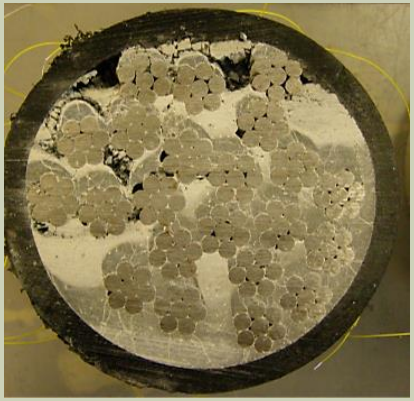
Material and Corrosion Evaluation of Deficient PT Grout with Enhanced Sulfate Concentrations


Krishna Vigneshwaran.K.K,
Samanbar Permeh and Kingsley Lau
Florida International University , Department of Civil and Environmental Engineering**,**
Ivan Lasa
Florida Department of Transportation, State Materials Office

INTRODUCTION

- Corrosion failures of post-tensioned tendons in a Florida bridge utilizing pre-packaged thixotropic grout products were recently documented.
- Localized occurrences of severe corrosion of the steel strand was not always consistent with the presence of voids .
- Severe corrosion were well associated with the deficient grout .

photo courtesy of FDOT

- Deficient grout characterized as having poor cohesive bulk properties, high moisture content and enhanced sulfate ion concentrations in the pore solution.
- Limited information is available on the corrosion behavior of PT strand in grout materials with enhanced sulfate content.
- Uniform description of corrosion activation processes of steel in relevant grout environments is needed.

OBJECTIVES AND APPROACH

- Steel corrosion in thixotropic grouts occur where both deficient grout with high bulk moisture content and enhanced sulfate ion concentrations.

- The work was aimed to identify the role of moisture in the formation of deficient grout and accumulation of sulfate ions and possible corrosion development.

- The approach included is to:
  - ❖ Differentiate physical and chemical grout characteristic by grout deficiency.
  - ❖ Differentiate corrosion behavior of steel by degree of grout deficiency and sulfate presence.

GROUT CONDITIONS

Pre-Exposed Grout (Product A and B)

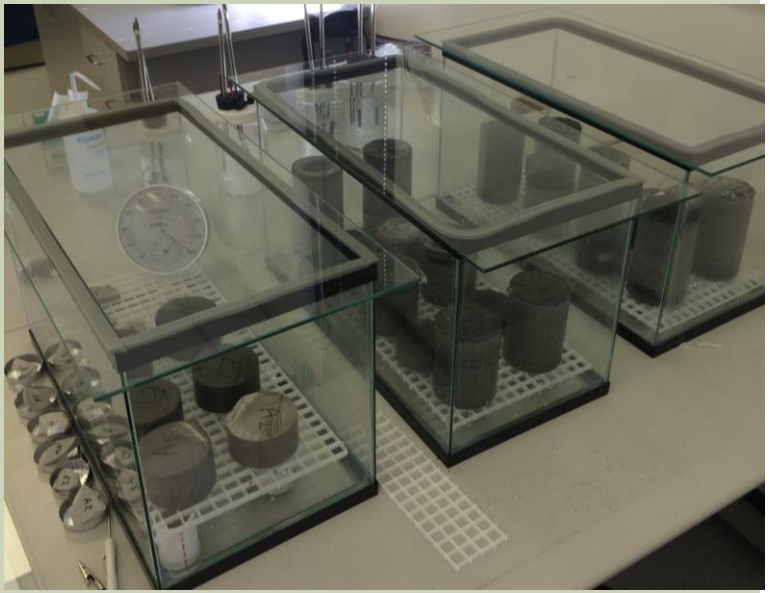
- 20% excess mix water content
- Pre-Exposed raw grout ~100%RH for 0, 3, 7, and 28 days
- 2,000, 20,000, and 150,000 ppm sodium sulfate
- Cured in ambient indoor conditions for 4 days
- Conditioned in ~100%RH

Expired Grout (Product A)

- 15% additional water
- 2,000, 20,000, and 150,000 ppm sodium sulfate
- Cured in ambient conditions for ~200 days
- Conditioned in ~100%RH .

Studied Parameters:

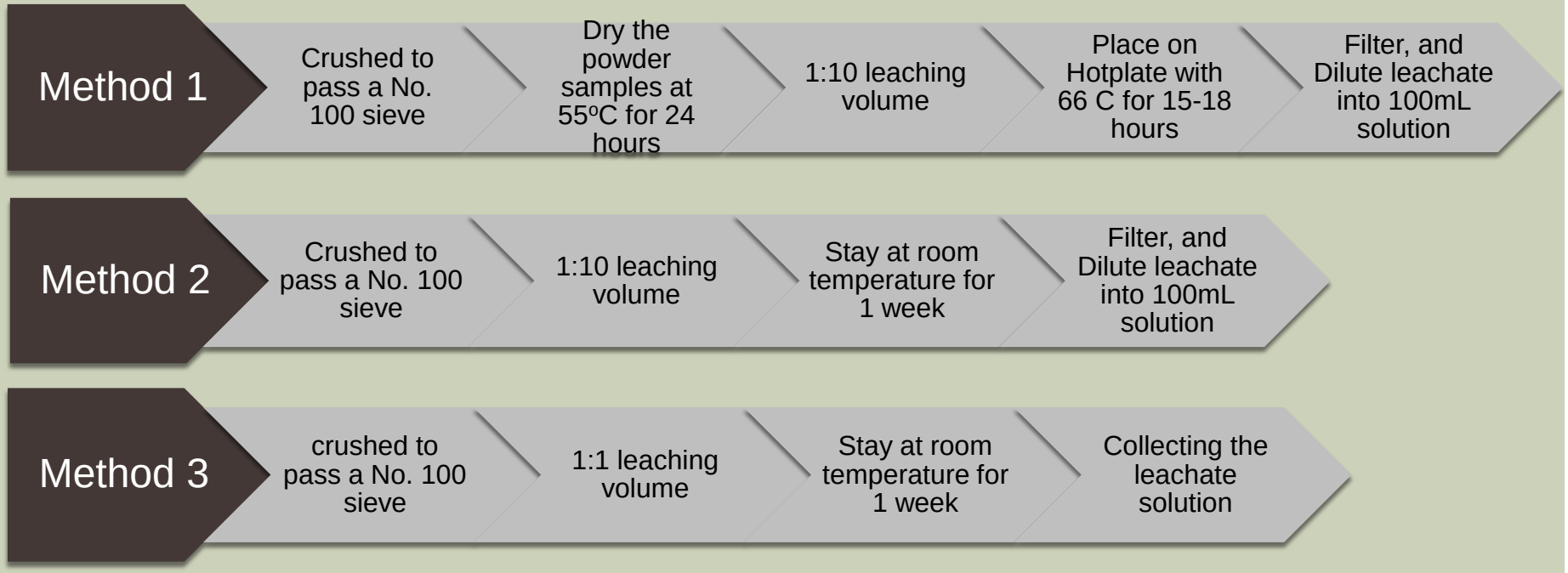
Void content, Moisture content, Wet resistivity, Sulfate content



SULFATE ION ANALYSIS

- Enhanced sulfate(SO_4^{2-}) content was found in deficient grout.
- Rapid change of moisture content due to environmental exposure and time of exposure.

❖ *Test methodology for uniform testing of discrepant grout sample conditioning*.



Evaluation of Corrosion Behavior in Enhanced Sulfates Conditions

Tendon Mockup

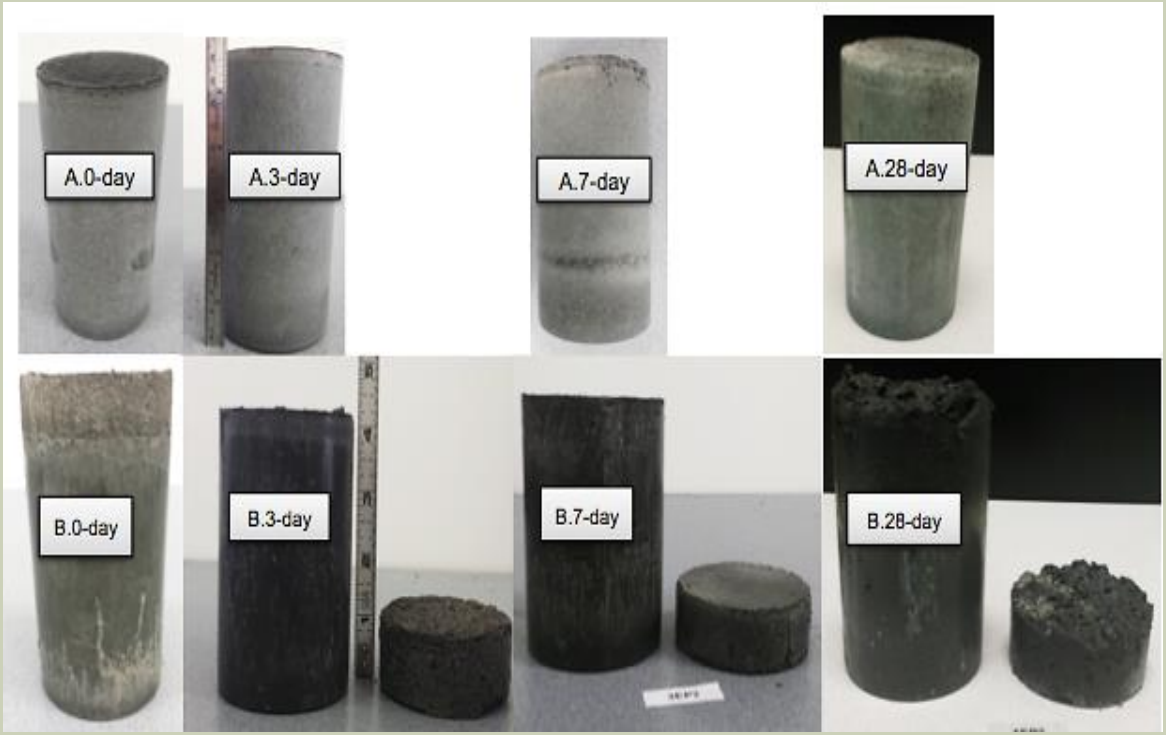
- 15’ long tendon mockups cast at 30^{o} incline
- Expired grout and 15% excess mix water
- Sulfate additions (0 ppm, 20,000 ppm, 150,000 ppm Na_2SO_4)
- 0.08% , 0.2 % chlorides by cement weight.

Studied parameters :corrosion potential (OCP), polarization resistance and anodic characterization

Electrochemical Testing in Solution

- Sulfate solution (pH=13.3)
- Naturally aerated
- Preconditioned 1 day in solution at OCP or -1V_{SCE}
- Anodic polarization (-1V_{SCE} to +500mV_{SCE}) at 0.05mV/s.

Grout segregation



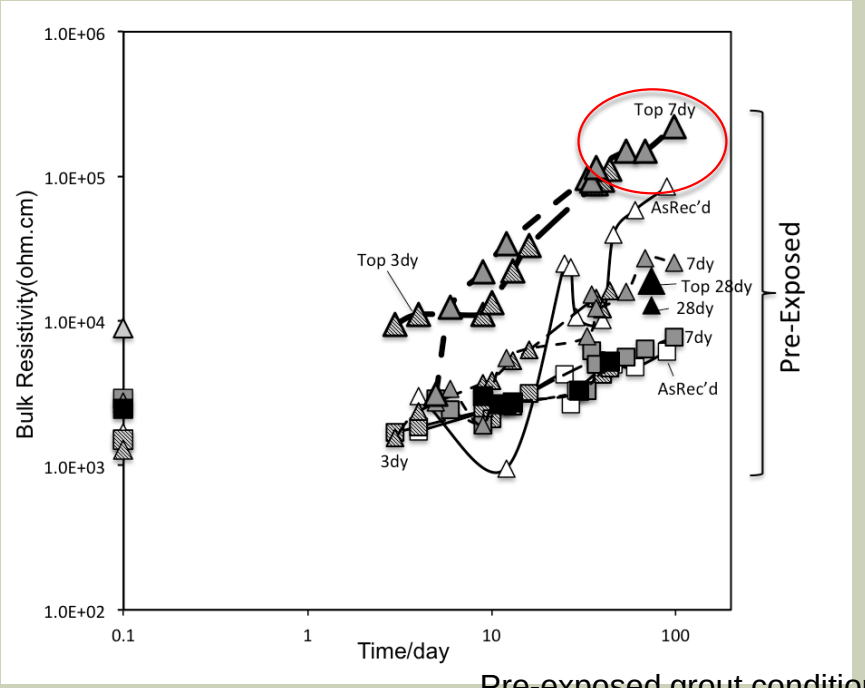
Pre-exposed grout condition (15 % excess water)

Grout A ~ 500 days

Expired grout condition-Mock up Tendons (15 % excess water)

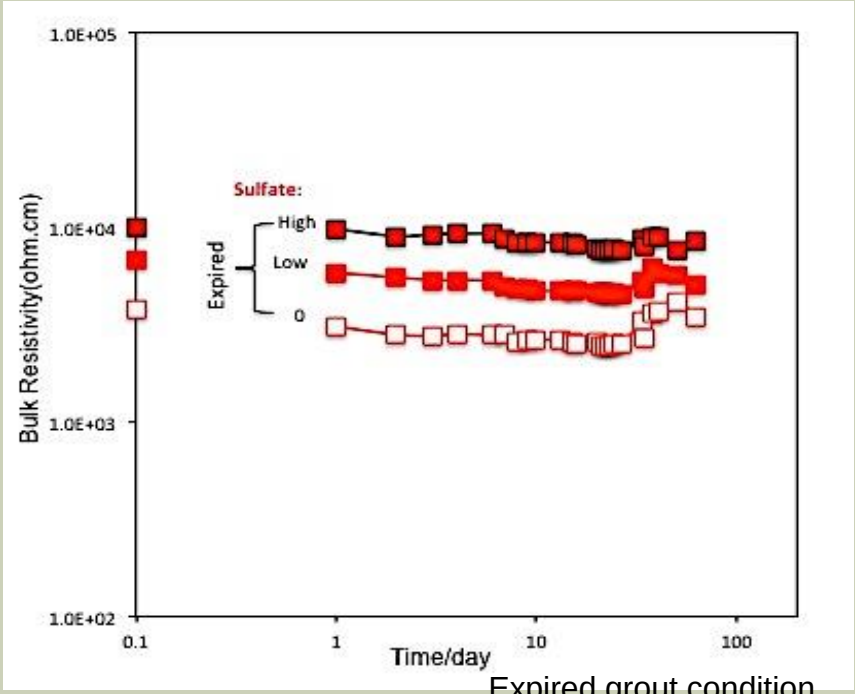
- Varied levels of grout segregation due to improper mixing conditions, pre-exposure of grout, and sample geometry.

Bulk Resistivity



Pre-exposed grout condition

(15 % excess water)

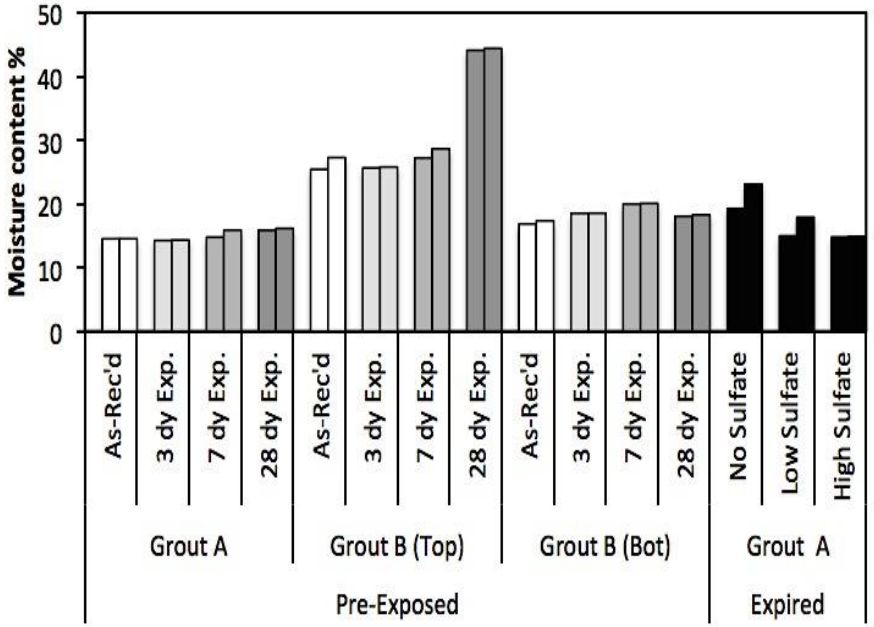


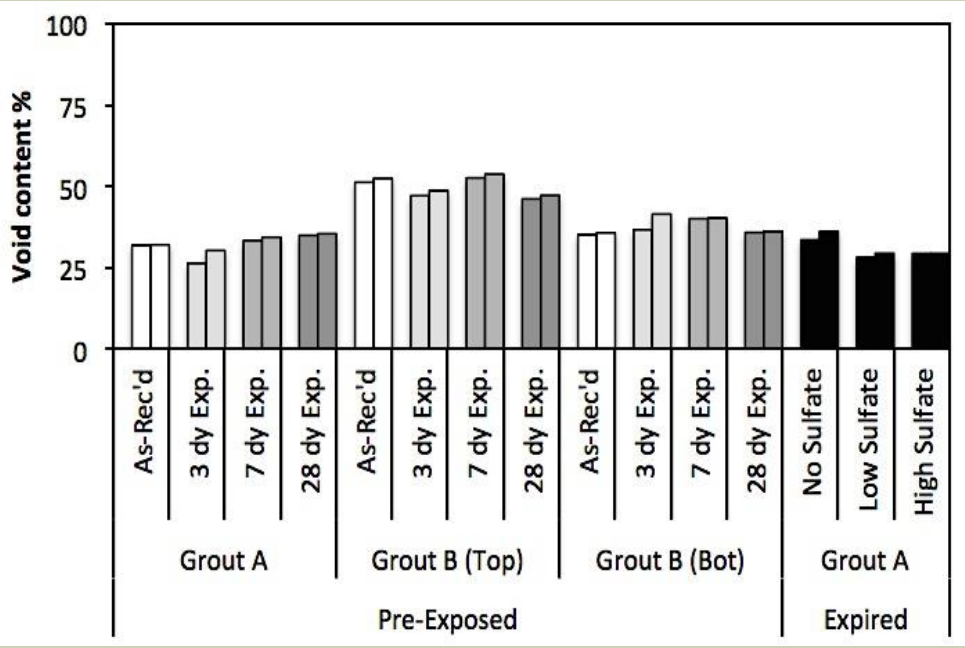
Expired grout condition

(15 % excess water)

- The wet resistivity increased with prolonged conditioning reflective of the continued hydration of the relatively young grout material
- The friable segregated material was shown to have relatively high wet resistivity .
- The mature grout samples in the expired condition showed terminal wet resistivity but differentiated by varying sulfate additions.

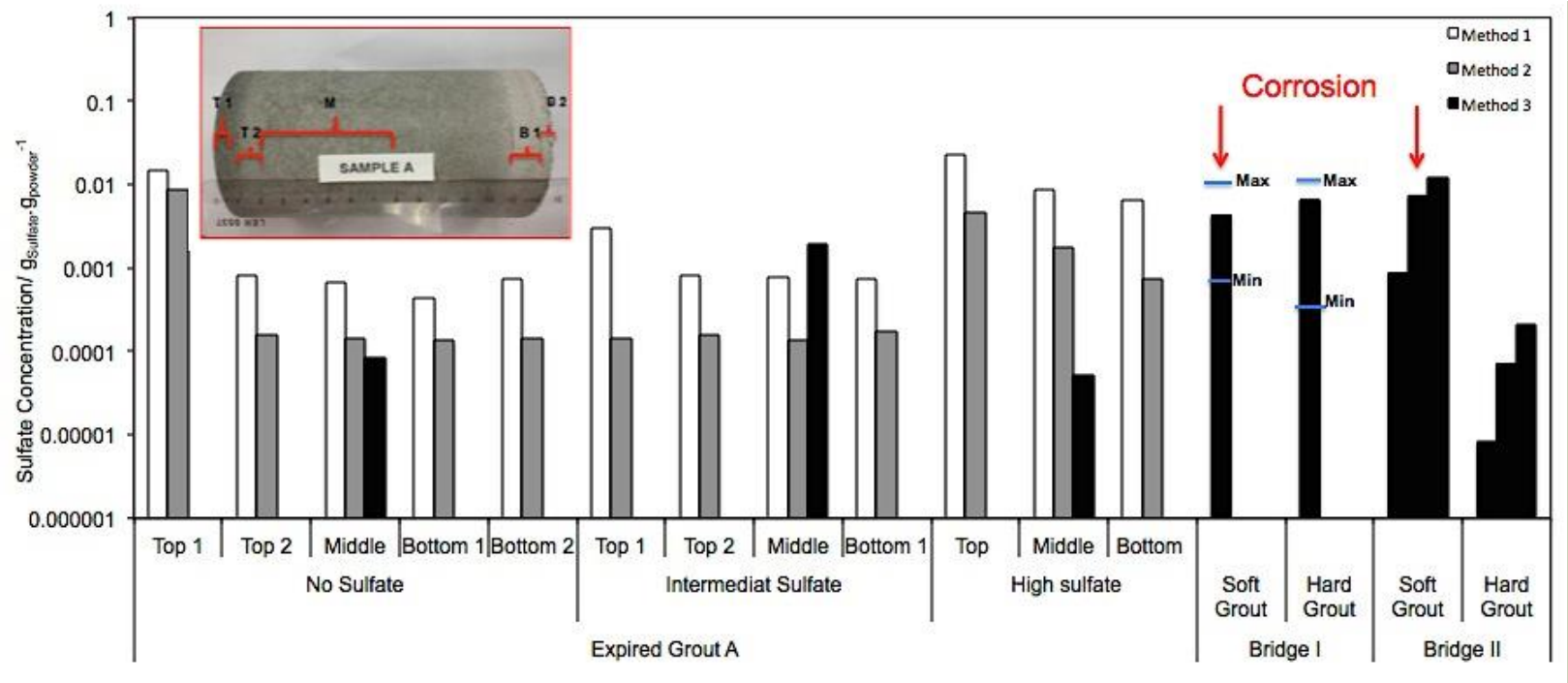
MOISTURE AND VOID CONTENT





- The segregated top portion of cast samples from Grout B showed higher moisture content and void content.
- In expired grout samples, the grout cast with enhanced sulfate concentrations in its mix water showed lower moisture and void content.

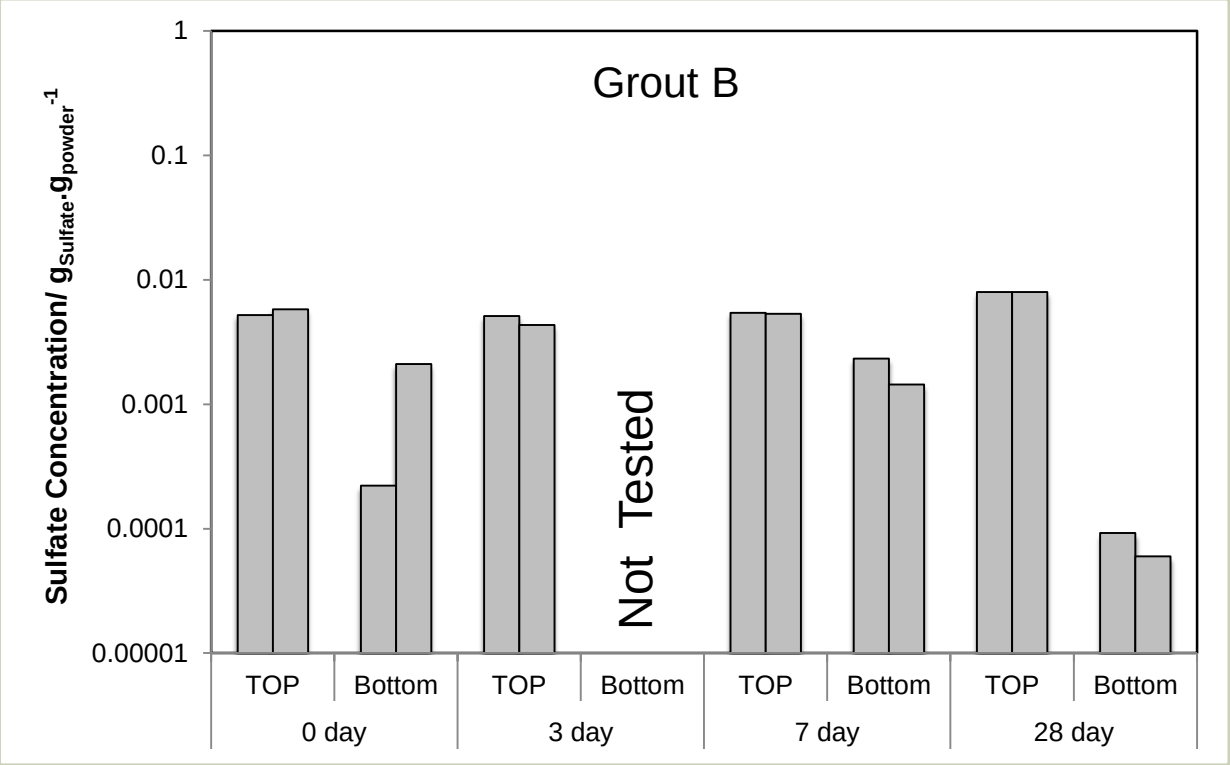
RESULTS: SULFATE CONTENT (EXPIRED GROUT)



- The test results indicated that material separation possibly due to enhanced moisture content at the top of the sample can affect the pore water chemistry.

- In comparison to the resolved sulfate content measured in grout from Bridge I and II, it is seen that separation of grout material can allow for accumulation of sulfate ions without external sulfate sources.

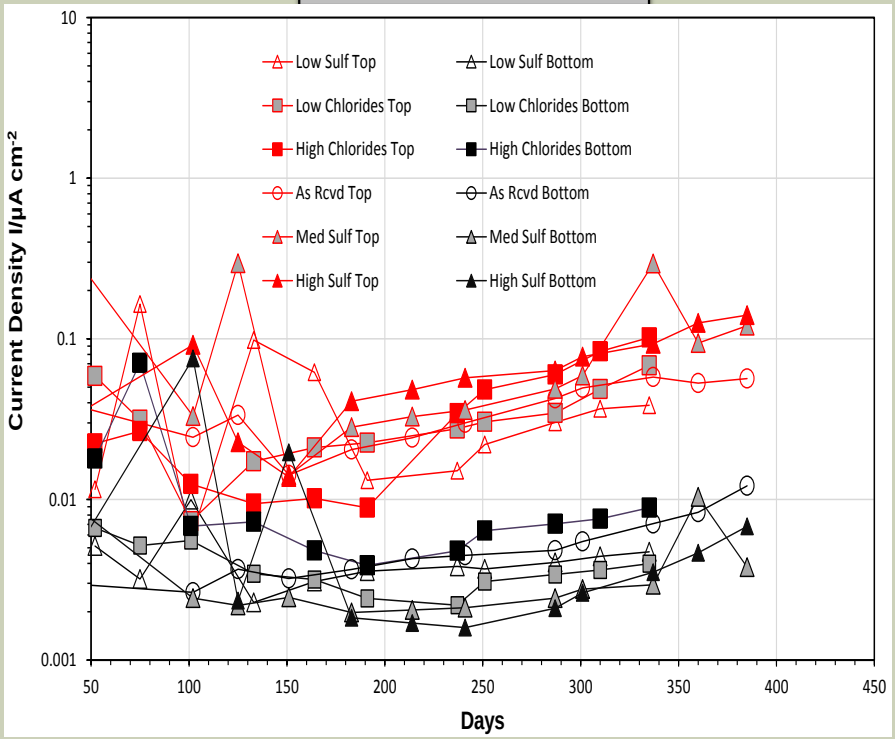
RESULTS: SULFATE CONTENT (PRE-EXPOSED - GROUT B)



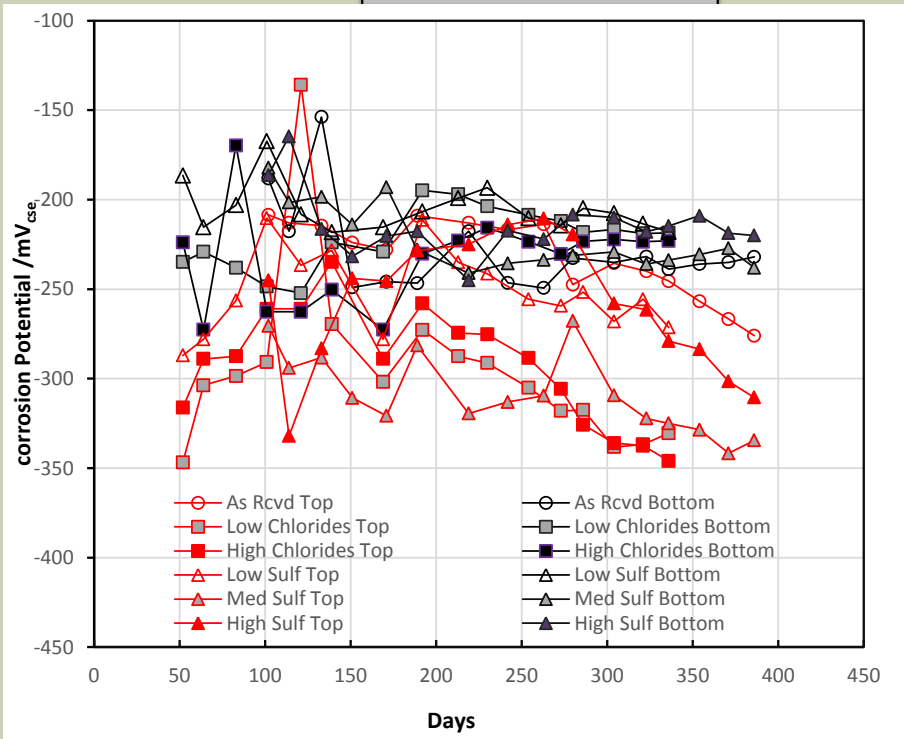
- Enhance sulfate concentration in segregated grout.
- The top segregated portion showed enhanced sulfate level concentrations.

Corrosion Behavior In Expired Grout Conditions

Current Density

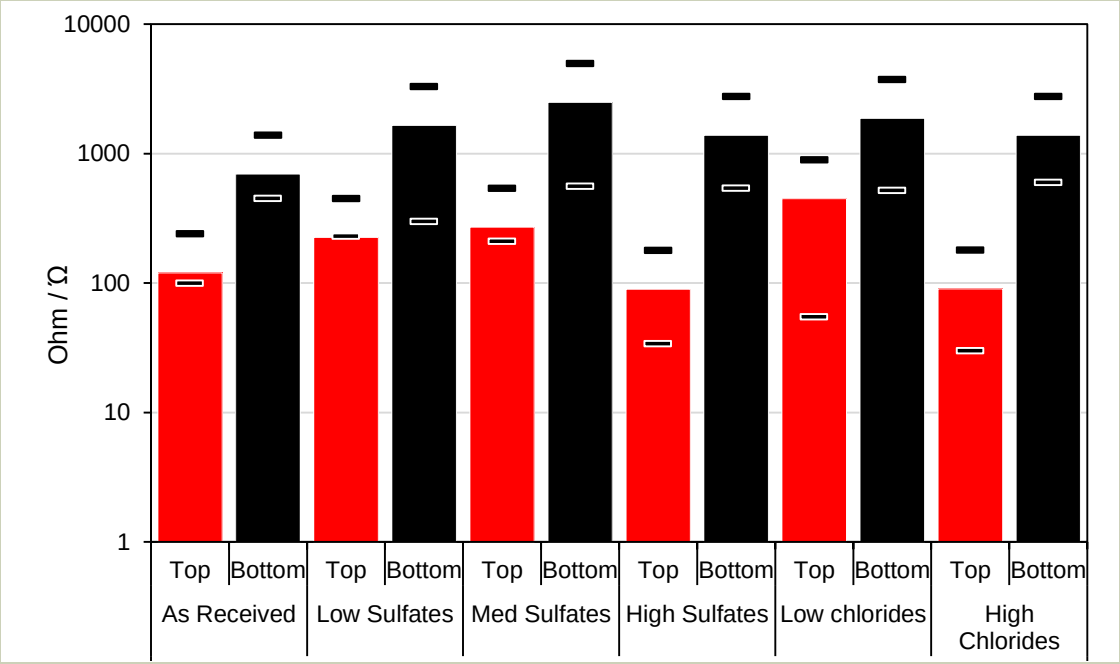


Corrosion Potential



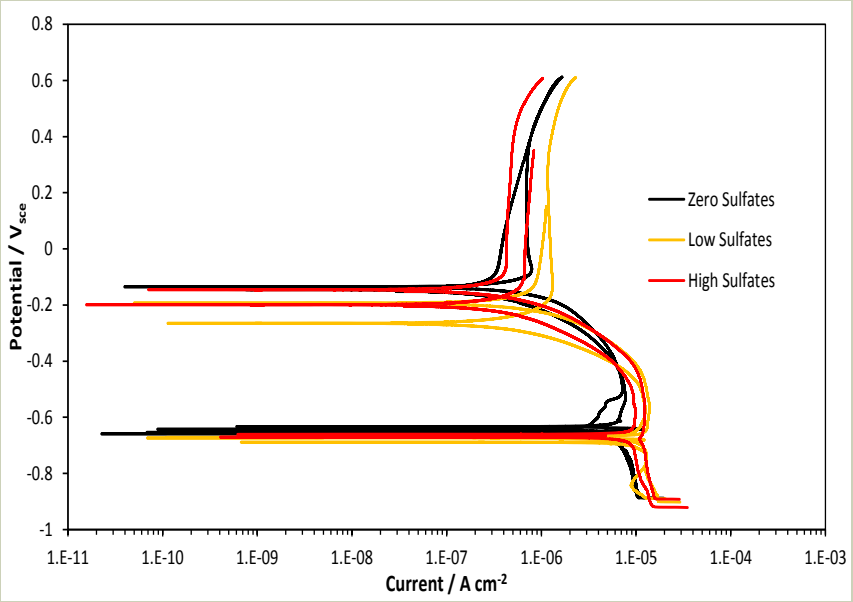
- Potentials indicative of possible active corrosion in top portion of tendon with both enhanced sulfates and chlorides .
- Active corrosion also apparent for steel with crevice including control condition.

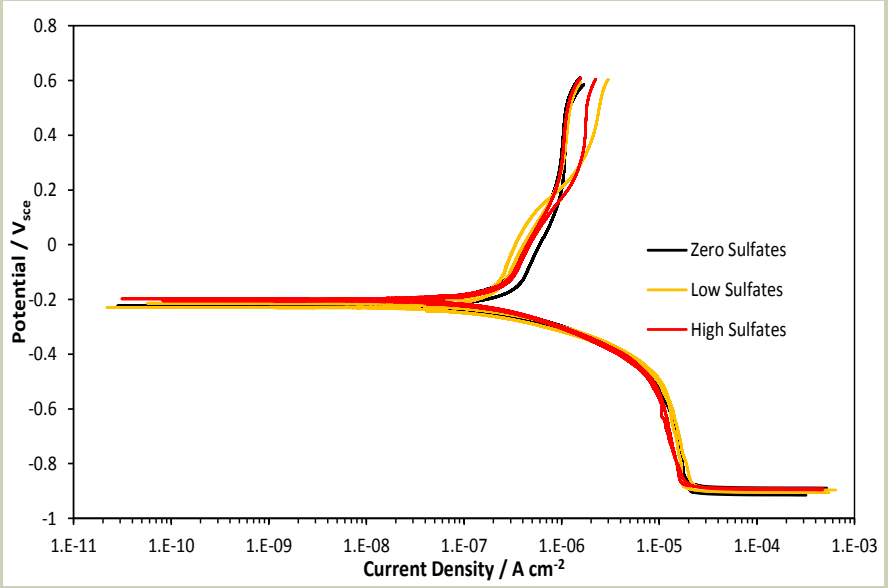
Solution Resistance of Grout in Mock-up Tendons



- ✓ Grout deficiency appears more severe at high elevation (TOP).
  - Generally, deficient grout at high elevations have lower solution resistance.

Corrosion Behavior in Sulfate Concentration(Room Temperature)

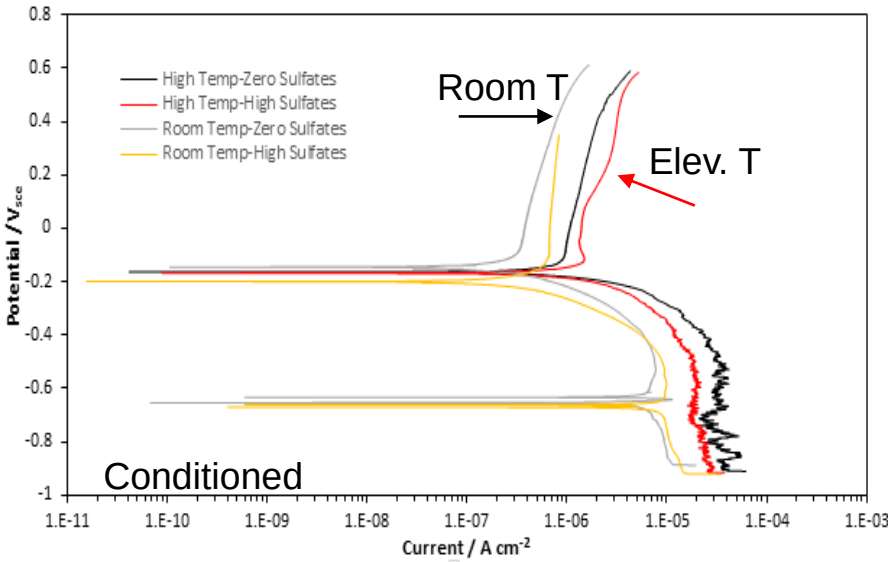


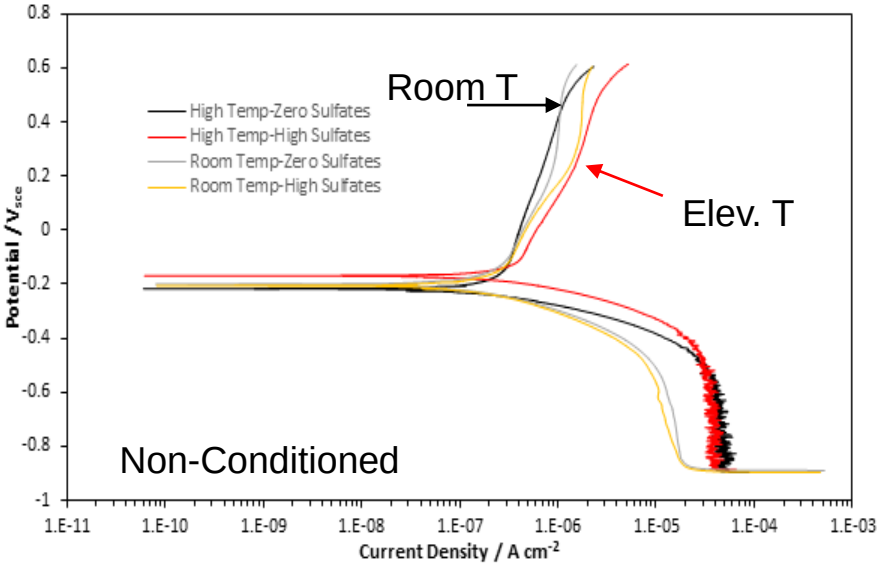


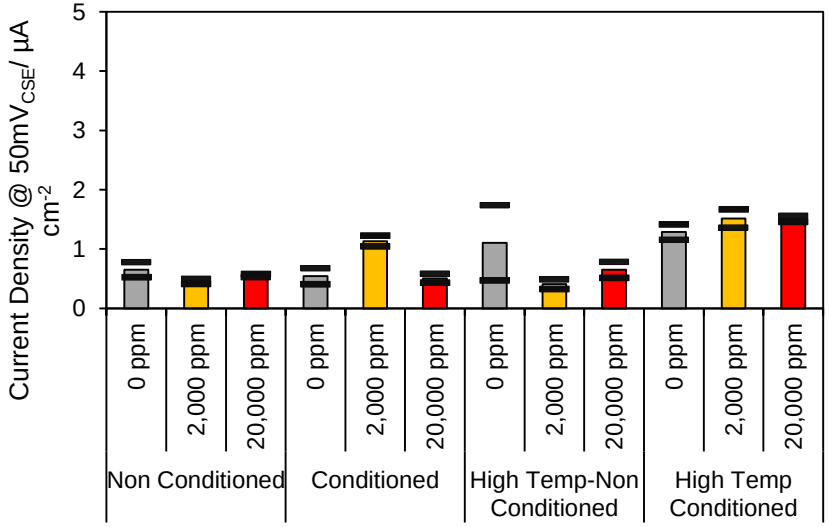
- Indication of Passive-like behavior for all test scenarios
- Increase in passive current for the steel in sulfate solution was greater which may indicate some adverse role of sulfate.
- Initial tests in the conditions described do not show strong capacity for sulfates to disrupt passive film formation.

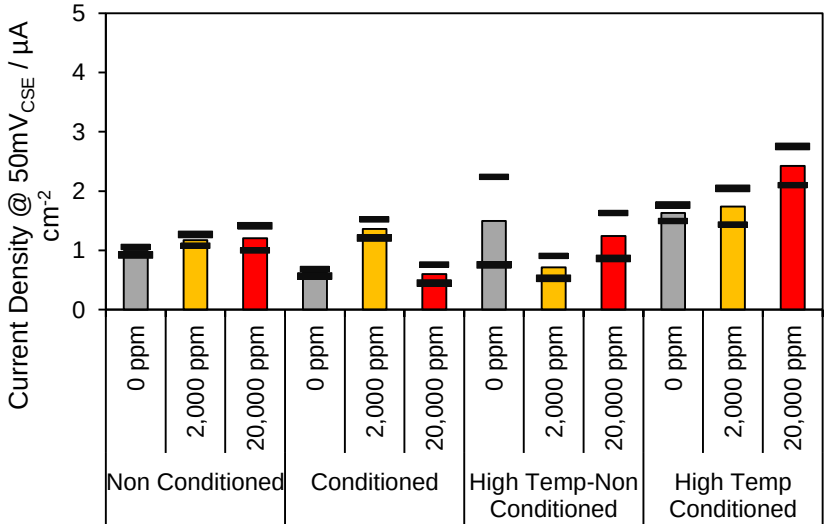
❖ Further testing on the role of higher sulfate concentrations ,lower pH and other parameters in crevice environments are in progress.

Corrosion Behavior In Sulfate Solution (Elevated Temperature)



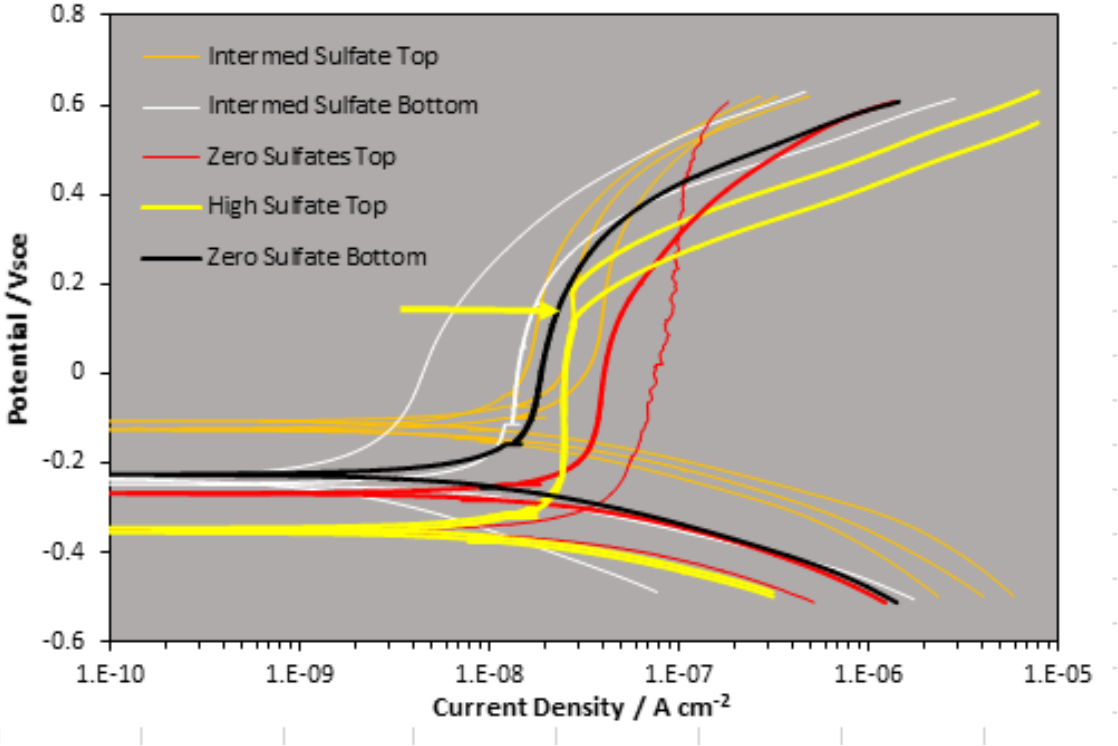






- Greater corrosion activity in elevated temperature as expected.
- Enhanced corrosion activity with cathodic pre-conditioning (early passive film destab.)
- Generally larger passive-like currents in sulfate solutions.

Anodic Characterization of steel in Mock-up Tendons



- Steel in top portion of mock-up tendon showed greater corrosion conditions than at bottom in steady-state condition, as expected.
- Indication of passive film development. Larger passive currents in higher admixed sulfate conditions.
- However, breakdown of passive-like conditions in high admixed sulfate conditions.

❖ Indication of possible role of sulfates in steel corrosion initiation. Severe corrosion occurred for steel in alkaline grout conditions with enhanced sulfate content. Sulfates were though to be related to localized corrosion process by reaction such as :

$$Fe^{2+} + 2H_2O + SO_4^{2-} \longrightarrow Fe(OH)_2 + H_2SO_4$$

(Jones.1992)

CONCLUSIONS

- High moisture content promotes grout deficiency. Excess mix water appears more significant than up to 28 days of grout powder pre-exposure in 100% relative humidity.
- The level of grout deficiency caused by excess mix water and pre-exposure in 100% relative humidity can vary by grout product.
- High sulfate concentrations can be accumulated in deficient grouts without external sulfate sources.
- Enhanced corrosion can occur in deficient grout created with expired grout and excessive mix water. The enhanced corrosion occurred at elevated portions of the tendon.
- Anodic polarization tests of steel in pH 13 and 20,000 ppm sulfate solution with preconditioning to large negative polarization (-1,000mVSCE) do not indicate strong tendency to disrupt passive film formation.
- Anodic polarization tests in mock-up tendons with enhanced sulfate concentrations showed propensity of development of passive film breakdown. Further testing in progress for verification and to resolve inconsistency observed in sulfate solutions.

Acknowledgments

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THANK YOU