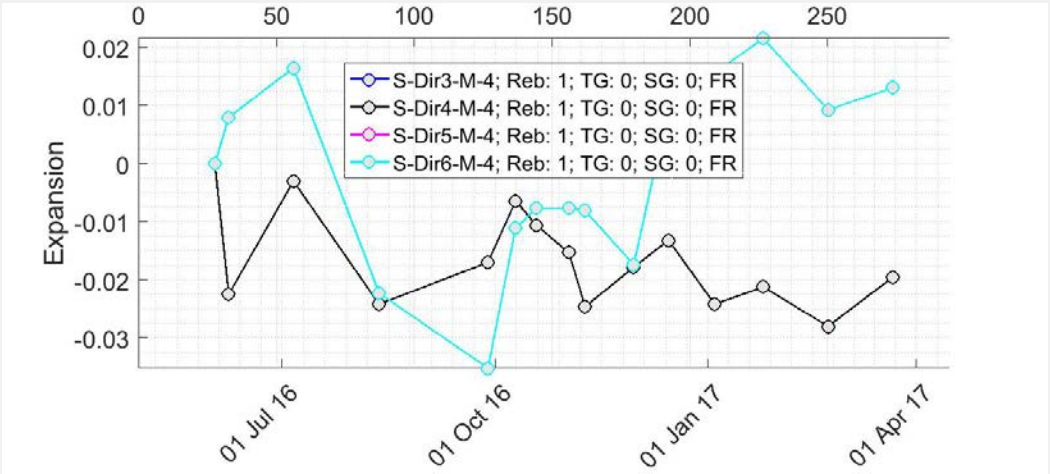


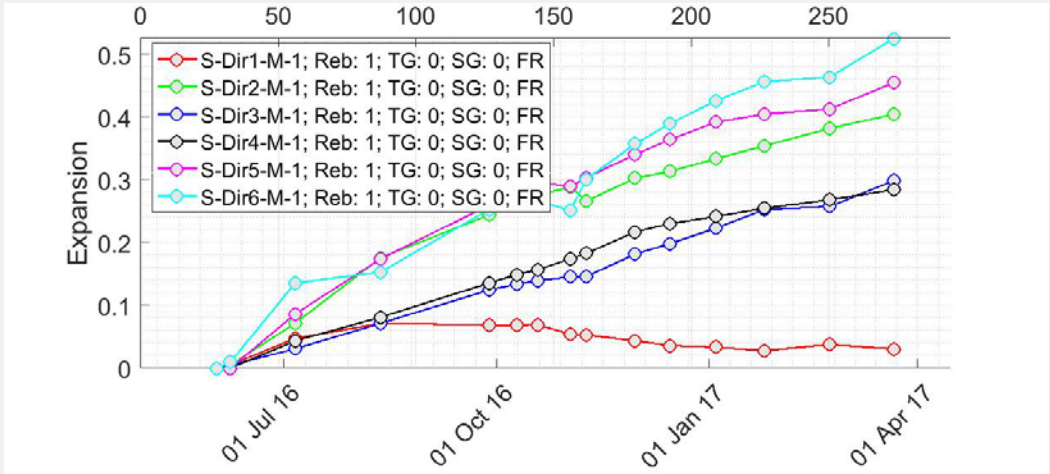

After Expansion

# INDIVIDUAL SHEAR SPECIMEN EXPANSIONS (16 GRAPHS TOTAL)



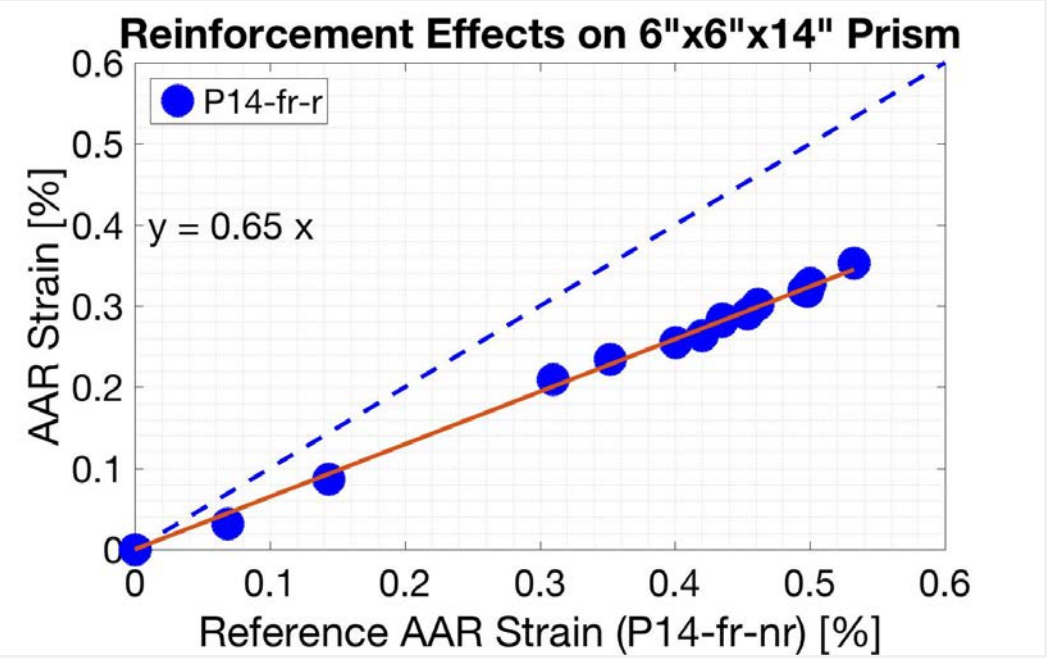



# REINFORCEMENT EFFECTS

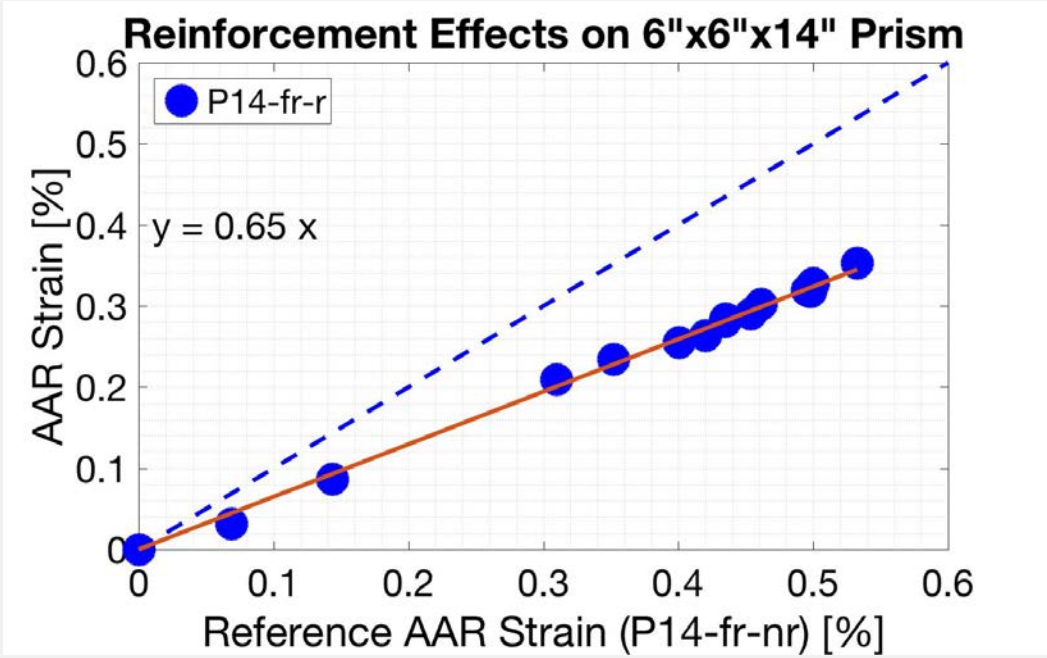
# PLOTS

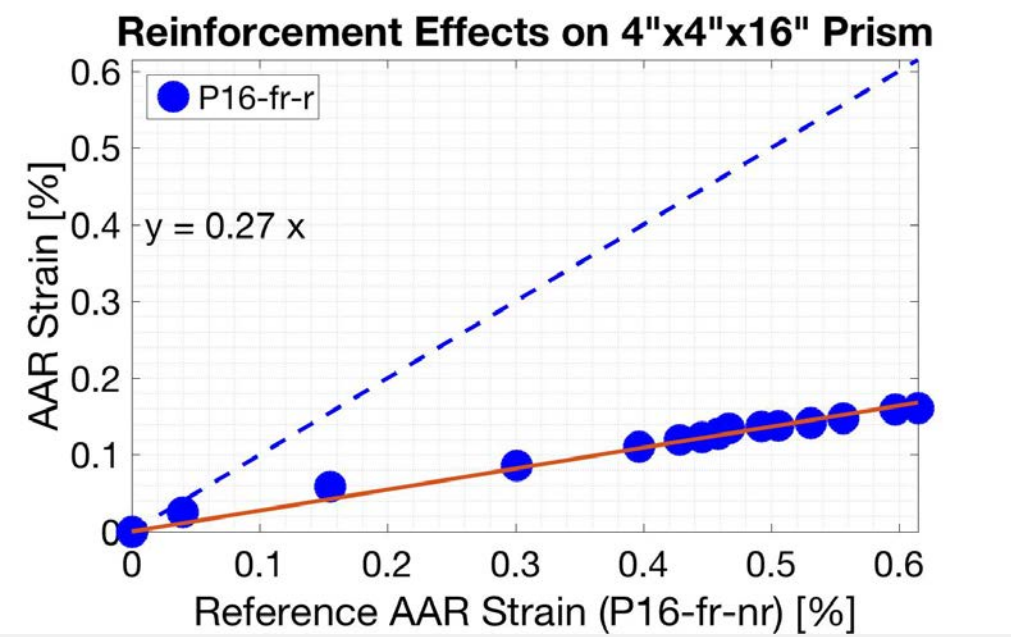
- Expansion of specimen plotted with to reference specimen on x axis
- Unreinforced vs. Reinforce or Fog Room vs. Lab
- Data fit with linear fit line and y intercept of zero. Equation of line is shown
- Dashed line corresponds to y = mx where m = 1
- Closer linear fit is to dashed line, the better correlation
- m < 1 means less expansion than reference specimen
- m > 1 means greater expansion than reference specimen



# PRISMS

- 6”x6”x14” Reinforcement Ratio = 1.53%
- Reinforced prism has less expansion than unreinforced

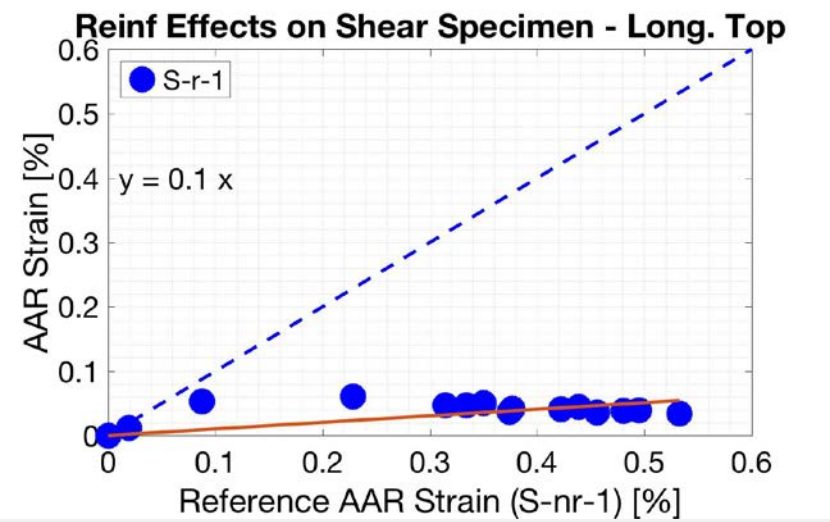


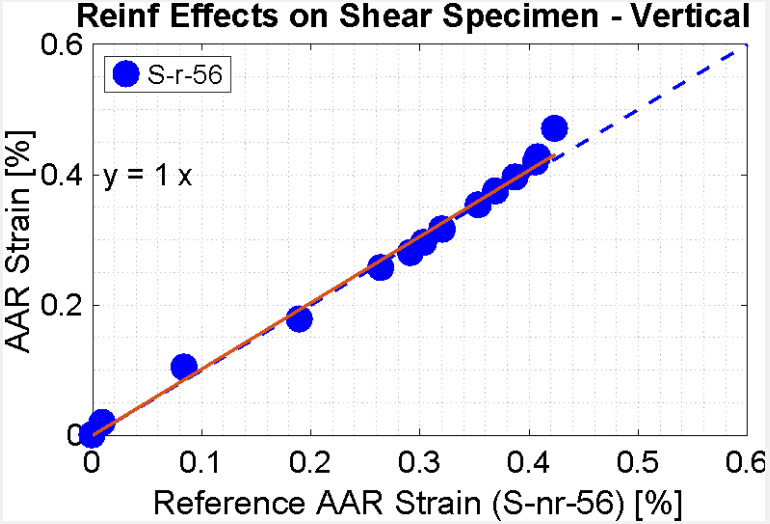



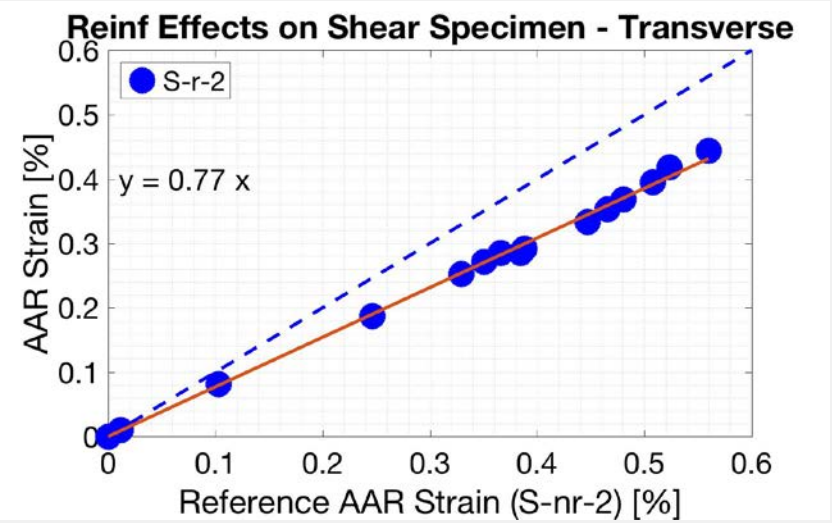

- 4”x4”x16” Reinforcement Ratio = 2.75%
- Reinforced prism has less expansion than unreinforced
- Prisms with greater reinforcement ratio have less expansion

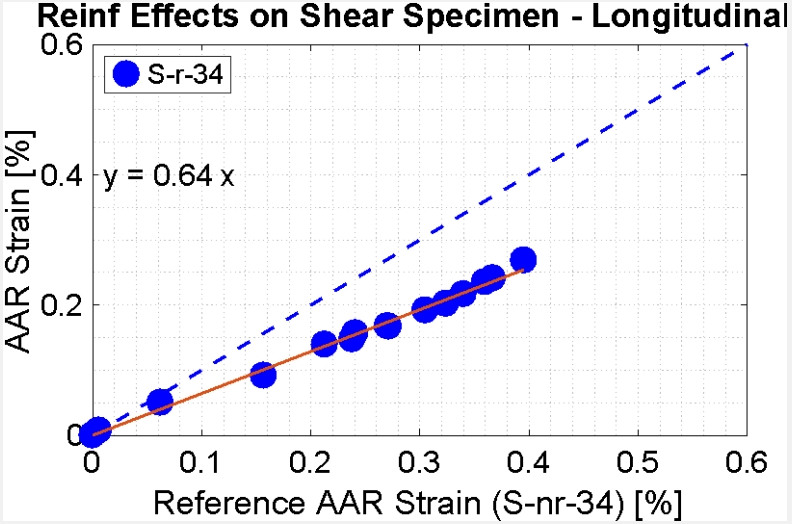
# SHEAR SPECIMENS

- Longitudinal top has low reinforcement due to cracking
- Vertical direction is always unreinforced. Vertical expansion is the same comparing reinforced to unreinforced
- Longitudinal has slightly greater reinforcement ratio (1.17%) than transverse (1.05%) and has slightly less expansion



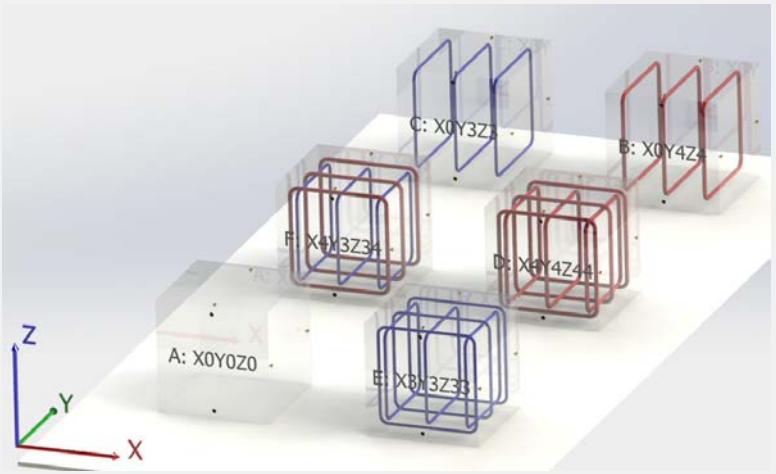



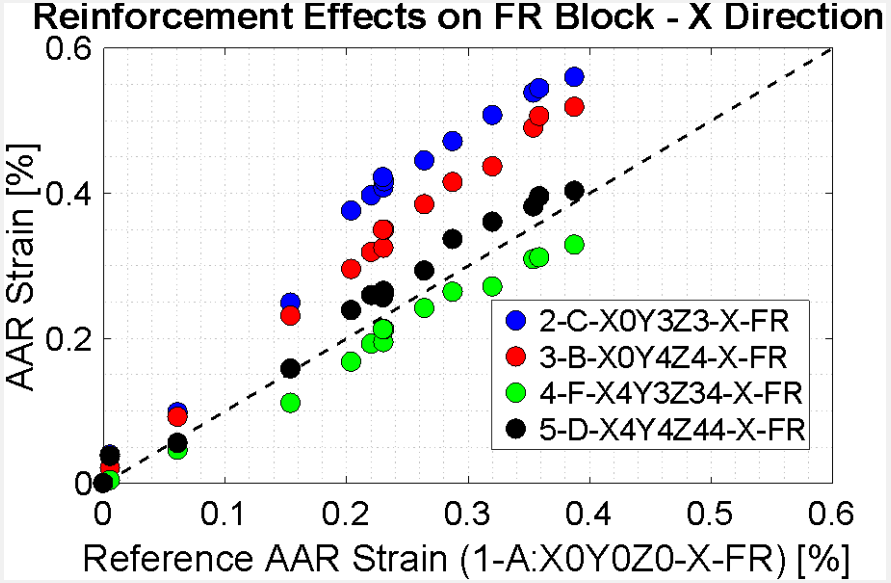



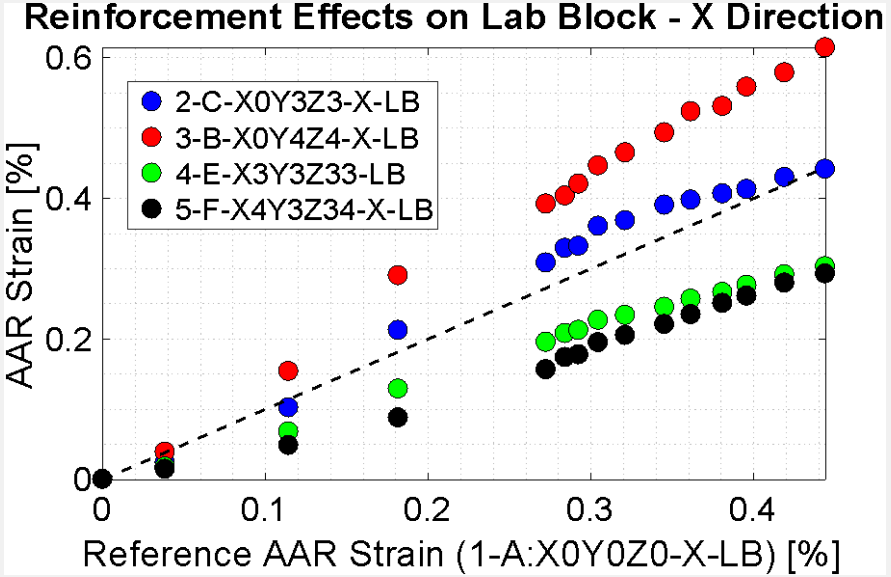



# REINFORCEMENT EFFECT ON BLOCKS

- Biaxially reinforced blocks (B & C) showing greatest expansion due to expansion redistribution.
- Triaxially reinforced blocks have about the same expansion in fog room as unreinforced block and less expansion in lab.

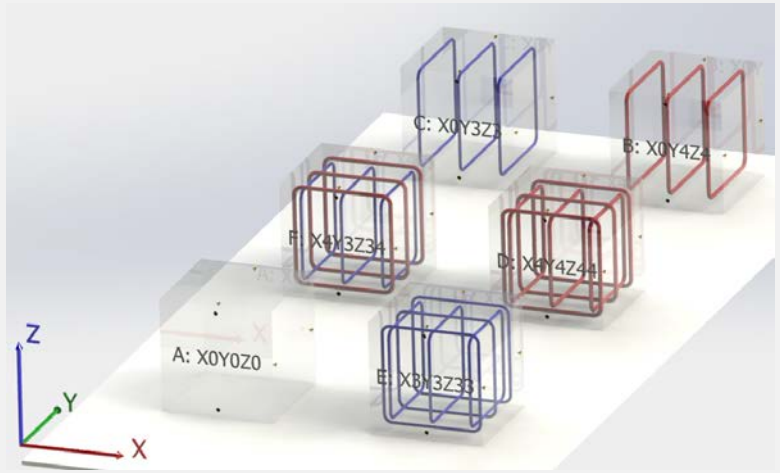


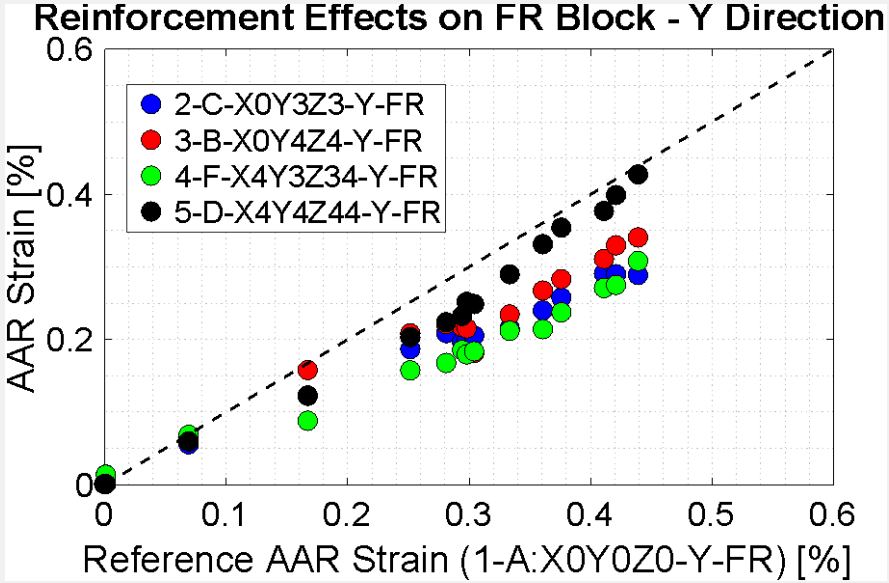



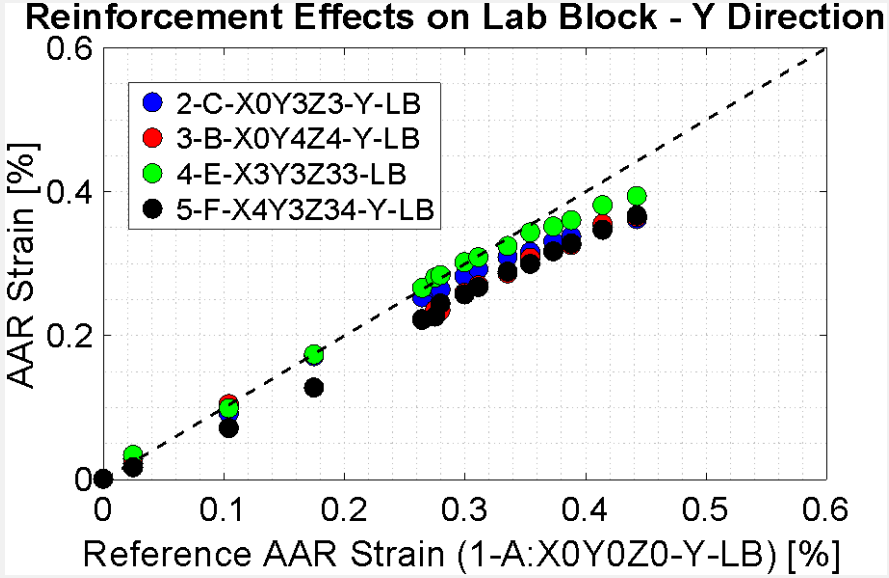



# REINFORCEMENT EFFECT ON BLOCKS

- In fog room, all reinforced blocks have less expansion than unreinforced but heaviest triaxial reinforcement has greatest expansion
- In lab, all reinforced blocks have similar or slightly less expansion than unreinforced.

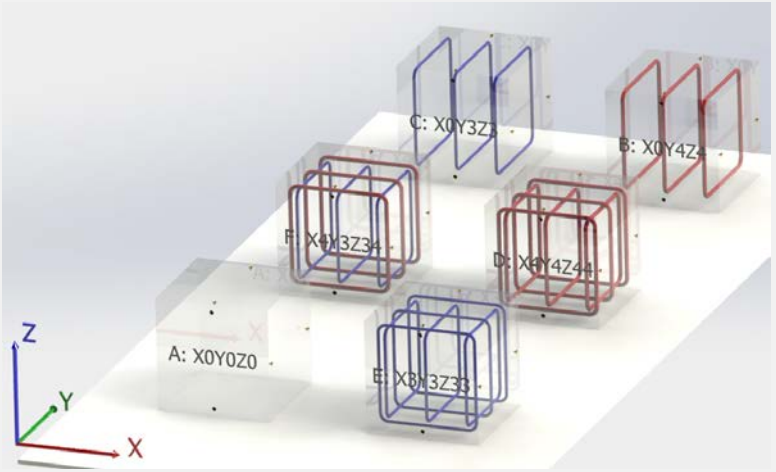


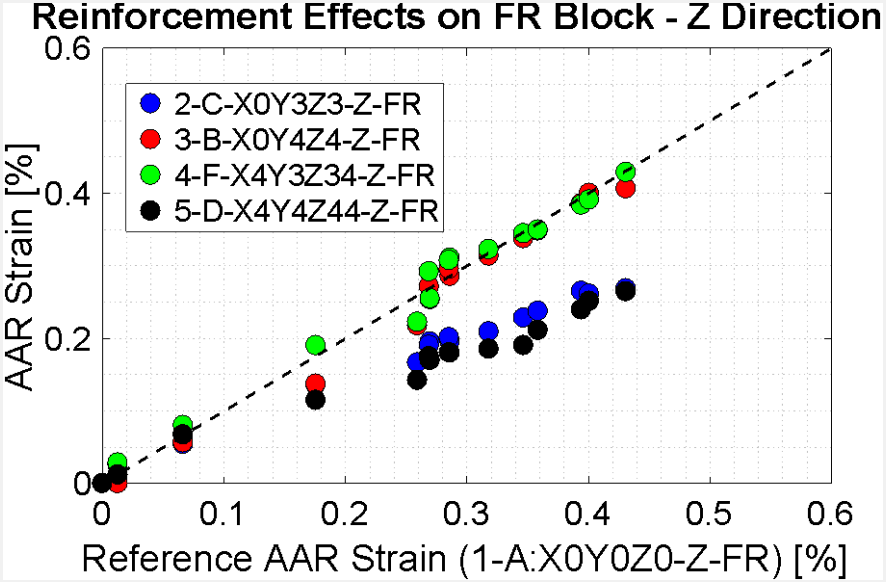



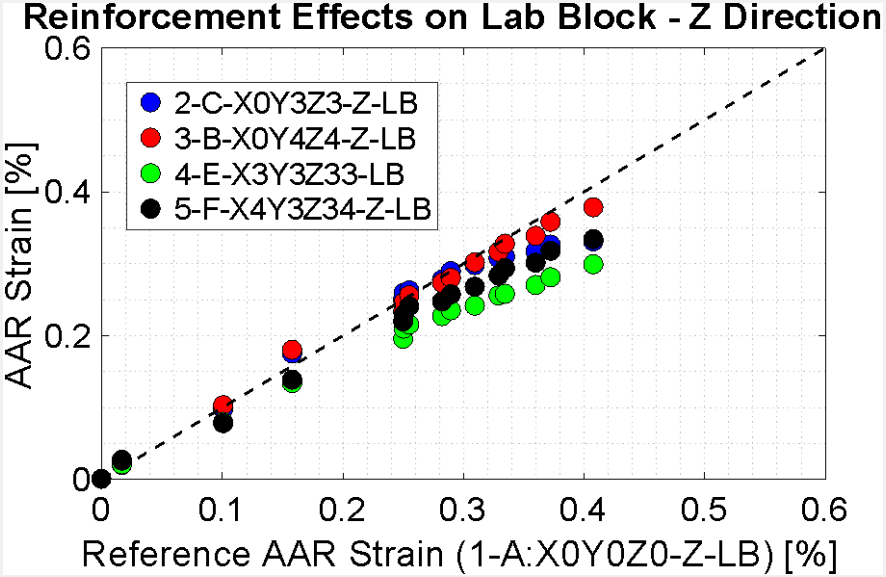



# REINFORCEMENT EFFECT ON BLOCKS

- In fog room, lightest biaxial and heaviest triaxial reinforcement block expand the least but similarly.
- Other biaxial and triaxial blocks expand about the same as unreinforced.
- In lab, all reinforced blocks expand slightly less than unreinforced.

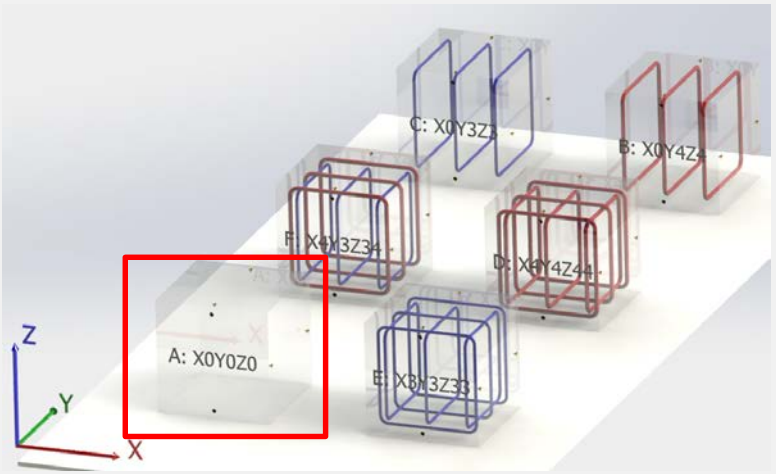


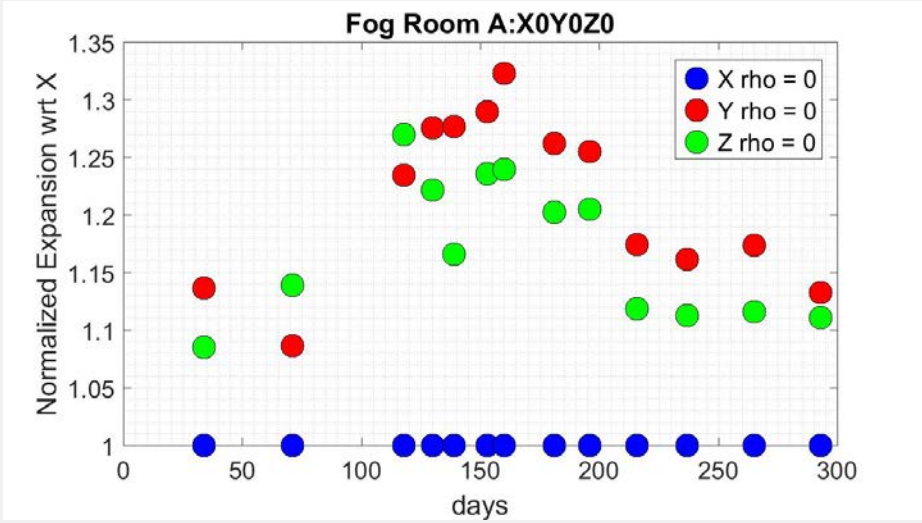



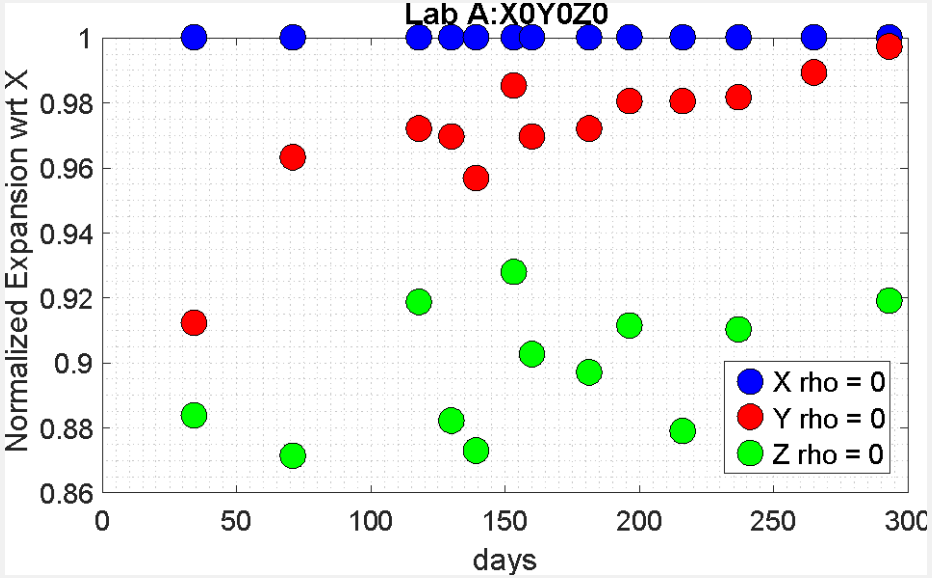



# UNREINFORCED BLOCK IN FOG ROOM AND LAB

- Expansion separated by direction over time and normalized to X direction
- Y & Z direction expansion is greater than X in Fog Room
- Y & Z direction expansion is less than X in Lab

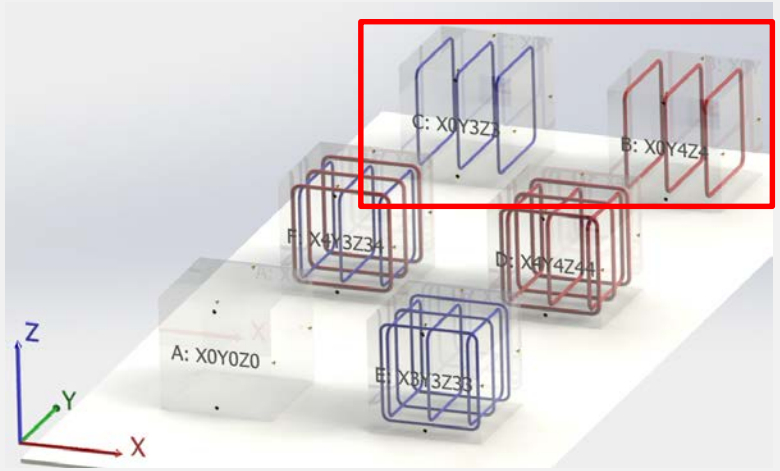


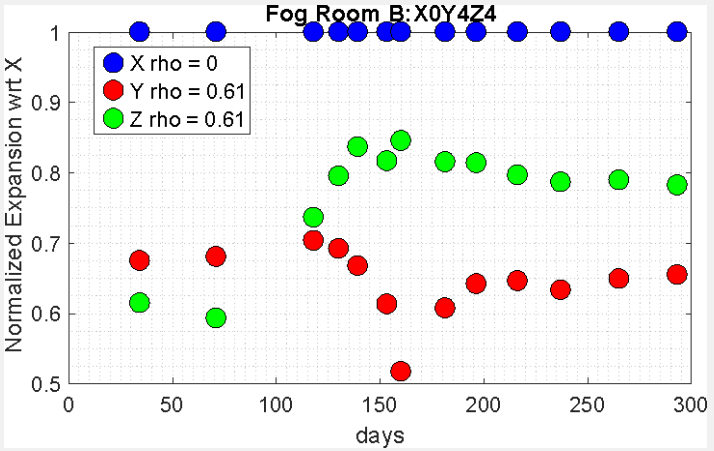



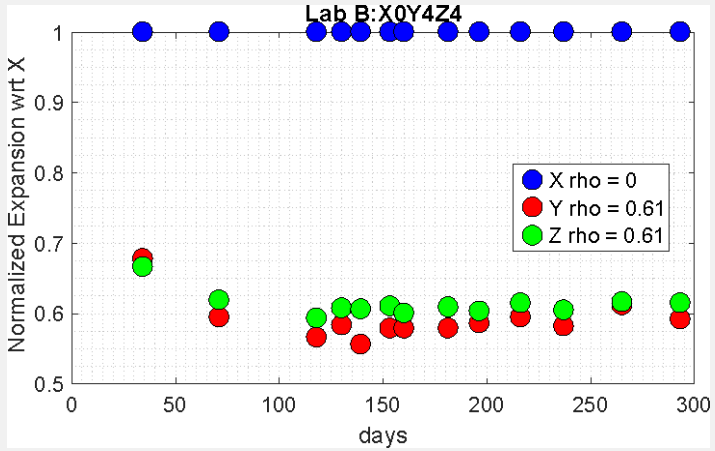



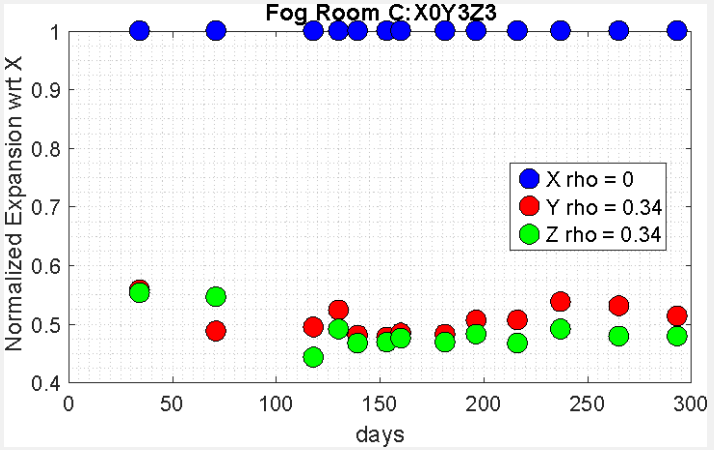
# B & C REINFORCEMENT BLOCK IN FOG ROOM & LAB

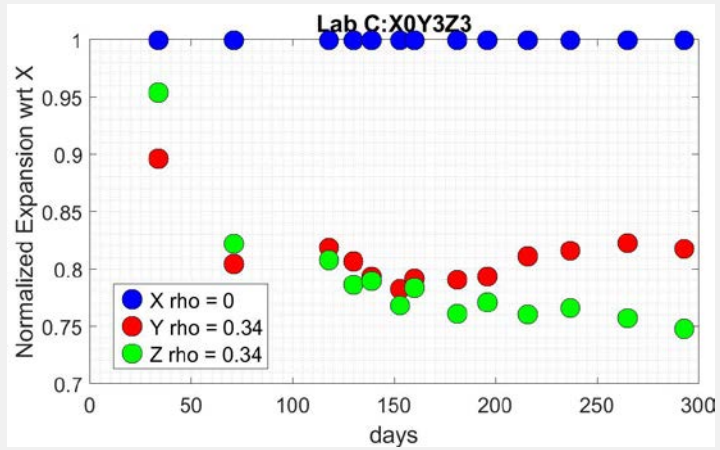
- Biaxial Reinforcement
- X Direction is unreinforced and showing significantly more expansion
- Expansion Transfer



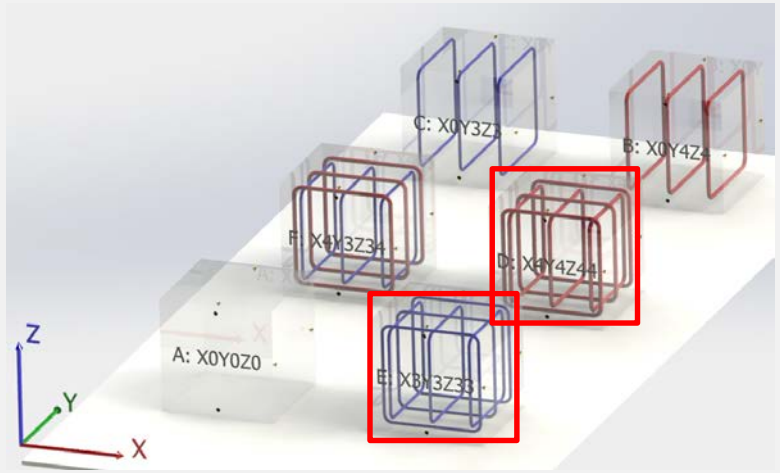



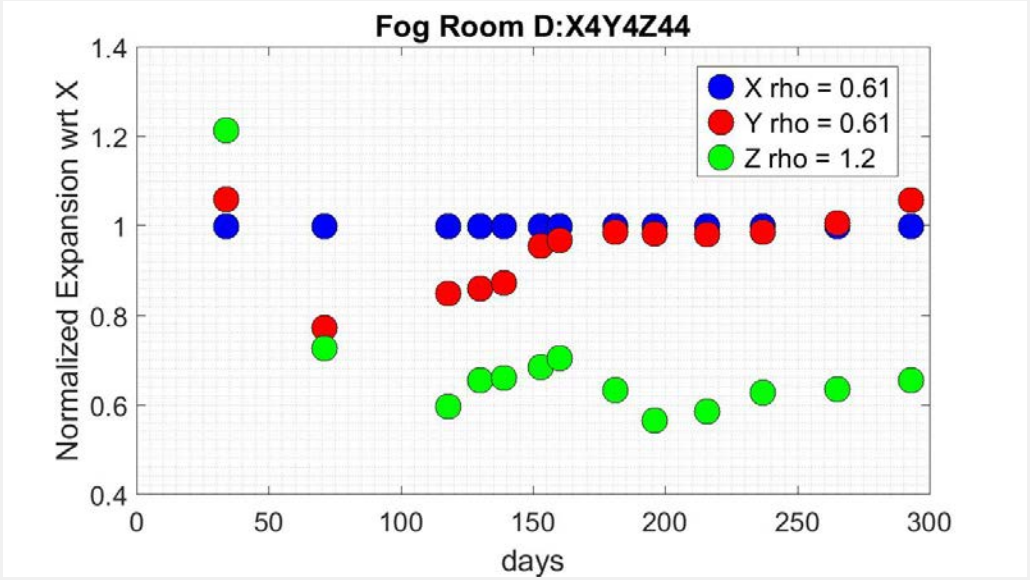



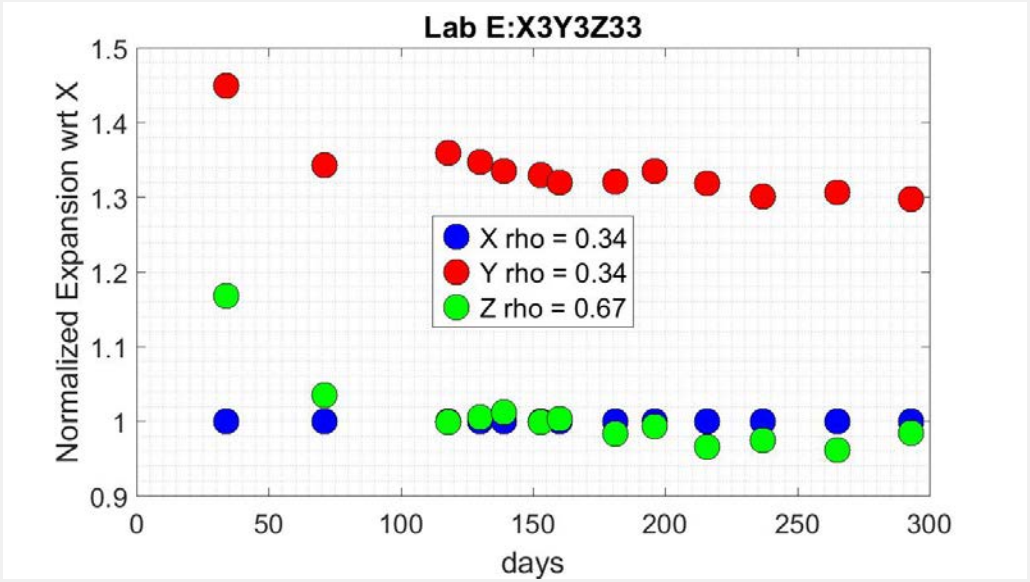



# D REINFORCEMENT IN FOG ROOM & E REINFORCEMENT IN LAB

- Triaxial Reinforcement with equal bar size in both directions
- D Block showing similar expansion in similar reinforcement ratios. Greater reinforcement ratio has less expansion
- E block X and Z Direction have same expansion despite different reinforcement ratio

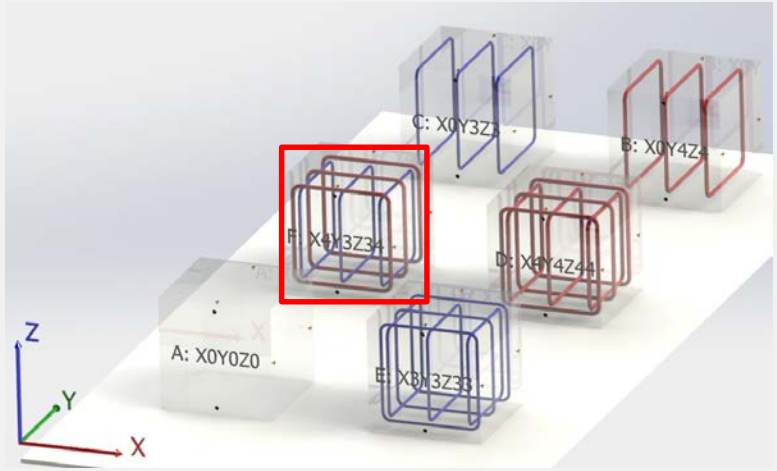


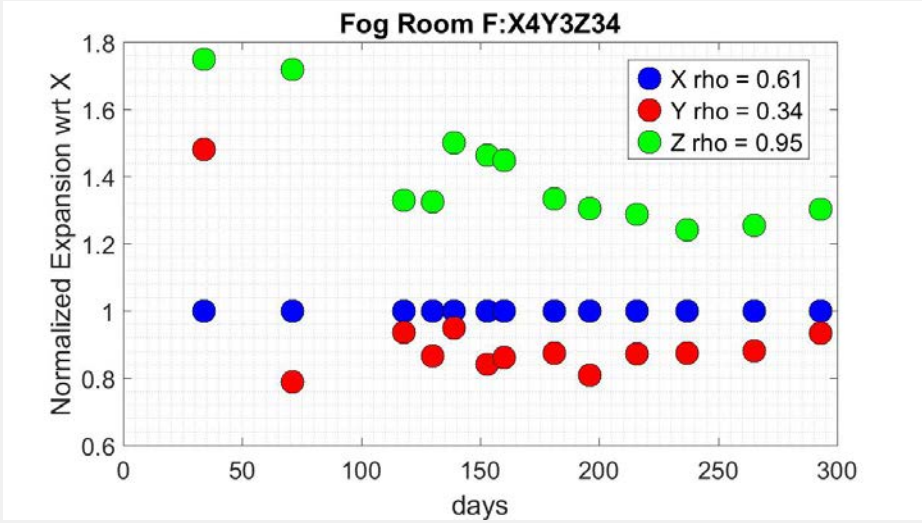



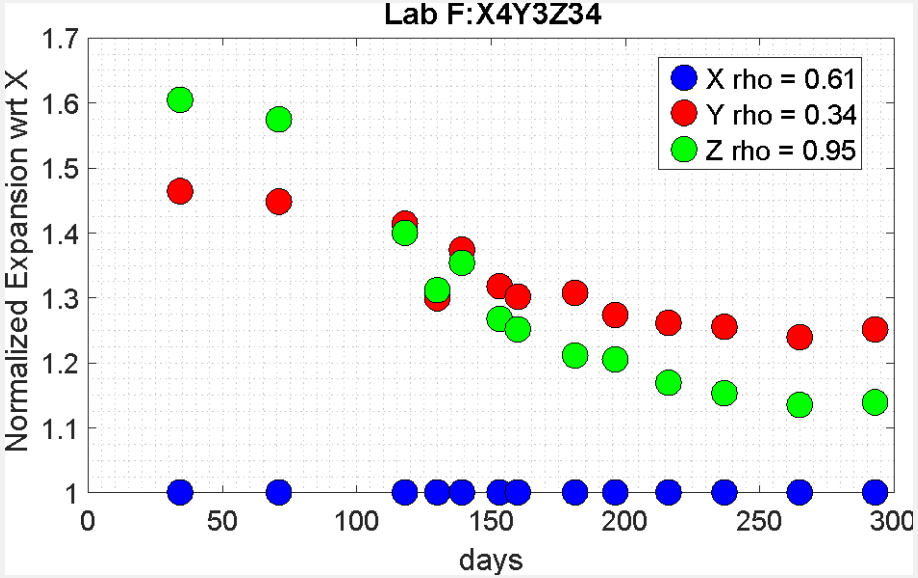



# F REINFORCEMENT BLOCK IN FOG ROOM AND LAB

- Triaxial reinforcement with different bar sizes in each direction
- In fog room, most reinforced direction showing the most expansions
- In lab, least and most reinforced directions showing similar expansions.



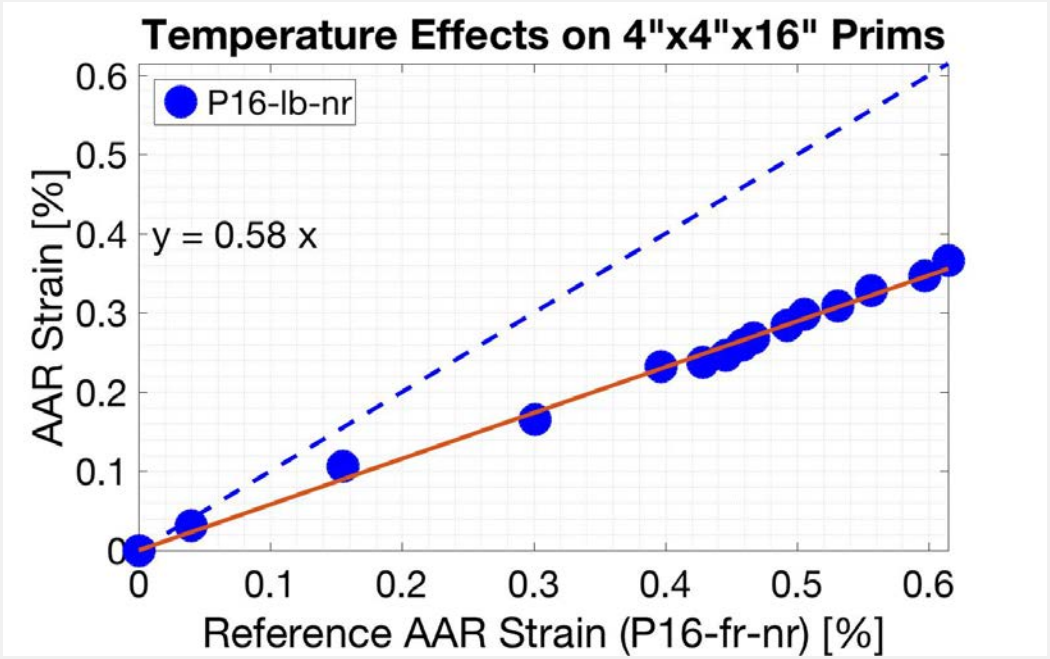



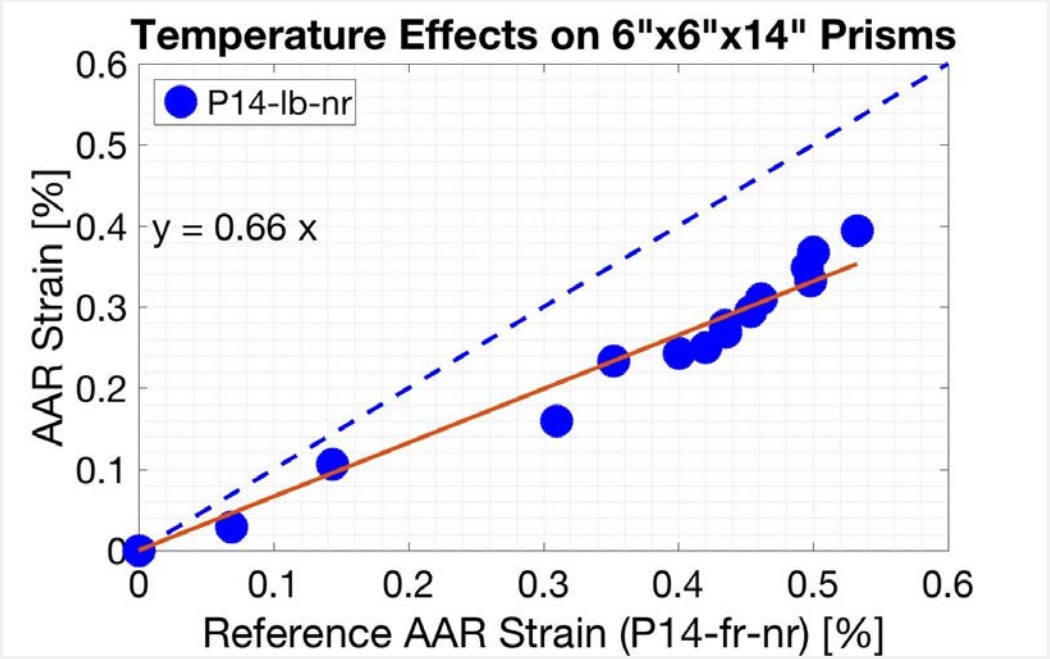
# REINFORCEMENT EFFECTS CONCLUSION

- Prisms and shear specimens showed good results
  - Greater reinforcement ratio decreased expansion
- Blocks generally did not support predictions
  - Expansion redistribution in biaxial blocks
  - Fog room blocks did not show expected results
  - Reinforced lab blocks showed similar or less expansion than unreinforced

# TEMPERATURE EFFECTS

# TEMPERATURE EFFECT ON PRISMS

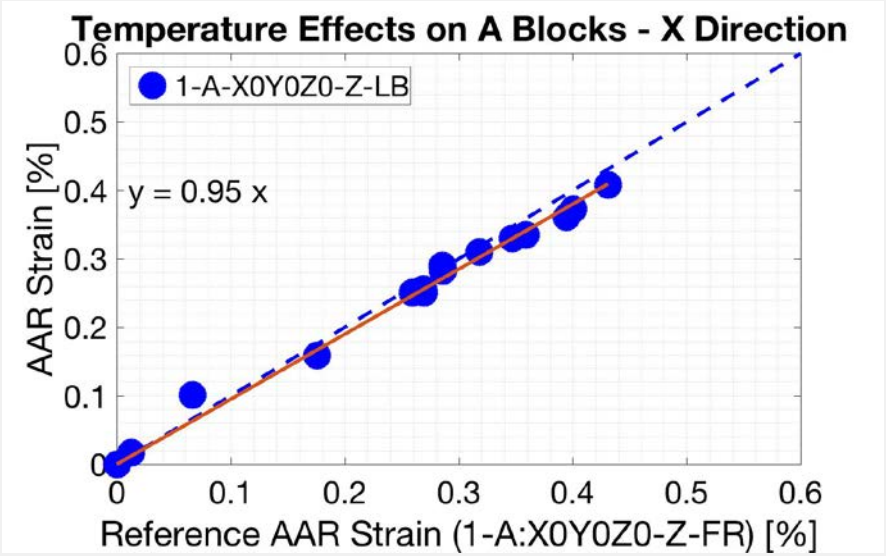


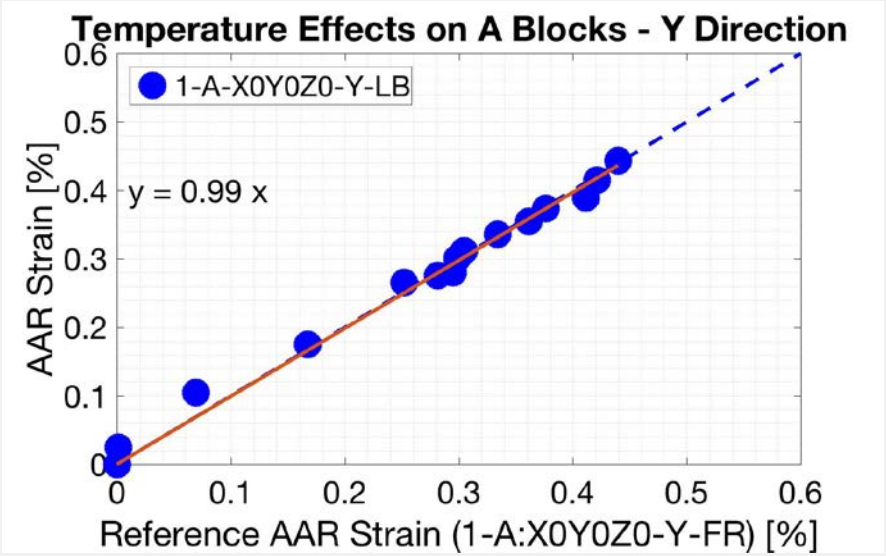



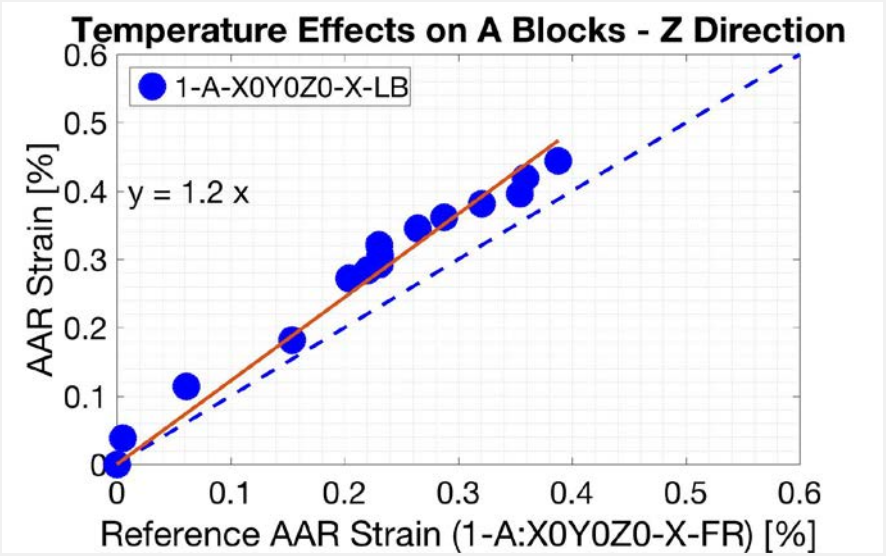

Prisms stored in the fog room have greater expansion than those in lab at ambient temperatures for both prism sizes

# TEMPERATURE EFFECT ON UNREINFORCED BLOCKS

- Lab blocks have similar (within 5%) or greater expansion than fog room blocks in all three directions
- No indication pouring direction influences

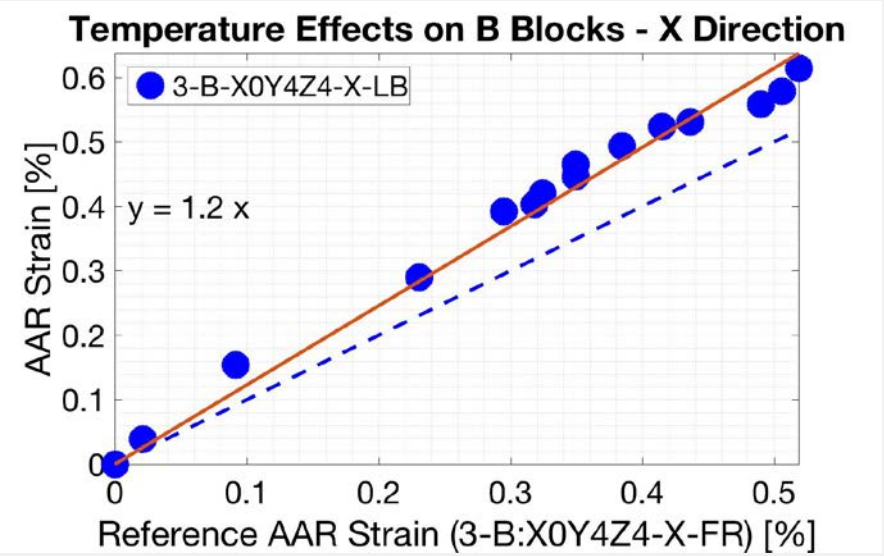


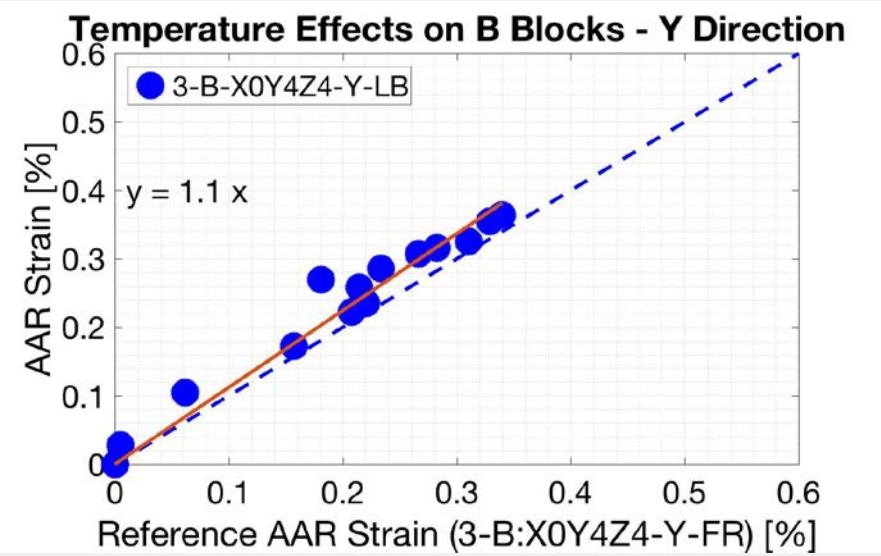



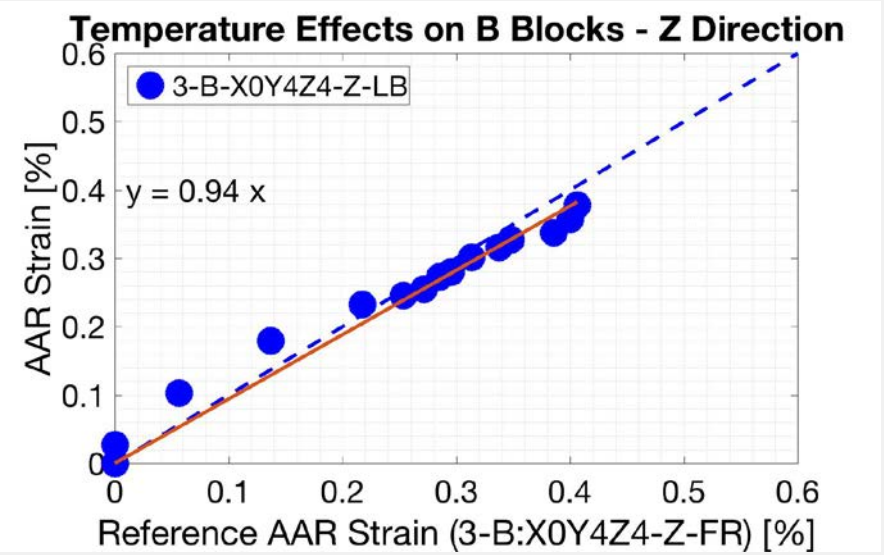



# TEMPERATURE EFFECT ON B REINFORCEMENT BLOCKS

- Lab blocks have similar (within 6%) or greater expansion than fog room blocks in all three directions

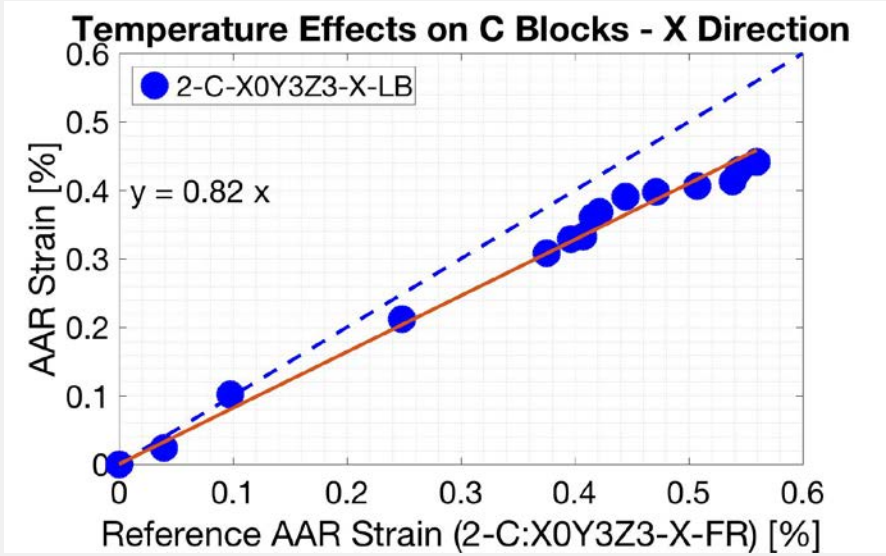


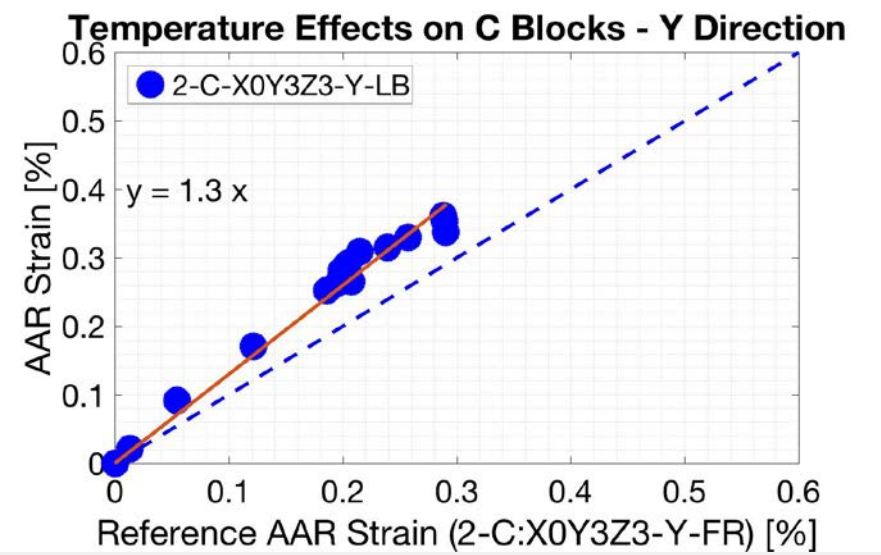



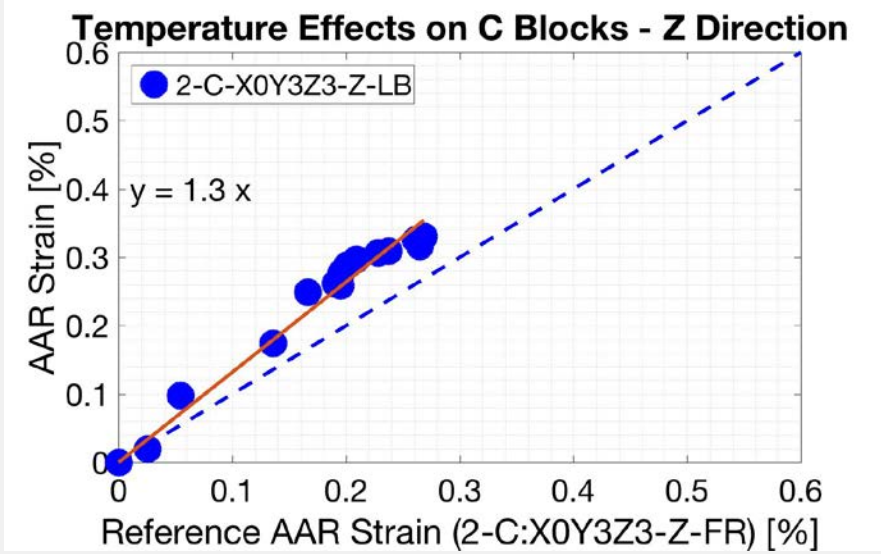



# TEMPERATURE EFFECT ON C REINFORCEMENT BLOCKS

- Lab blocks have 30% greater expansion than fog room blocks in Y & Z Direction
- X Direction expansion in lab is 82% of fog room expansion
- No clear correlation between reinforcement type and temperature effects on expansion.

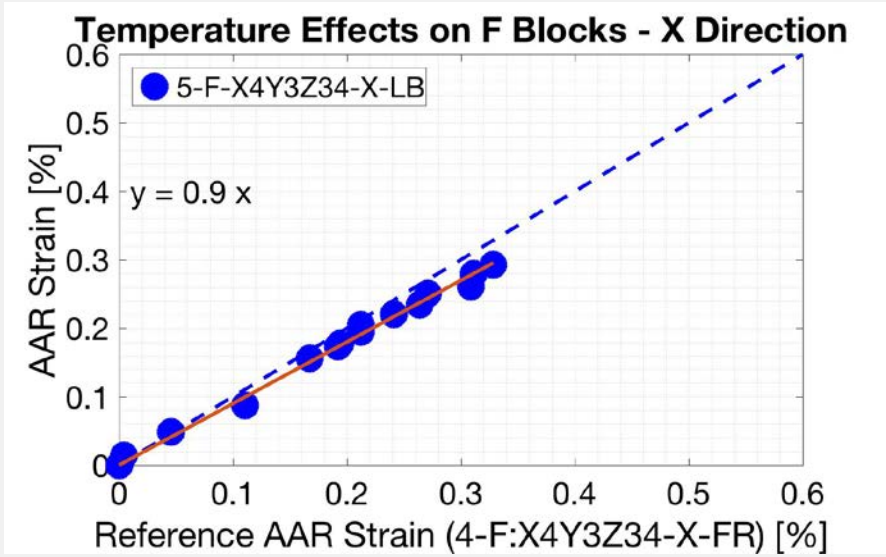


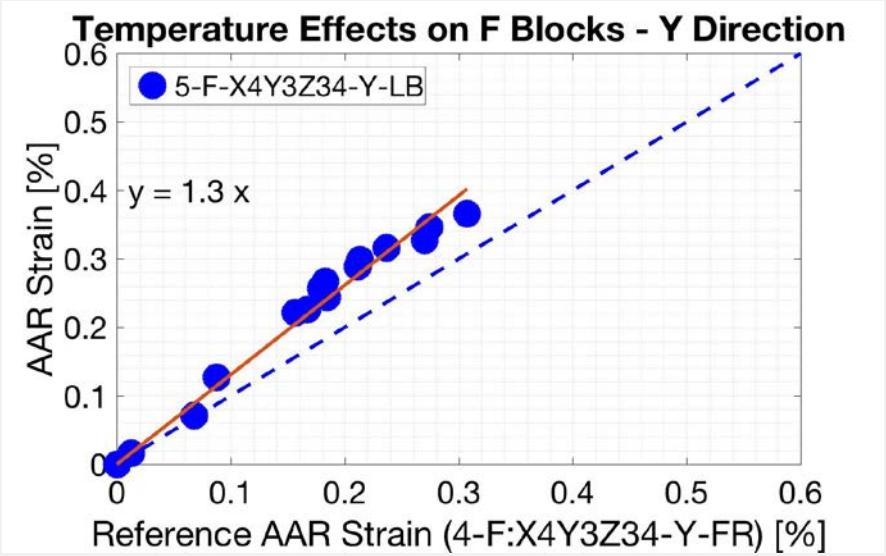



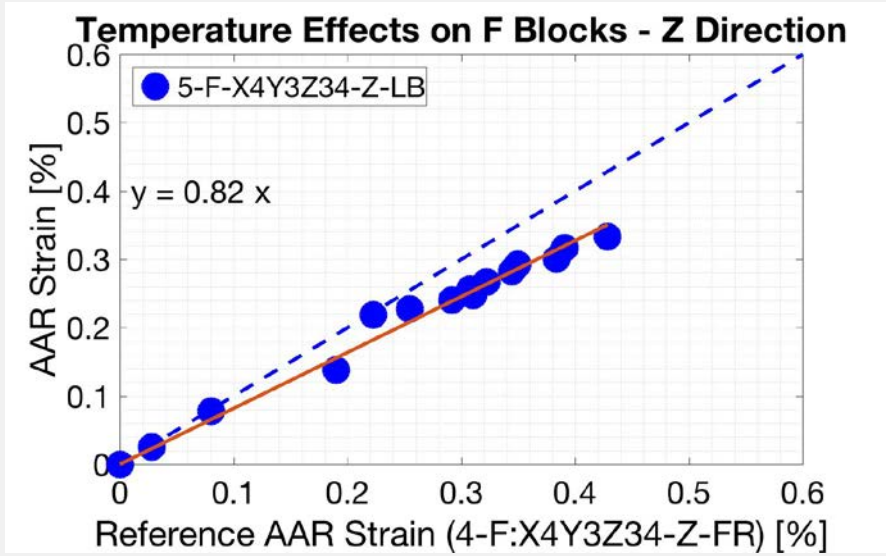



# TEMPERATURE EFFECT ON F REINFORCEMENT BLOCKS

- Lab blocks have 30% greater expansion than fog room blocks in Y Direction
- X & Z direction expansion in lab is less than fog room expansion
- Possibly due to lab block are submerged and fog room blocks are wetted



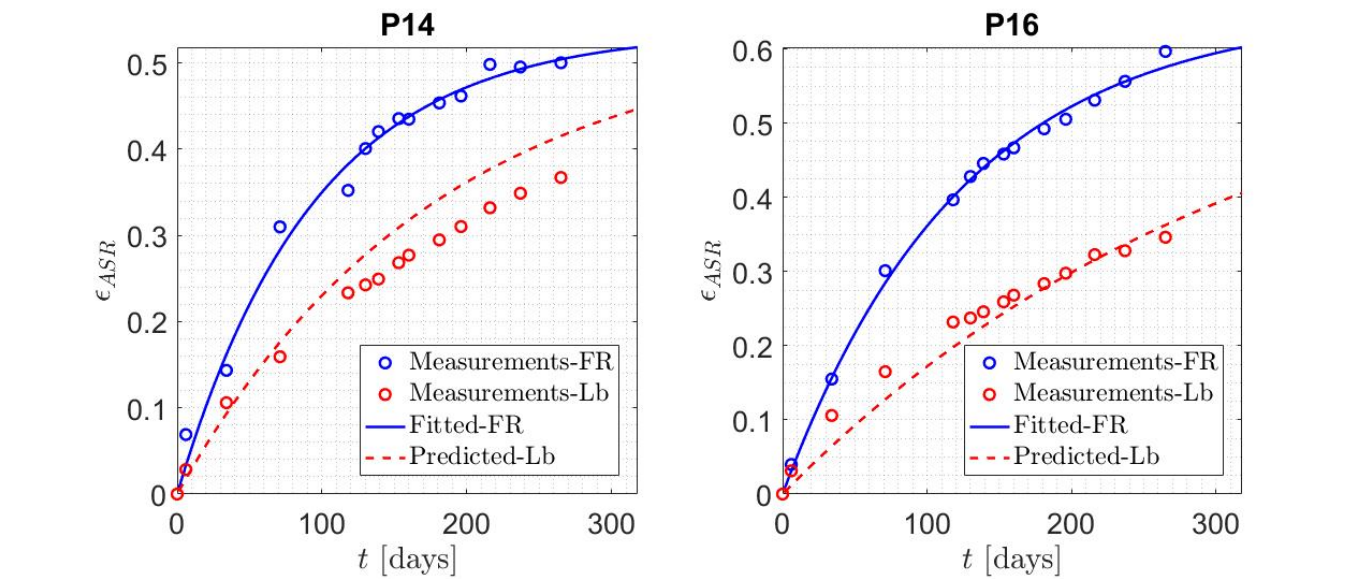
# TEMPERATURE EFFECTS CONCLUSION

- Prisms showed good results
- Blocks generally did not support predictions
  - Most measurements did not show expected results
  - No identifiable trend in why some directions showed less expansion

# OTHER ANALYSES AND OBSERVATIONS

# EXPERIMENTAL RESULTS VS. LARIVE'S EXPANSION EQUATIONS

- For unreinforced prisms in fog room, line fitted to data using Larive expansion equations
- Latency and characteristic times are estimated using average fog room temperatures
- Iteratively determine activation energies (beginning with universal values)
- Continue until curve (dashed line) reasonably matches actual data
- $U_L$ = 9,400 K  $U_C$ = 6,800K

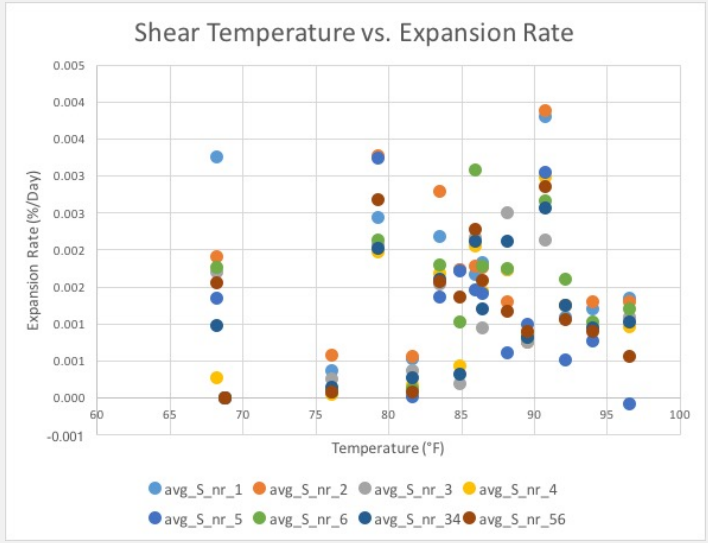


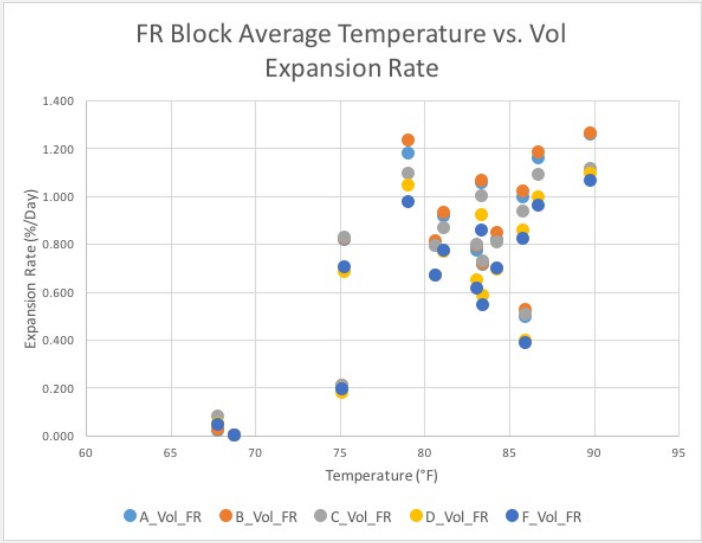

$$\xi(t,\theta) = \frac{1 - e^{-\frac{t}{\tau_c(\theta)}}}{1 + e^{-\frac{(t-\tau_l(\theta))}{\tau_c(\theta)}}}$$

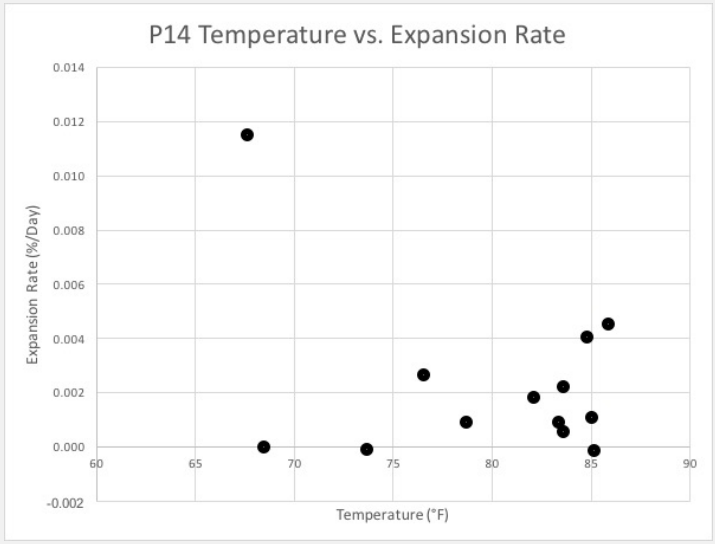
$$\begin{cases} \tau_c(\theta) = \tau_c(\theta_0)\exp\left[U_C\left(\frac{1}{\theta} - \frac{1}{\theta_0}\right)\right]; \; U_C = 5,400 \pm 500K \\ \tau_L(\theta) = \tau_L(\theta_0)\exp\left[U_L\left(\frac{1}{\theta} - \frac{1}{\theta_0}\right)\right]; \; U_L = 9,400 \pm 500K \end{cases}$$

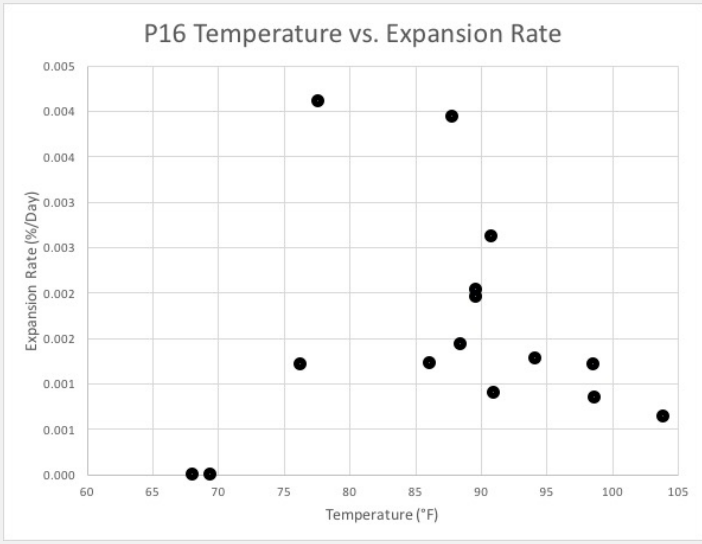
# AVERAGE TEMPERATURE VS. EXPANSION RATE

- Average temperature between measurements compared to the average expansion per day between measurements
- No trend between average temperature and expansion rate found



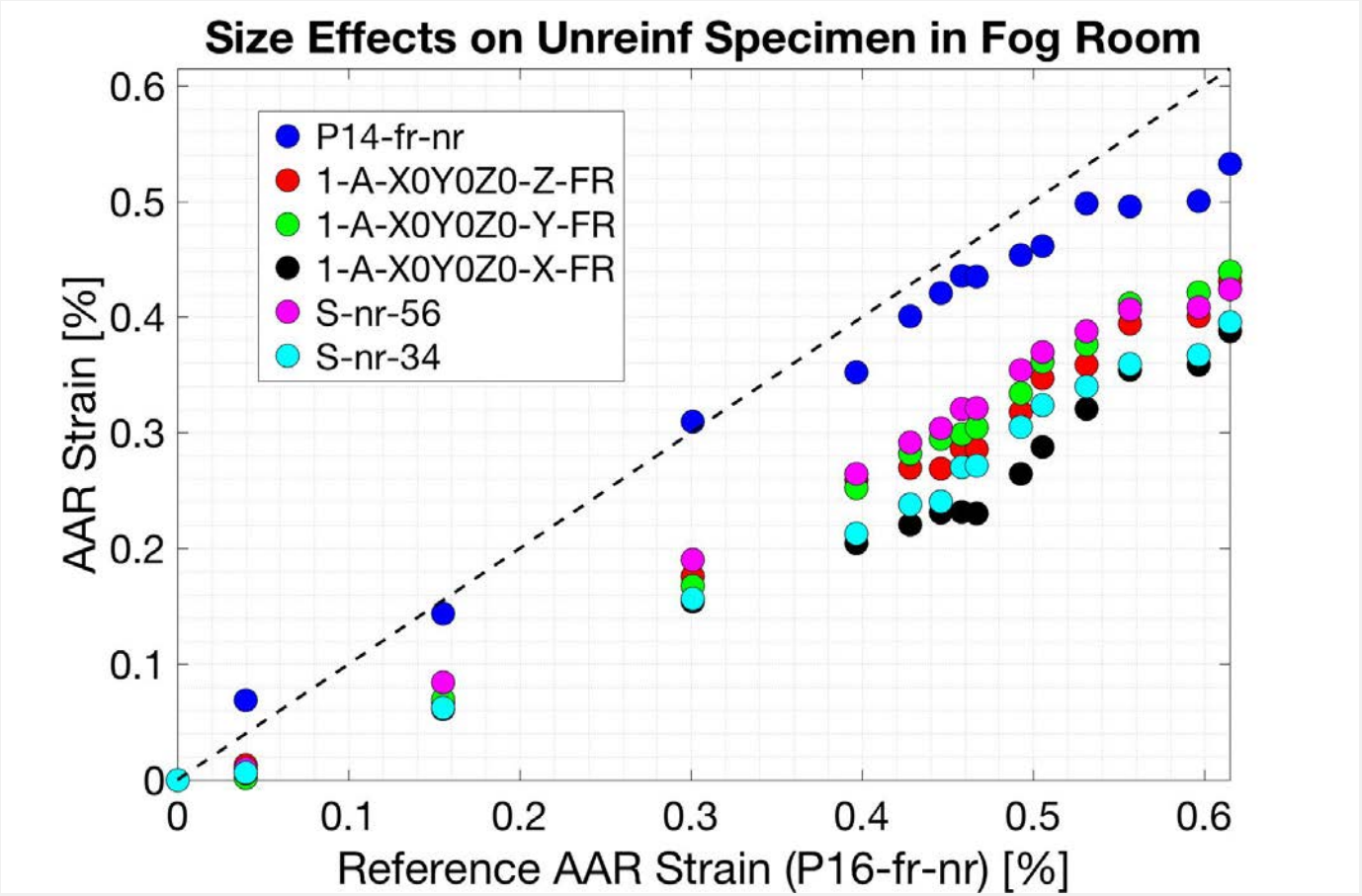



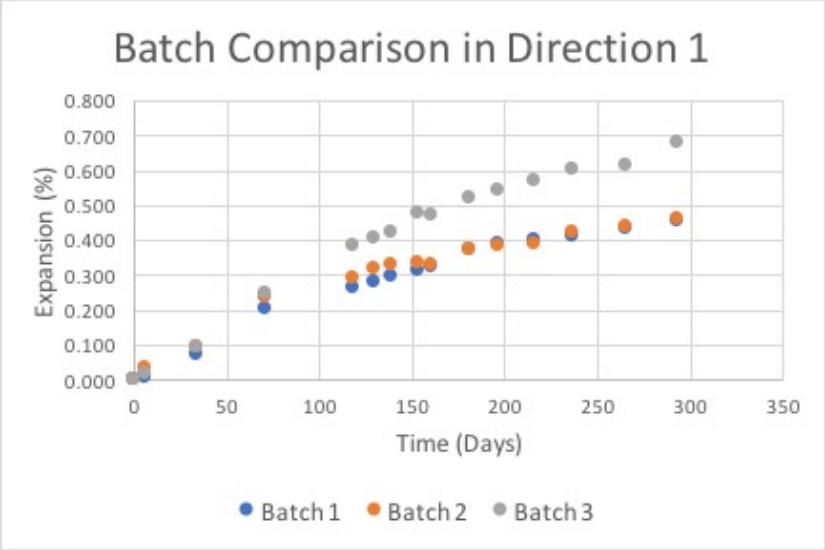
# SIZE EFFECTS

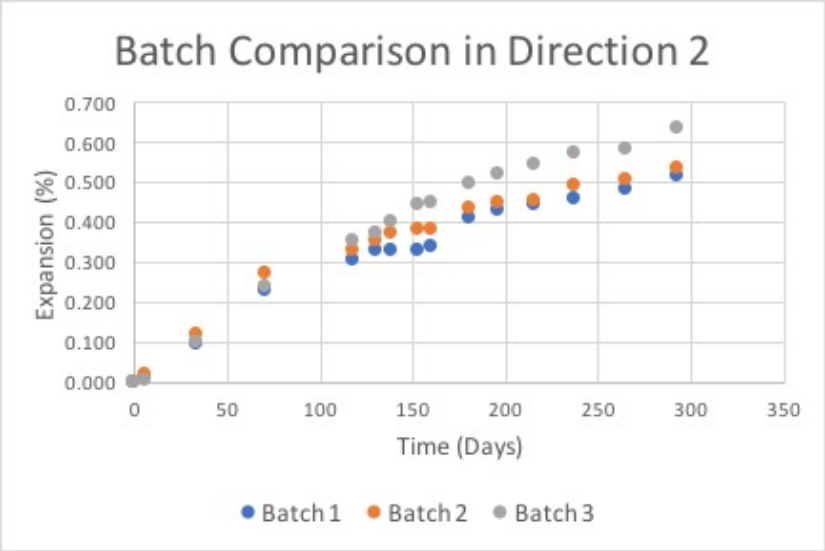
- Prisms have similar expansions
- Larger (P14) prism has slightly less expansion than smaller (P16) prism
- No clear size effect between block and shear specimen
- Similar wetting could be playing a role. Prisms are submerged while block and shear specimens are wetted

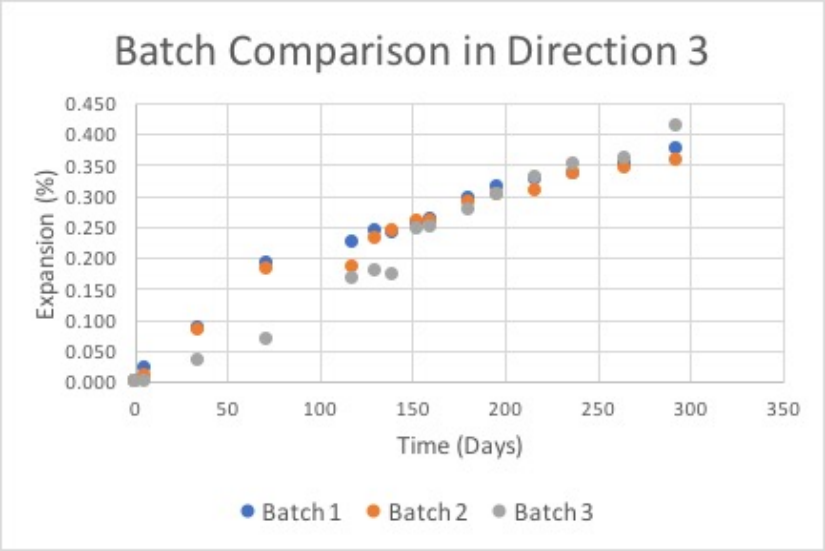


# BATCH COMPARISON OF SHEAR SPECIMENS

- In shear specimens, Batch 3 is the most reactive batch



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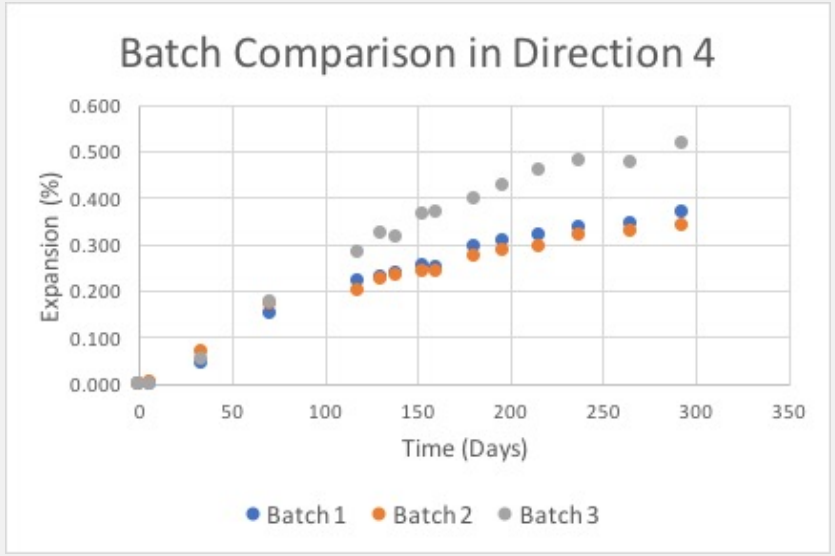
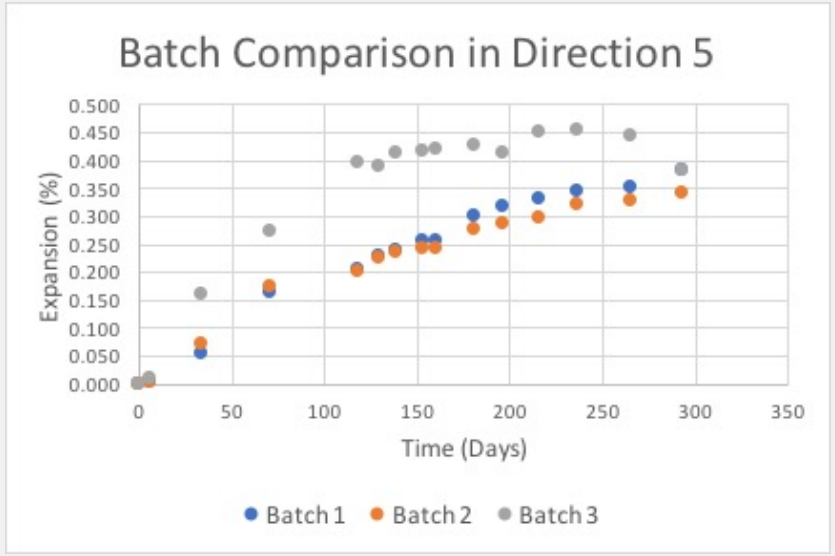
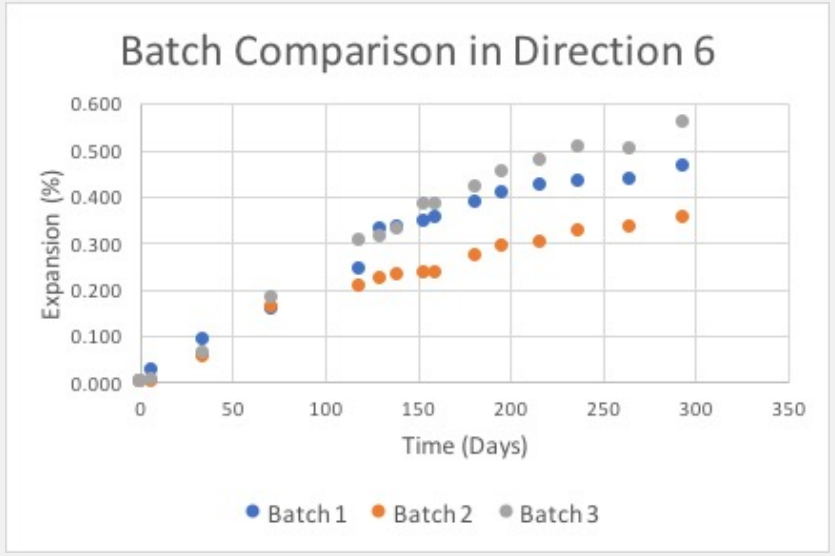
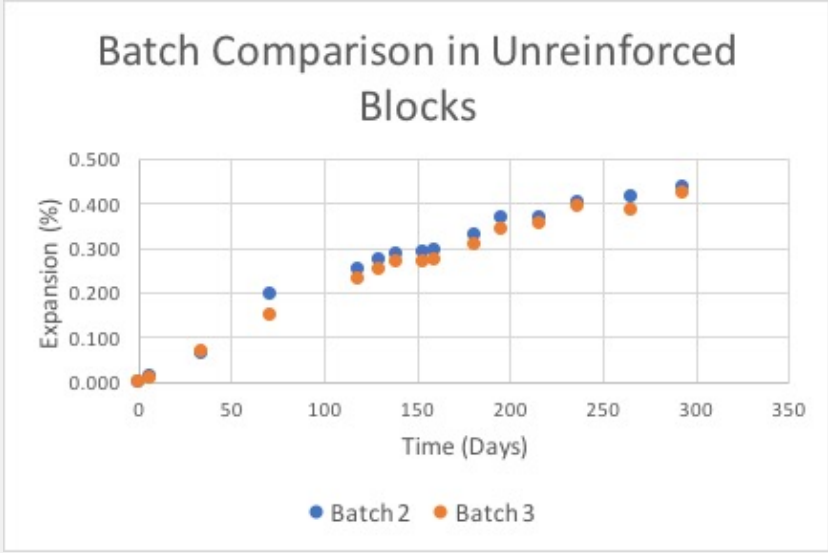


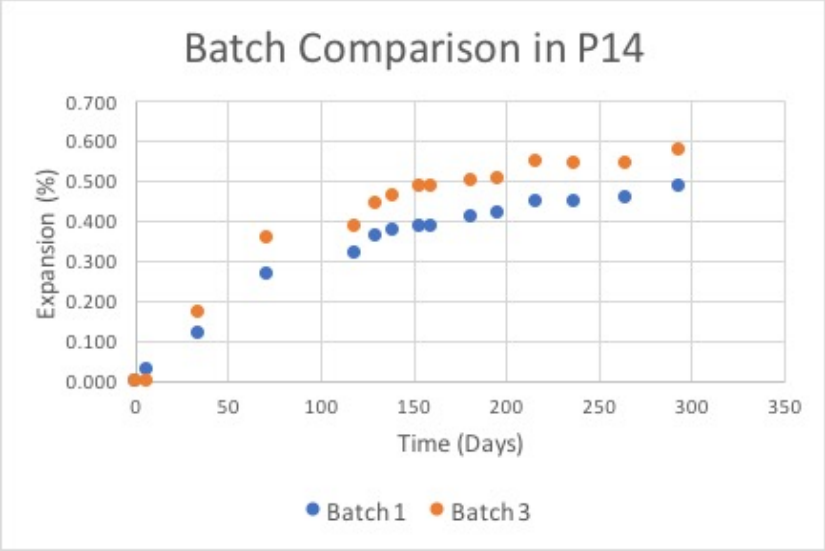



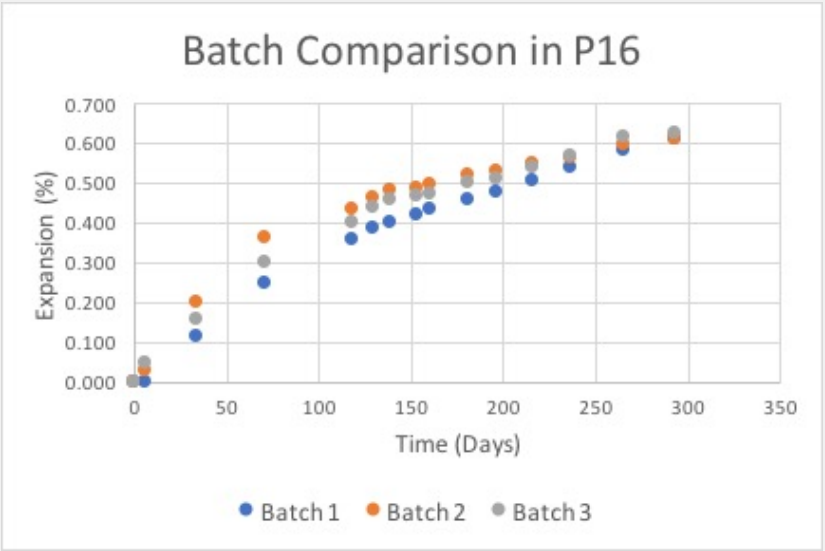



# BATCH COMPARISON OF BLOCKS AND PRISMS IN FOG ROOM

- In blocks and prisms, it is less clear Batch 3 is most reactive

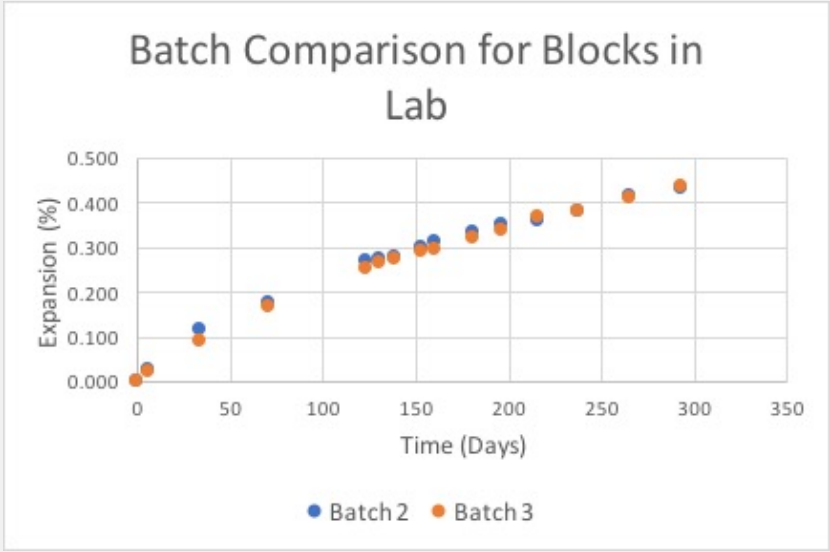


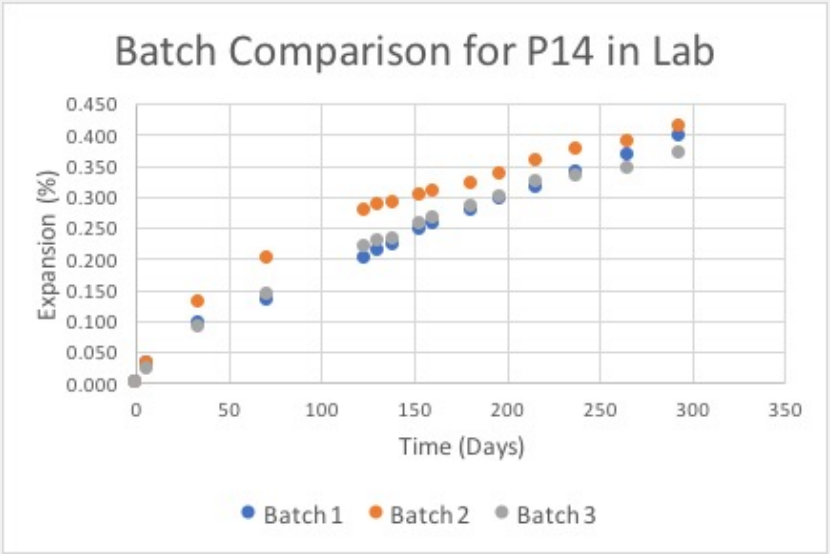



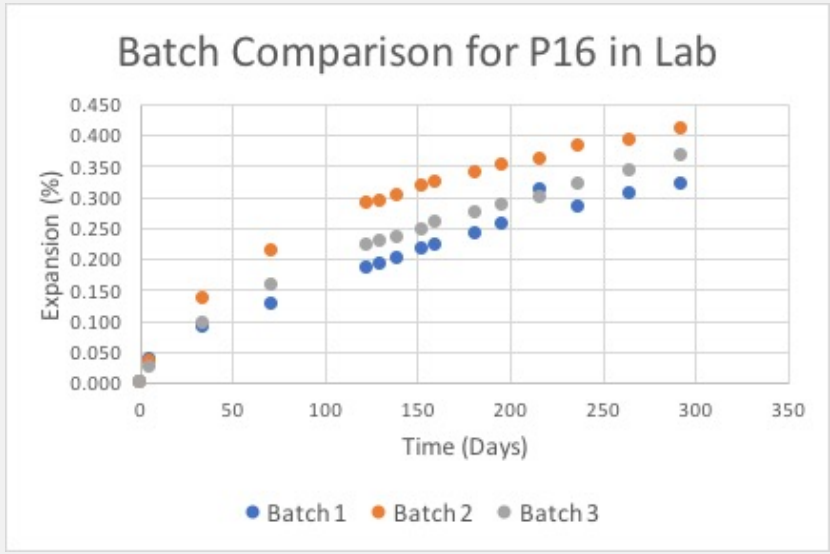



# BATCH COMPARISON OF BLOCKS AND PRISMS IN LAB

- In shear specimens, Batch 3 is the most reactive batch



# ORGANIZATION

1. Introduction
2. Background Information
3. Specimen Casting
4. Specimen Curing
5. Expansion Monitoring
6. Results & Discussion
7. Conclusions

# CONCLUSION

# CONCLUSIONS

- Substantial expansion is observed in all specimens indicating production of ASR.
- Volumetric expansion for blocks is similar, regardless of reinforcement configuration. Indication of expansion redistribution.
- No substantial expansion observed in the control specimens.
- Observed expansion similar to predicted expansion using Larive's expansion equation.

# CONCLUSIONS

- Reinforcement caused a reduction in expansion in prisms and shear specimens.
- Expansion of prisms and shear specimens increased as reinforcement ratio decreased.
- Reinforcement did not necessarily result in a significant reduction in block expansion.
- No direct correlation found between the reinforcement ratio for blocks in a given direction and expansion in that direction.

# CONCLUSIONS

- Increased temperature caused an increase in expansion for the prisms.
- Most blocks stored at ambient temperatures showed similar or greater expansion that those stored at elevated temperatures
  - Likely due to the blocks submerged in NaOH at ambient conditions and wrapped in NaOH wetted burlap in the fog room.
- Little evidence showed that the specimen temperature independently correlated to the expansion rate.

# CONCLUSIONS

- Concrete mixed in Batch 3 was found to be the most reactive in shear specimens.
- A size effect could be seen in that prisms the showed greater expansion than the blocks and shear specimens.
- No size effect was definitively found when comparing block and shear specimens

# RECOMMENDATIONS FOR FUTURE WORK

- Use blocks solely to study temperature or reinforcement effects.
- More specimens for each rebar type.
- Ensure all other variables are equal.
- When studying reinforcement effects, have larger rebar size difference.
- More thoughtfully specimen design to study size effect.

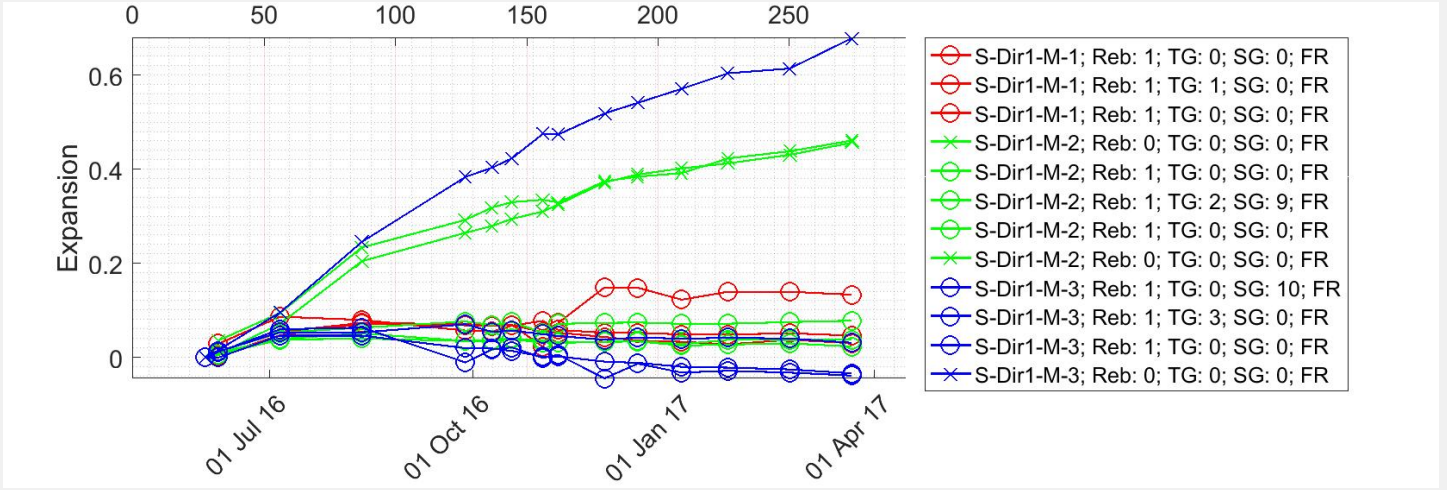
# ACKNOWLEDGMENTS

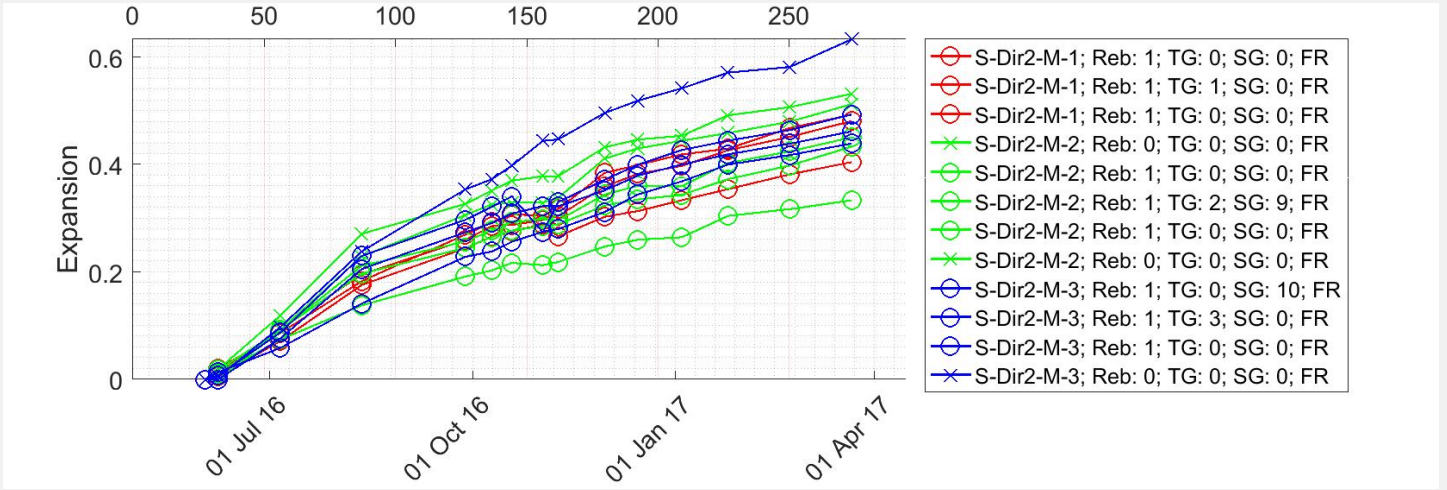

- Nuclear Regulatory Commission (NRC) Grant No. NRC-HQ-60-14-G-0010
- Dana Schwartz and everyone at Fall Line Testing & Inspection
- Mohammad Amin Hariri-Ardebili and Robb Sparks for the support, guidance, and advise
- Derek Carpenter, Damon Howard, and John Schneck for all their help in the lab

# THANK YOU!
# QUESTIONS?

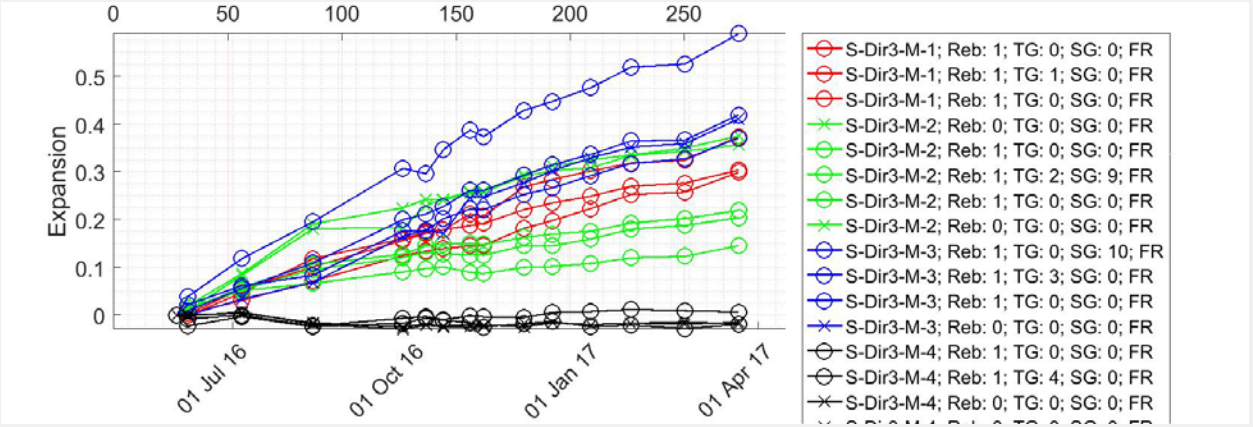
# APPENDIX

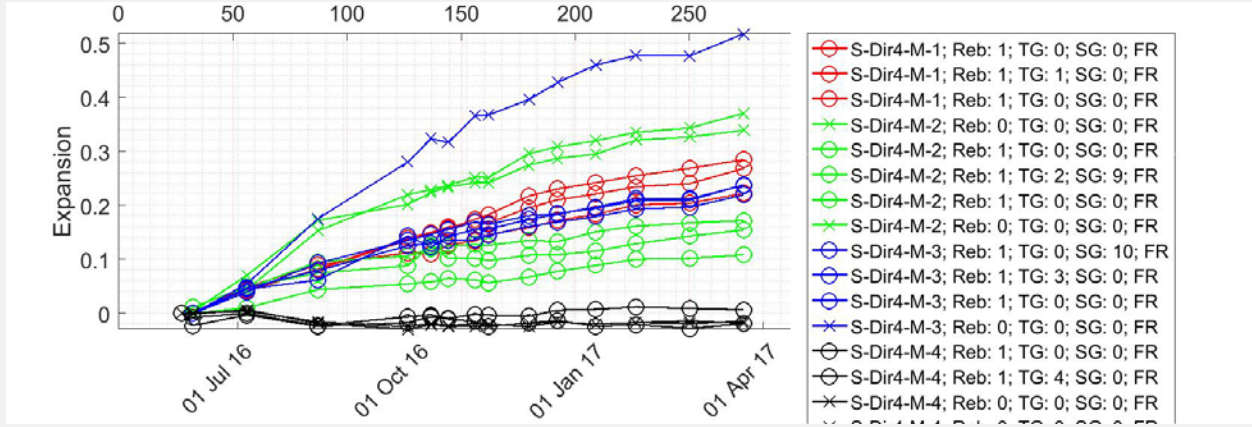
# INDIVIDUAL SHEAR SPECIMEN COMPARISON PER DIRECTION (DIRECTION 1-2)

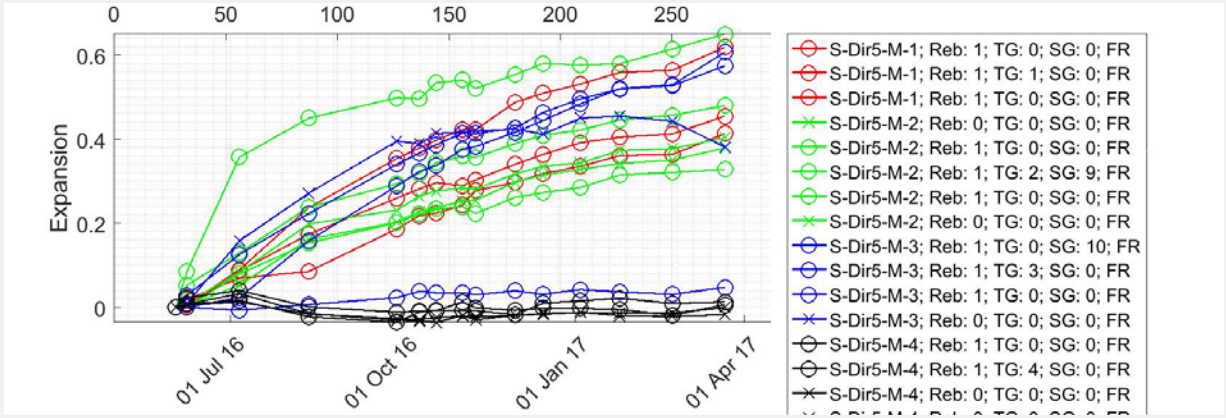


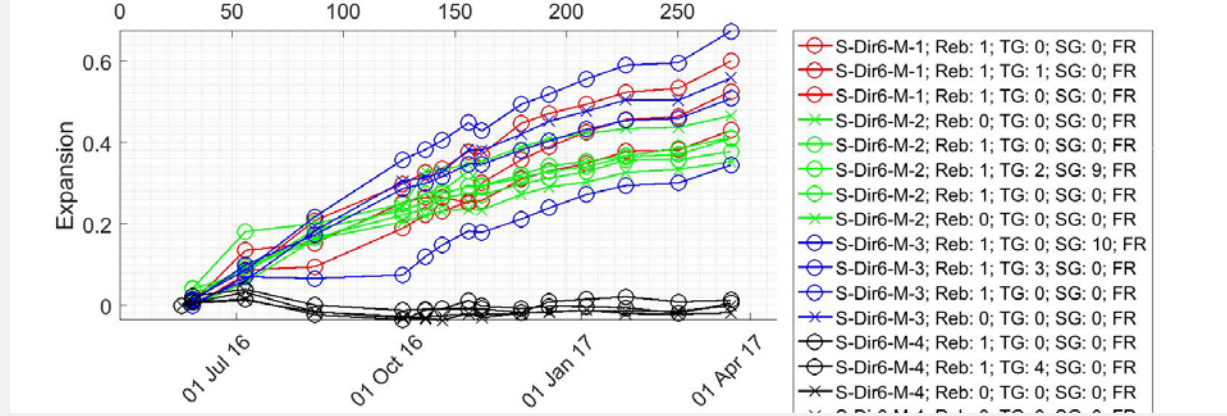



# INDIVIDUAL SHEAR SPECIMEN COMPARISON PER DIRECTION (DIRECTION 3-6)

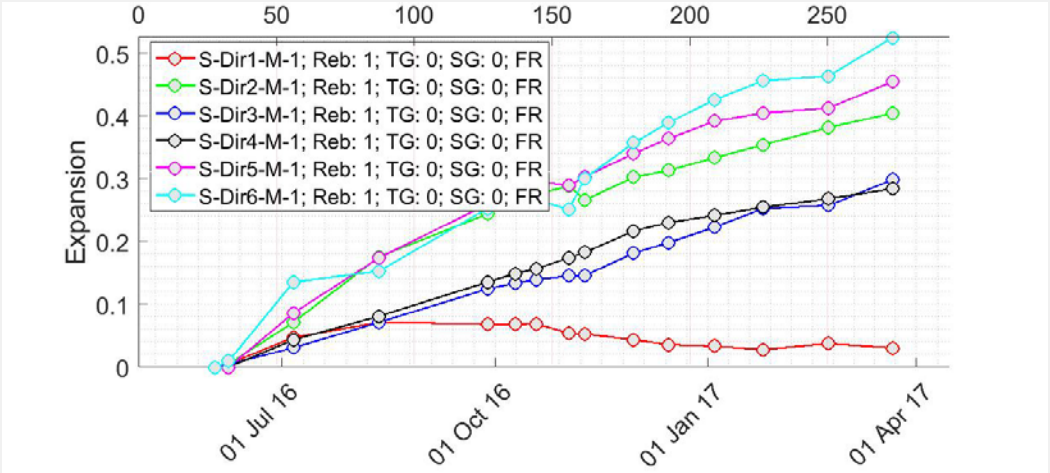


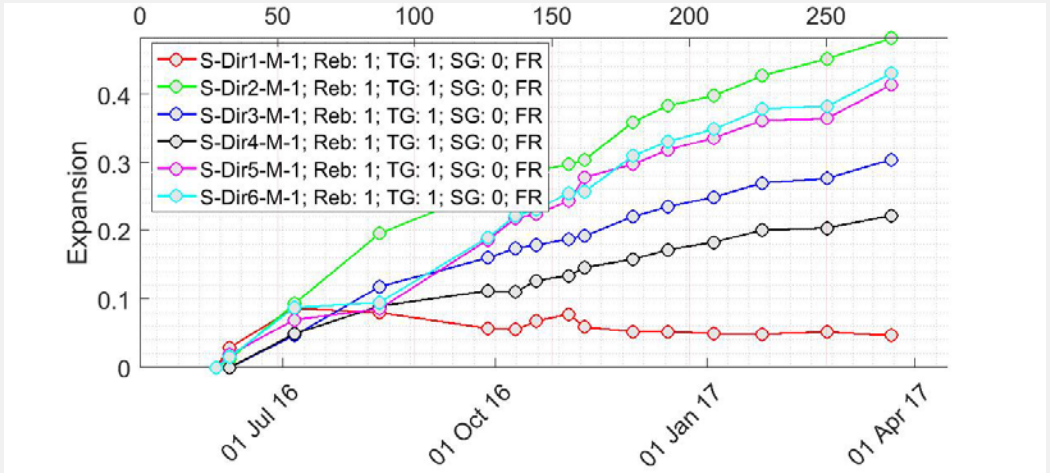



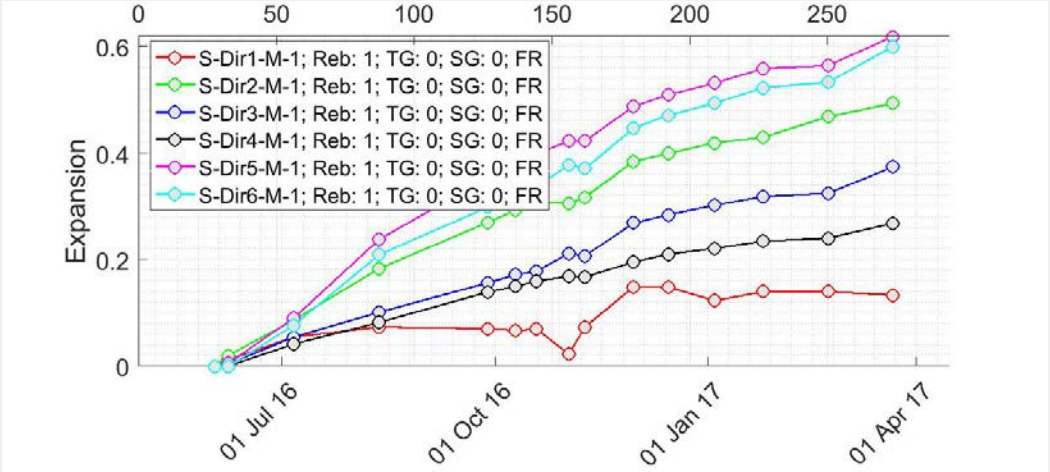



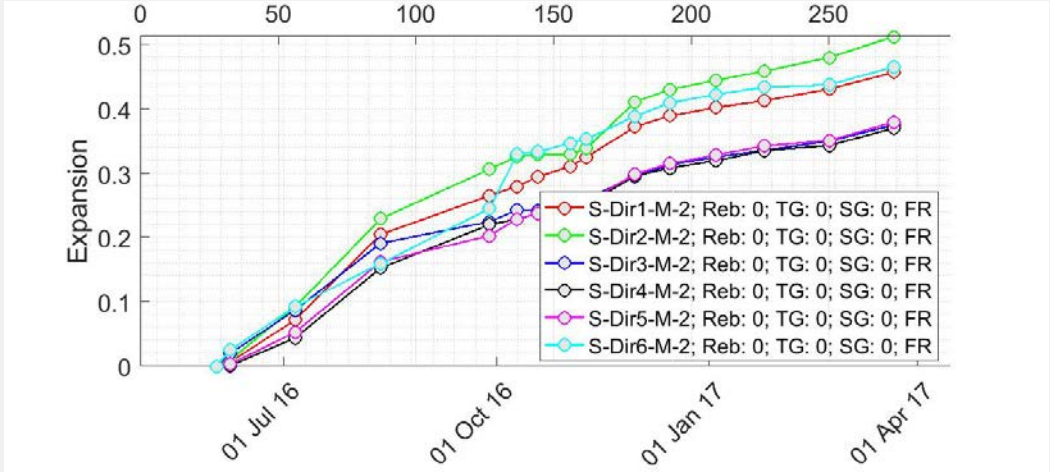



# INDIVIDUAL SHEAR SPECIMEN EXPANSIONS (#1-4)

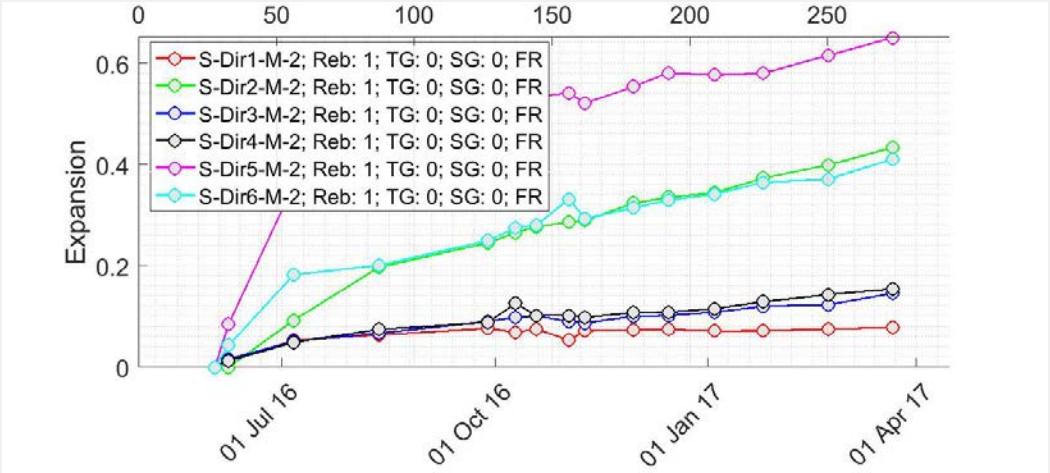


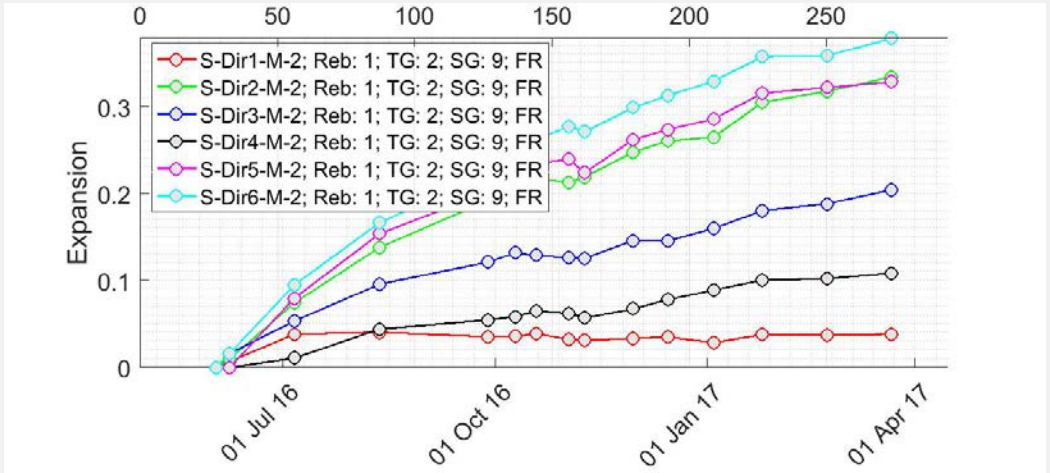



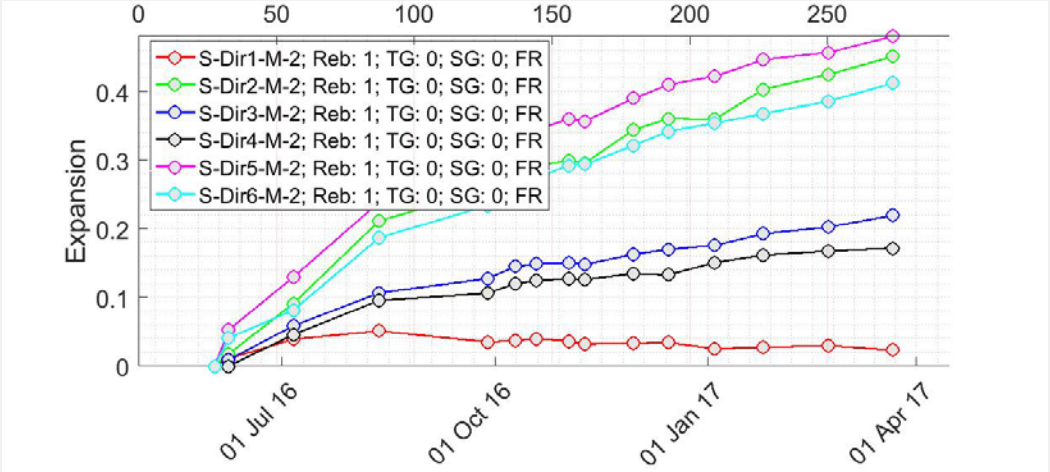



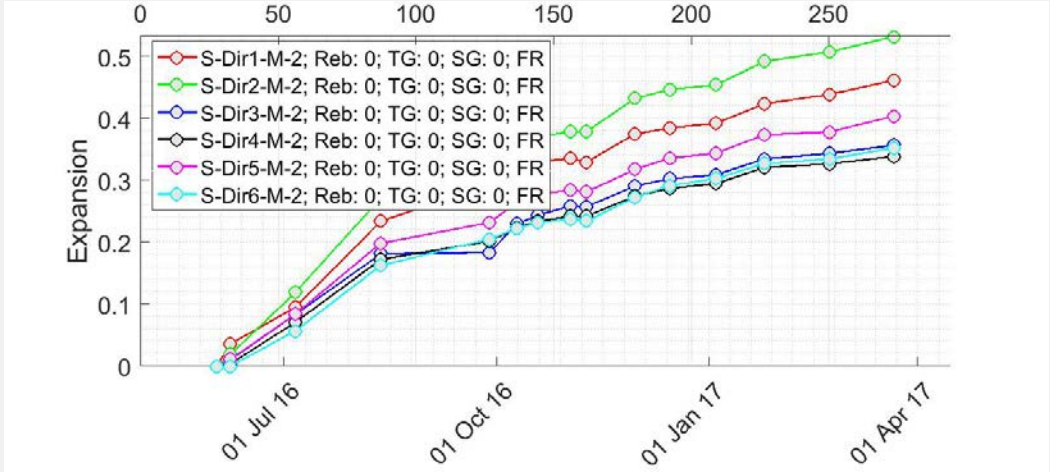



# INDIVIDUAL SHEAR SPECIMEN EXPANSIONS (#5-8)

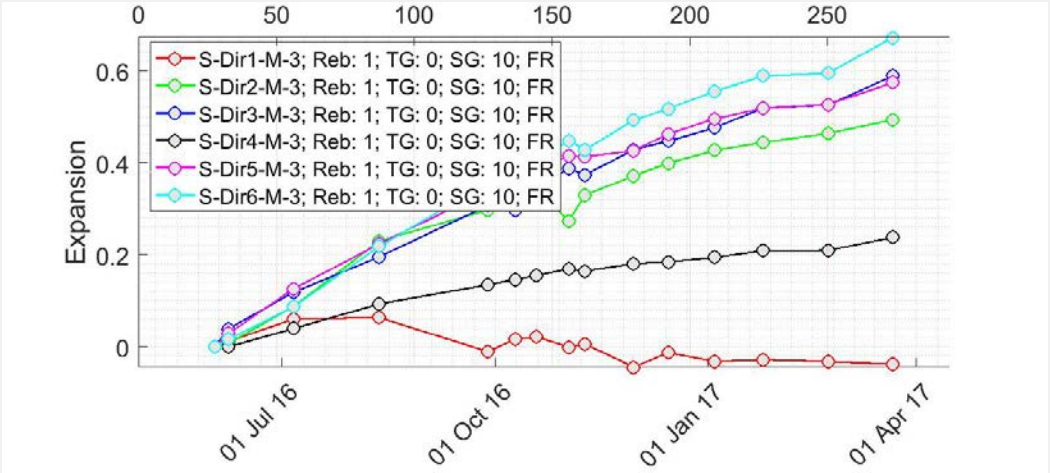


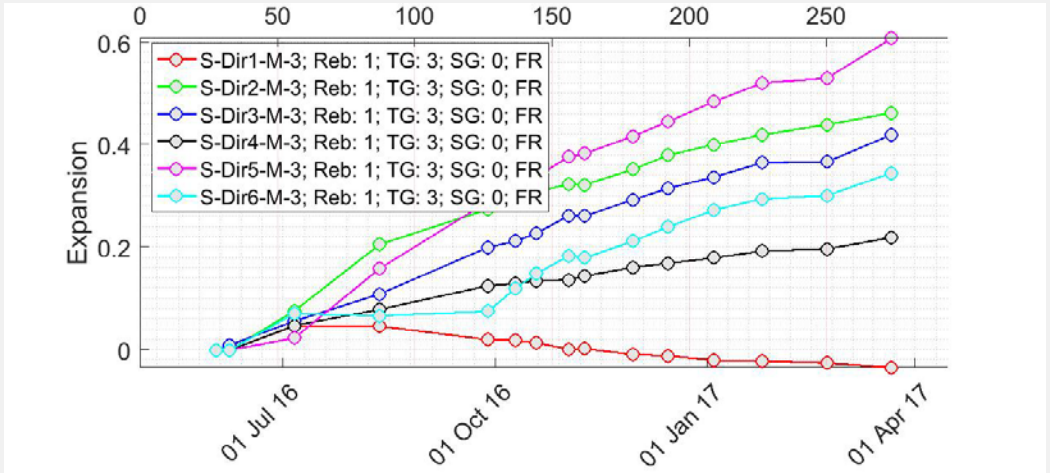



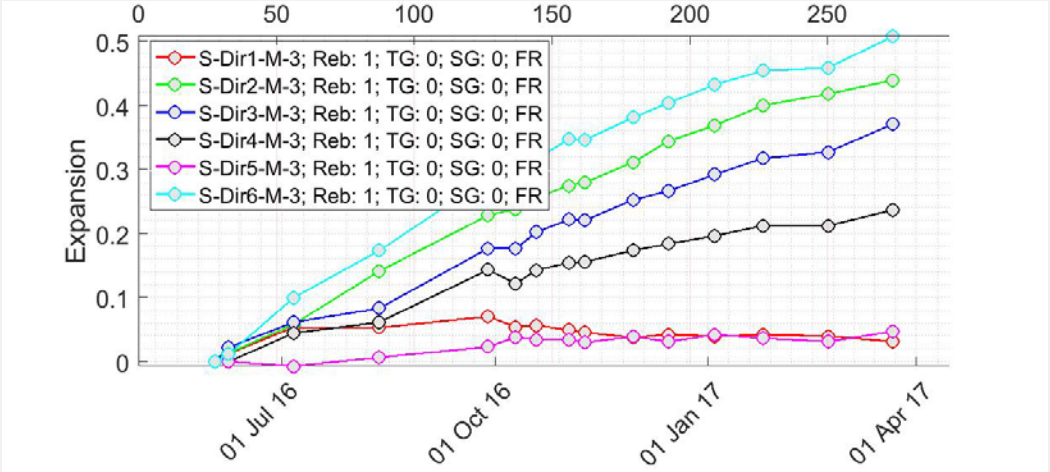



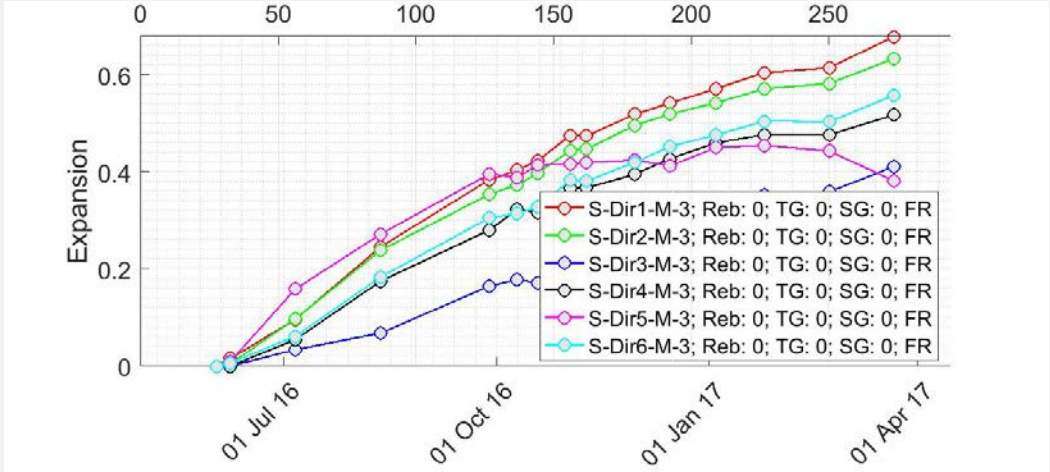



# INDIVIDUAL SHEAR SPECIMEN EXPANSIONS (#9-12)

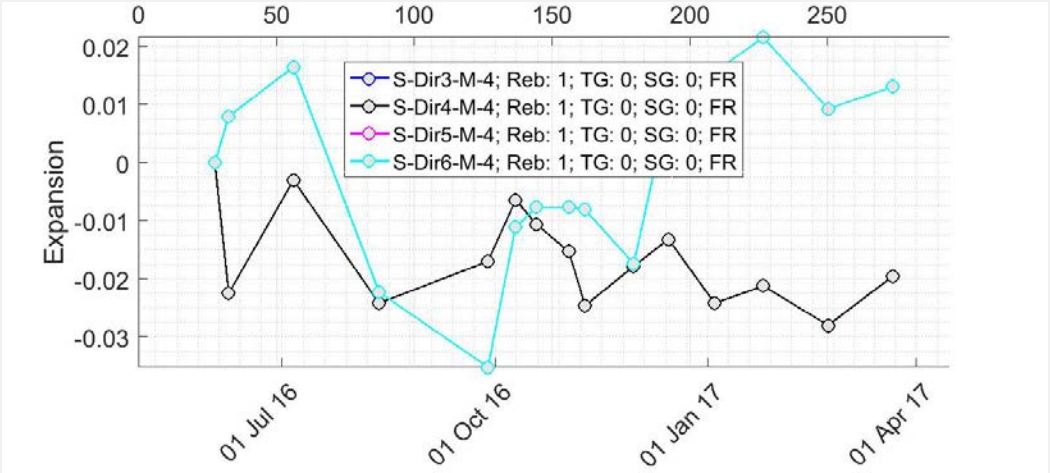


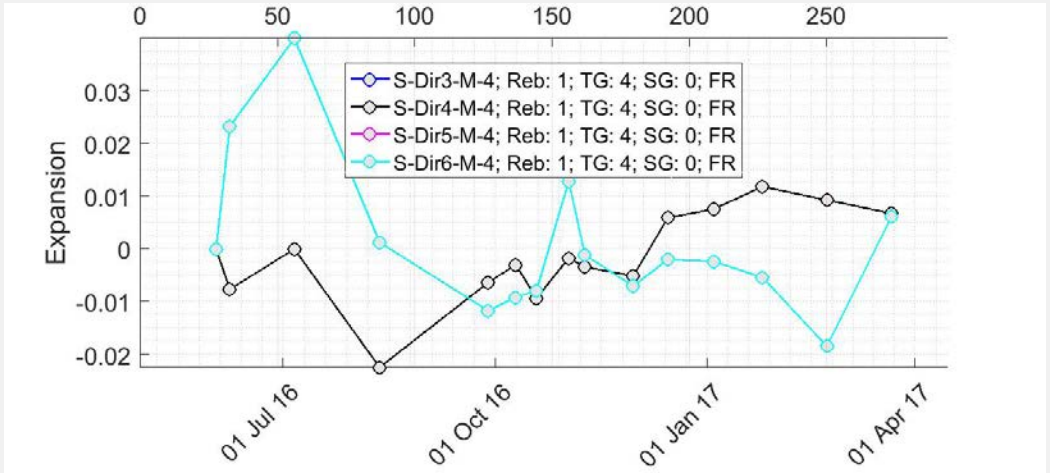



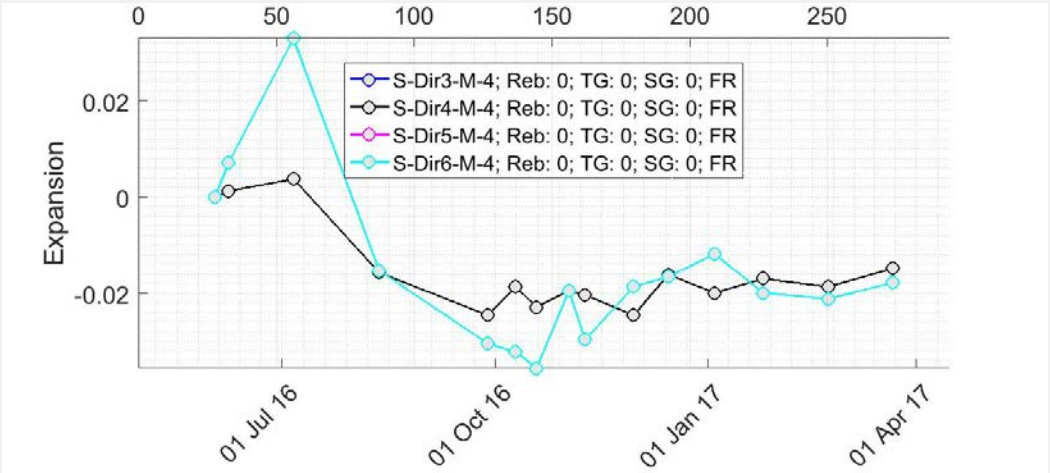



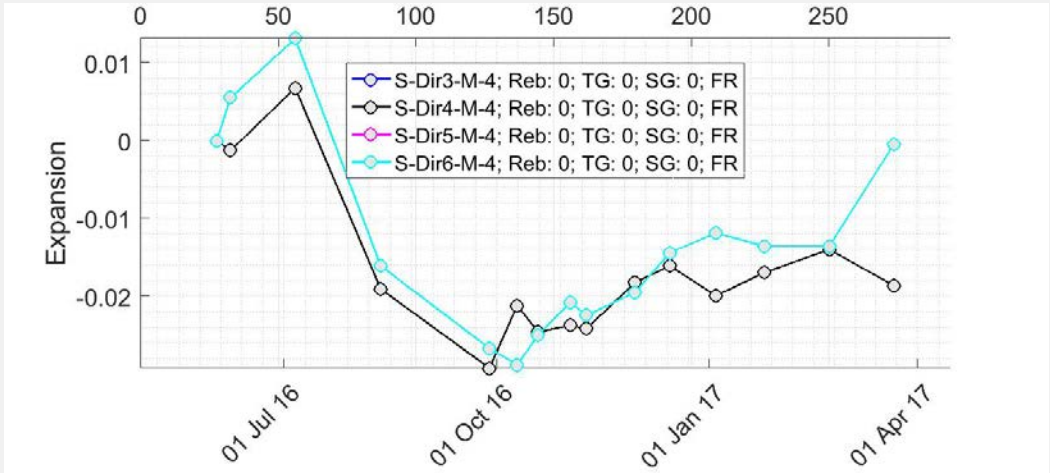



# INDIVIDUAL SHEAR SPECIMEN EXPANSIONS (#13-16)

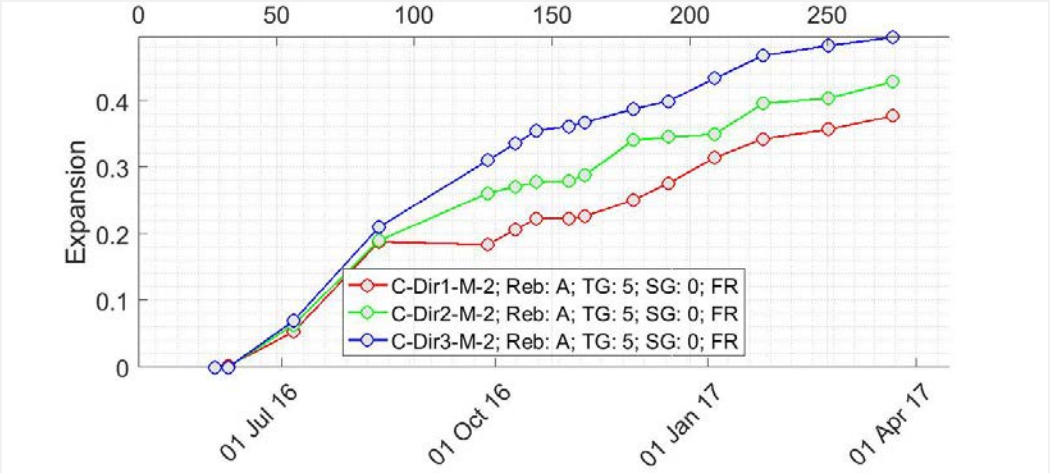


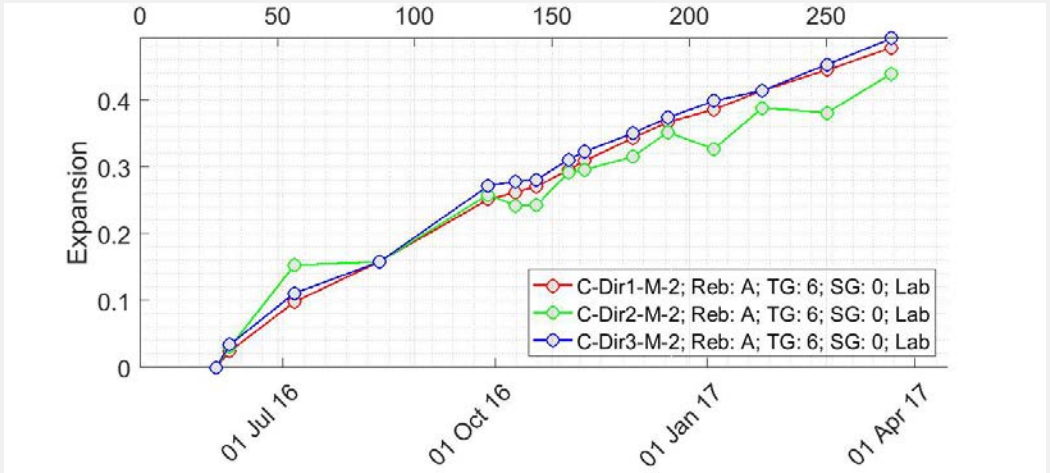



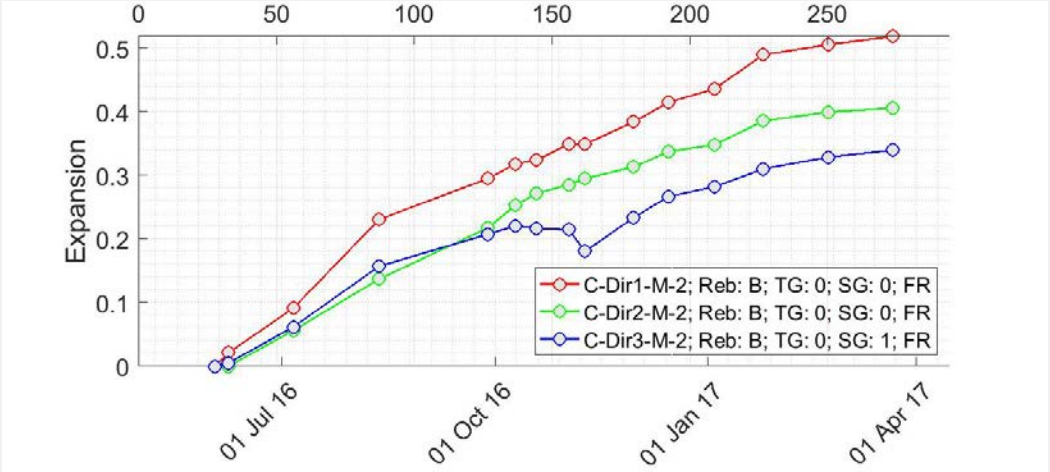



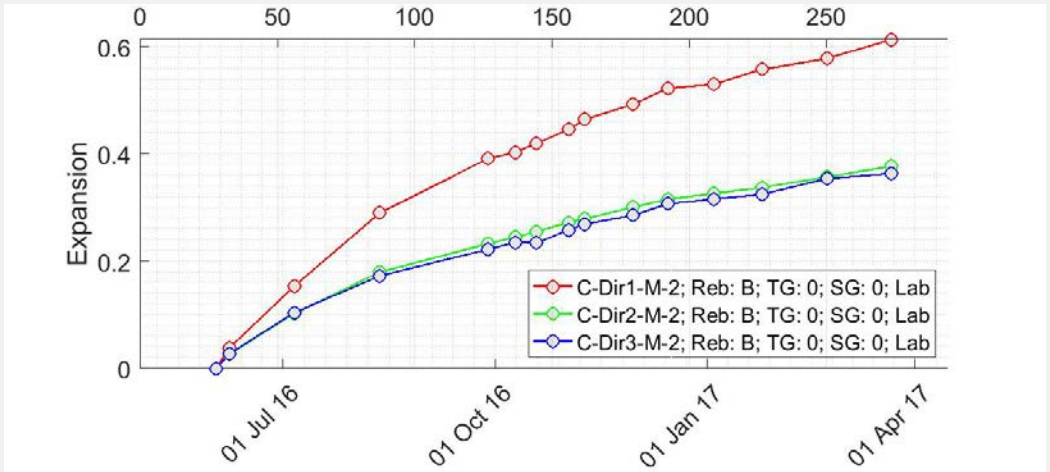



# INDIVIDUAL BLOCK EXPANSIONS (#1-4)

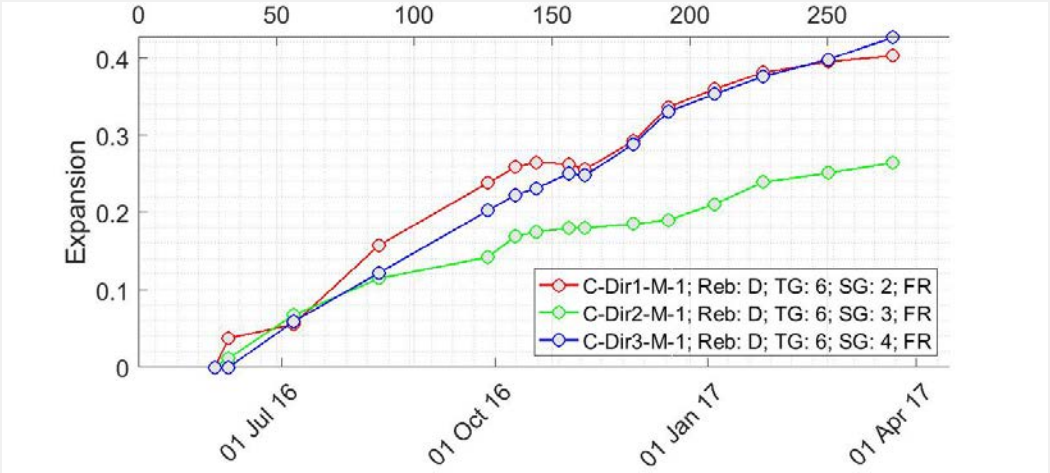


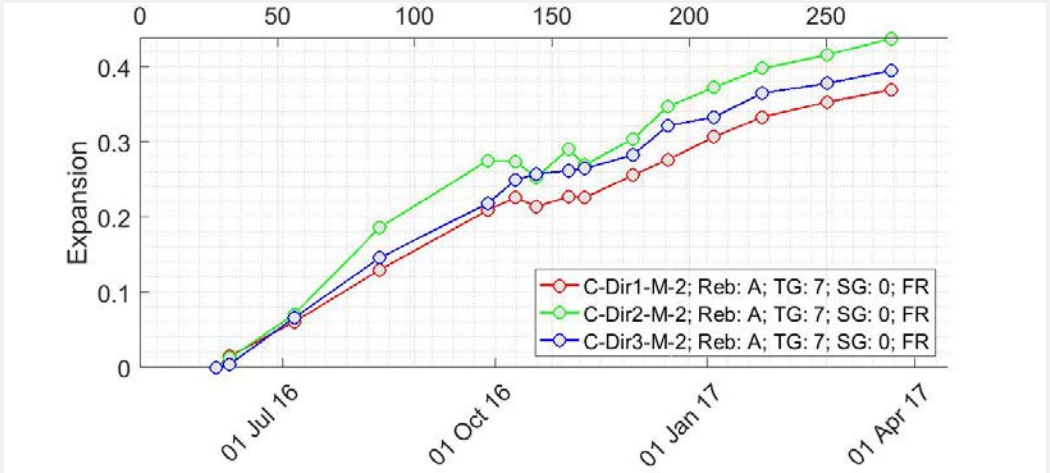



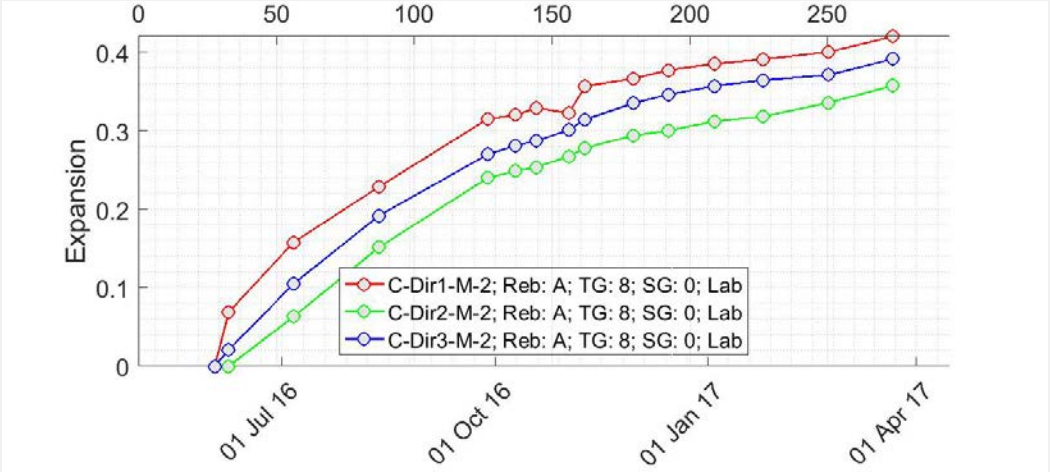



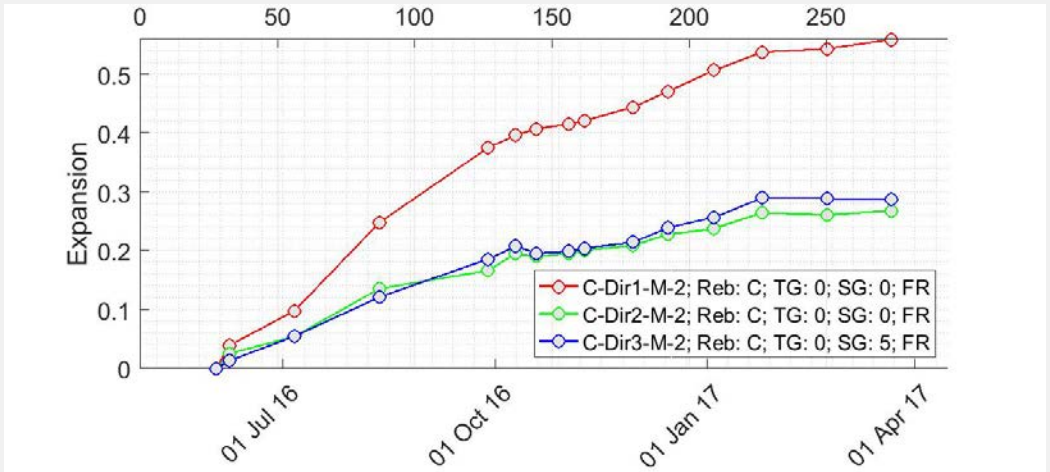



# INDIVIDUAL BLOCK EXPANSIONS (#5-8)

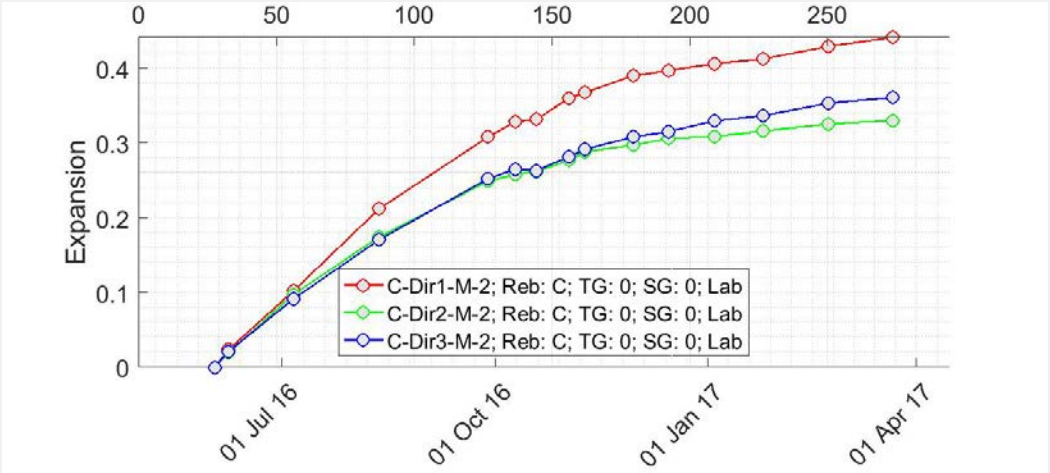


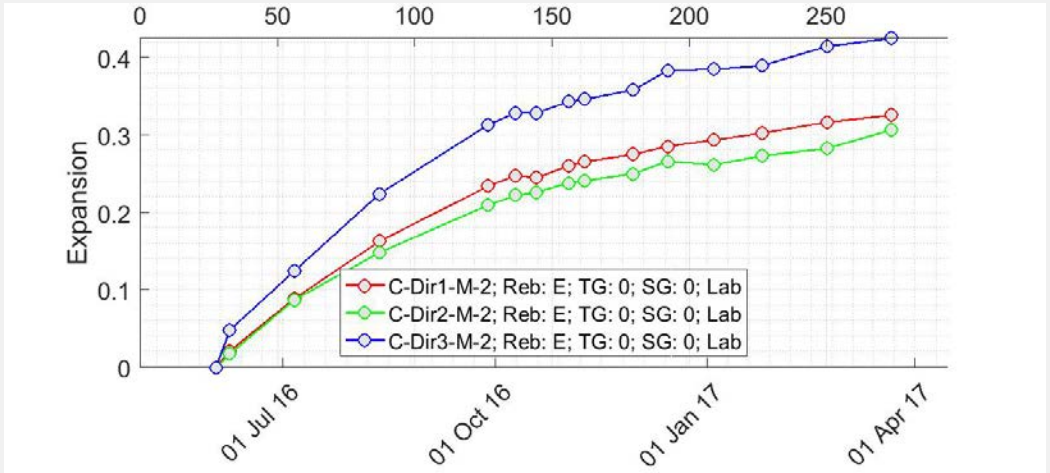



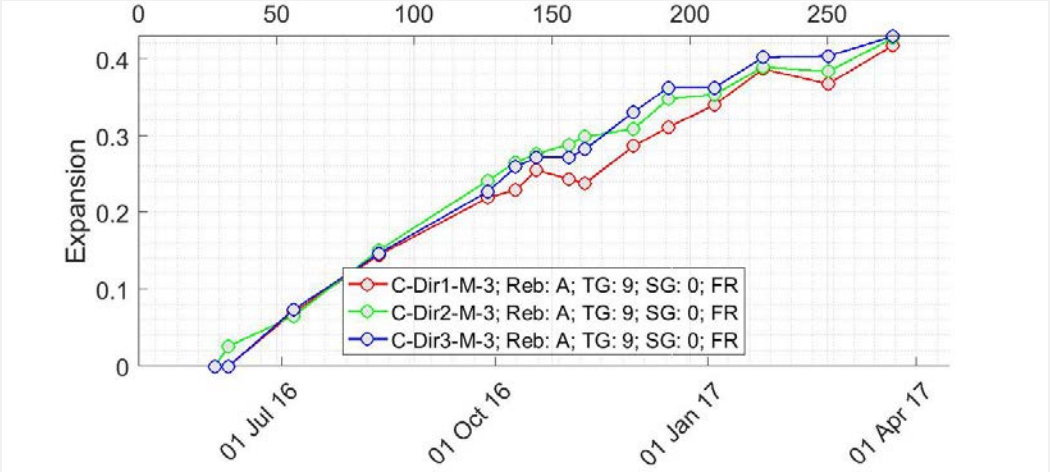



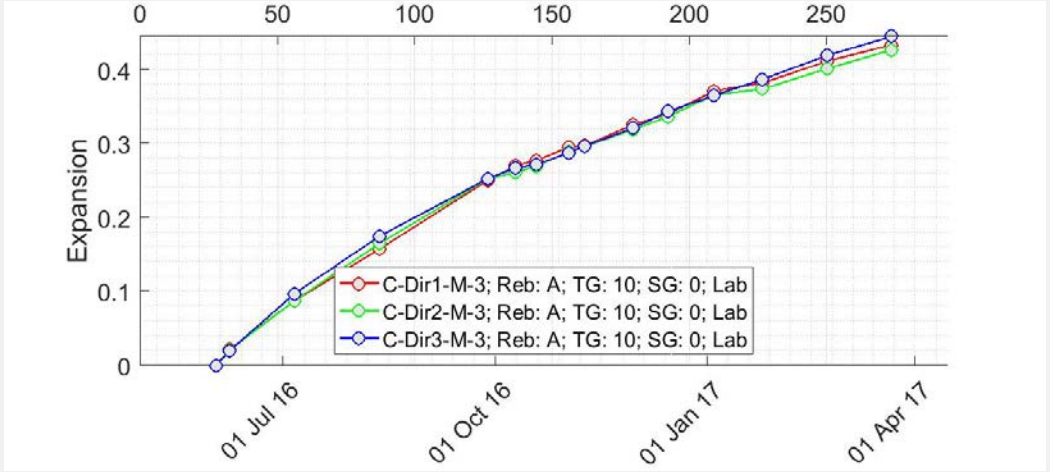



# INDIVIDUAL BLOCK EXPANSIONS (#9-12)



# INDIVIDUAL BLOCK EXPANSIONS (#13-15)