An Experimental Investigation of Textured Response Between Micropile Forming Grout and Synthetic Rock

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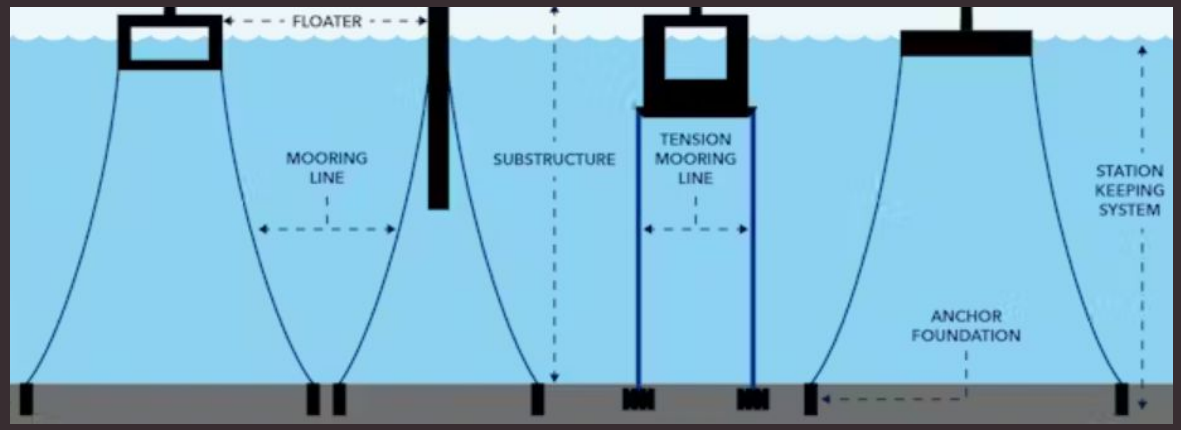
Mooring MHKs and FOWTs

Semi-submersible

Spar

Platform

Barge



Taught

Catenary

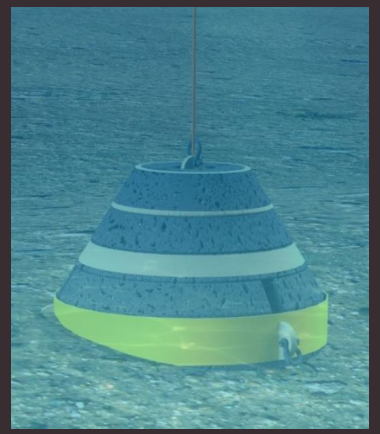
Block Island Wind Farm

WETS: Ocean Energy USA

Some Available Anchor Options

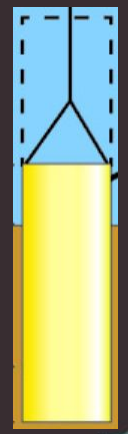
Anchor Type	Sediment Requirement	Deep Water Assist Requirement
Gravity	None	None
Suction Pile	Depth of Pile	Yes
Drilled and Grouted	None	Yes
Driven Piles	Depth of Pile	Yes
Drag Embedment	Depth of Plate	None

Gravity



Plates

Suction Piles/ Drilled and Grouted/ Driven Piles

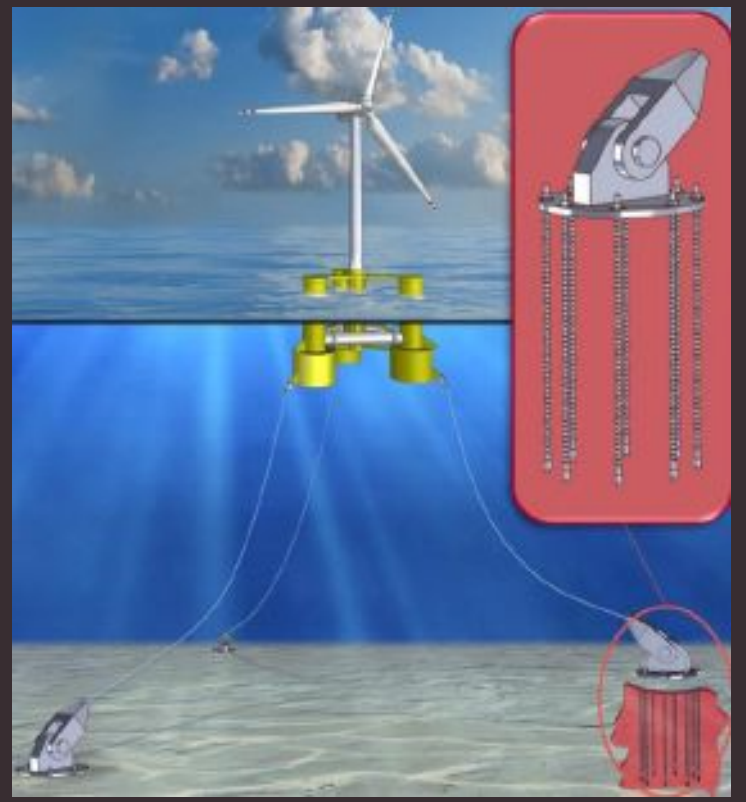


The Micropile Solution in Rock

No sediment required: Rock bits enable rock penetration

Cost effective installation: Small diameter holes mean small bits and rods that can be manipulated by remote-controlled equipment from a barge

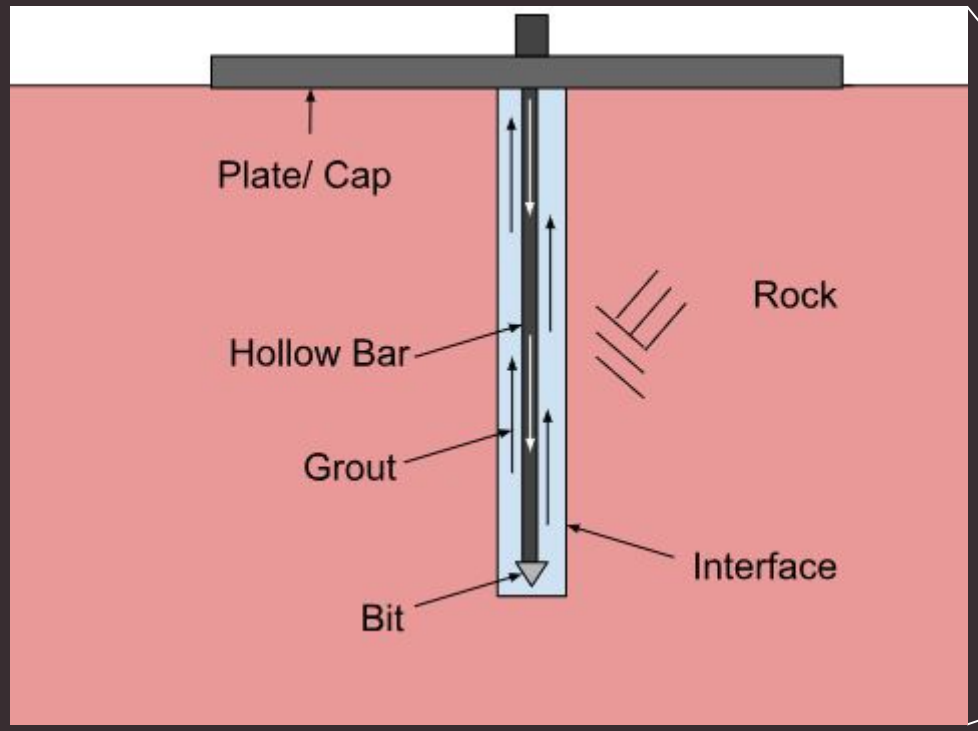
Meets load demand: accomplished with micropile groups



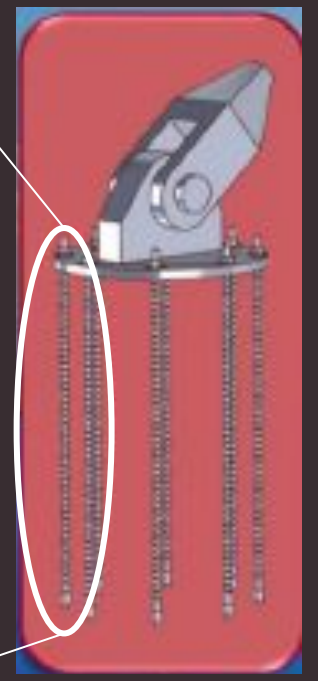
Makai Ocean Engineering

Micropile Design

- ✓ Mechanical properties of center hollow bar
- ✓ Physical and mechanical properties of rock
- ? Influence of interface texture on shear resistance



1 micropile



8 micropiles,
1 cap, 1 anchor

Characterizing Shear Strength Between Textured Grout and Rock

$$\tau = \sigma_n \tan\left[JRC \log\left(\frac{JCS}{\sigma_n}\right) + \phi_b\right]$$

Barton, Choubney 1977

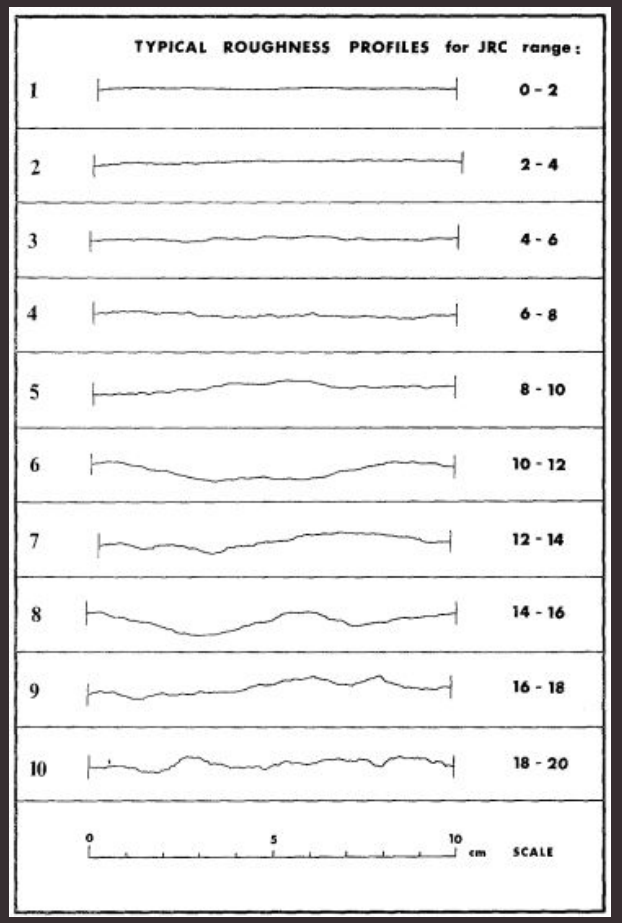
T: shear strength

σ_n: applied normal stress

φ_b: basic friction angle

JRC: joint roughness coefficient

JCS: joint compressive strength



Barton, Choubney 1977

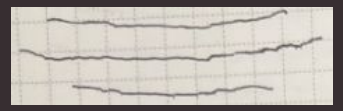
Specimen Fabrication

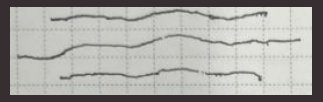
Smooth
JRC 0-2

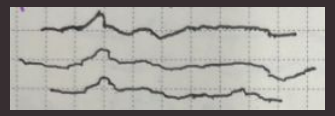
Low
JRC 8-10

Medium
JRC 10-12

High JRC
18-20

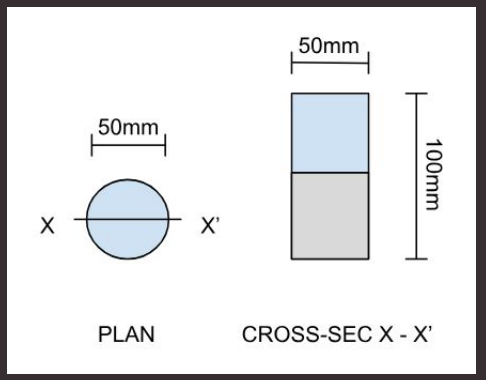






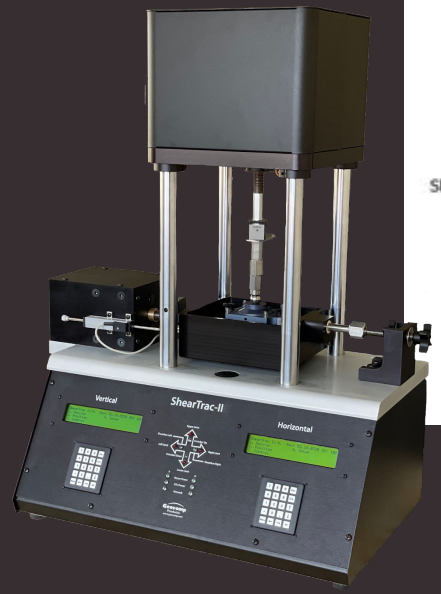
Grout

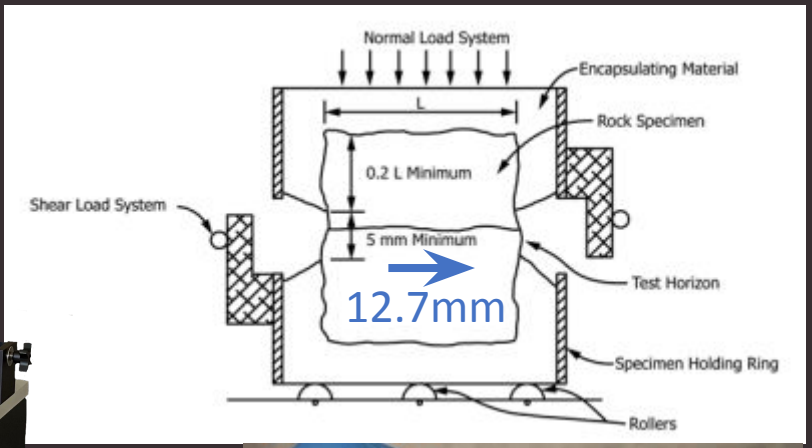
Synthetic
Rock



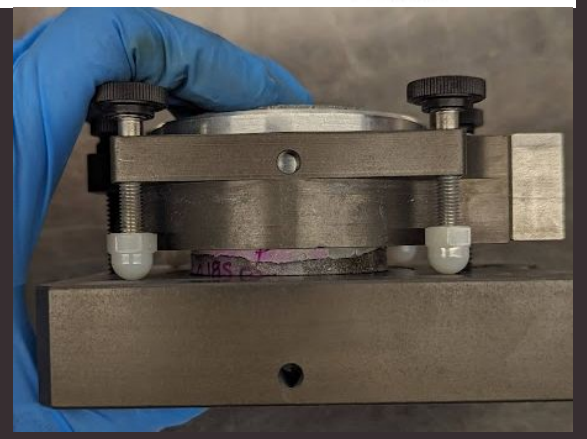
Test Equipment

Uniaxial Compressive Strength (UCS), ASTM C39



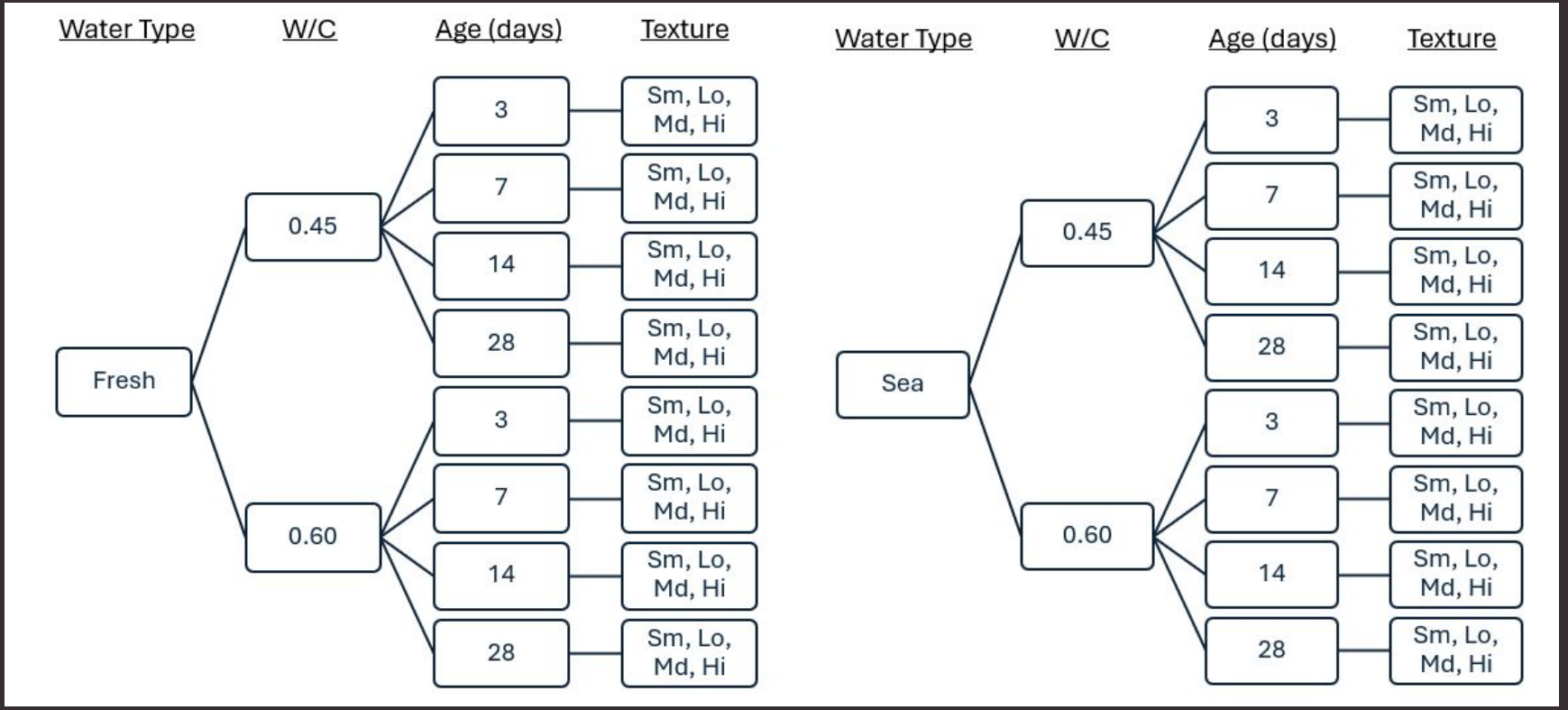


Direct Shear (DS), ASTM D5607



Ultrasonic Pulse Velocity (UPV), ASTM C597

Test Program (Composite Specimens)



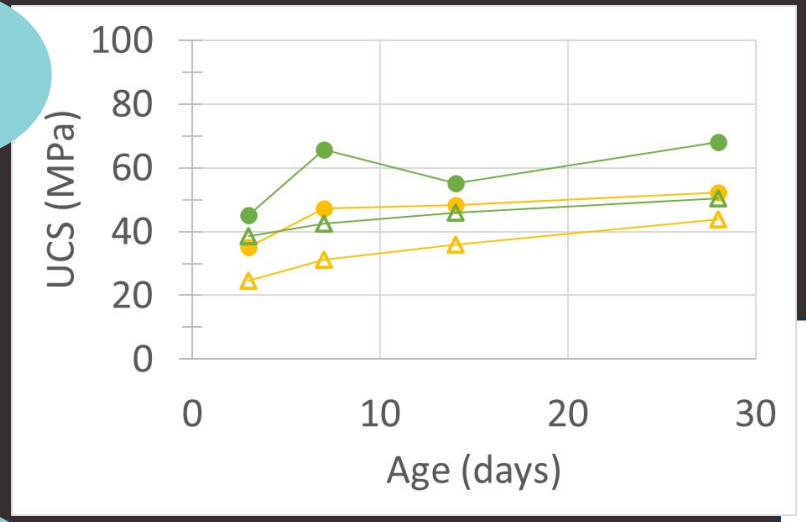
*Each recipe DS tested at 5, 10 30 40 and 60 kPa + 1 UCS test + 1 UPV test

Test	Composite	Baseline
UCS	64	16
DS	320	80
UPV	64	16

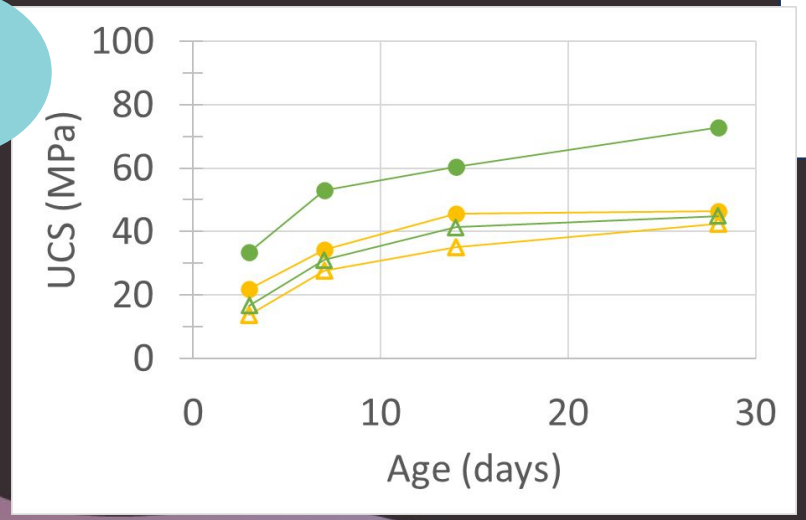
(Plus 5% triplicates for reproducibility analysis)

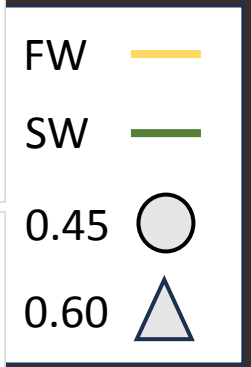
Sample Complimentary Test Results

Grout 20°C

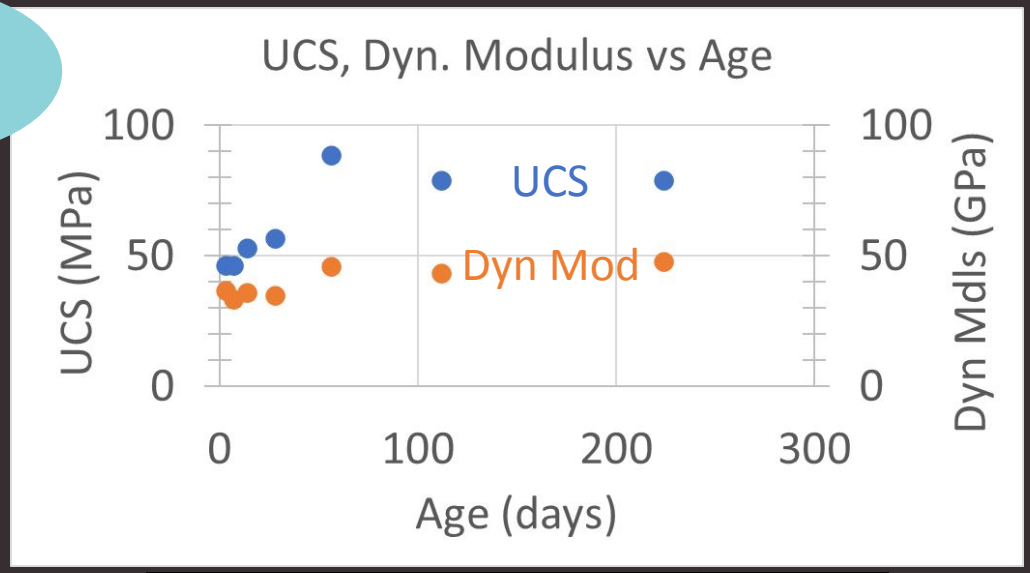


Grout 4°C

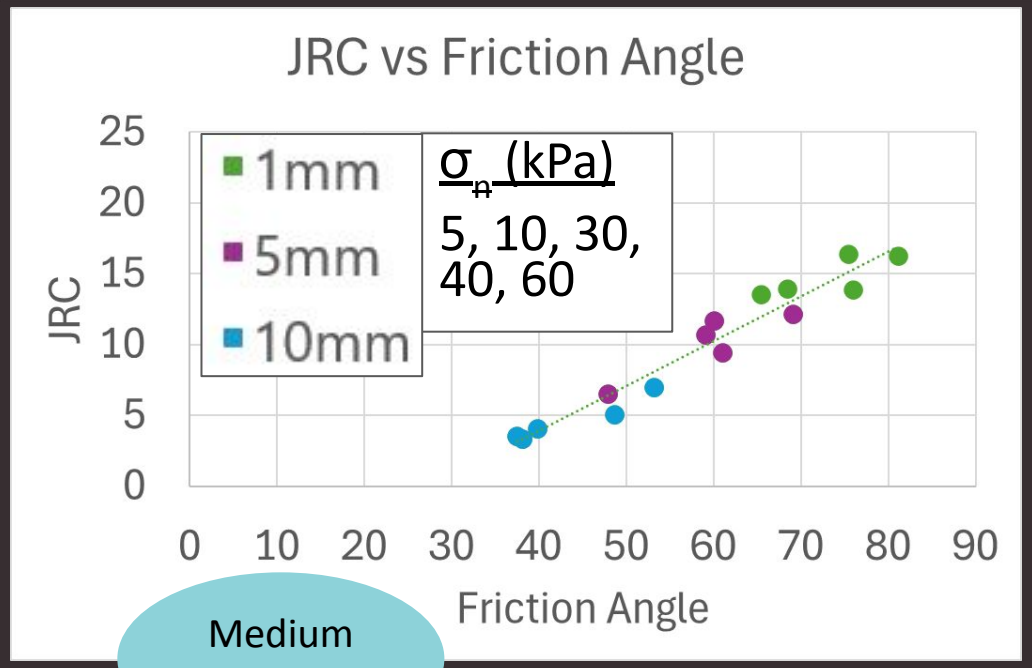




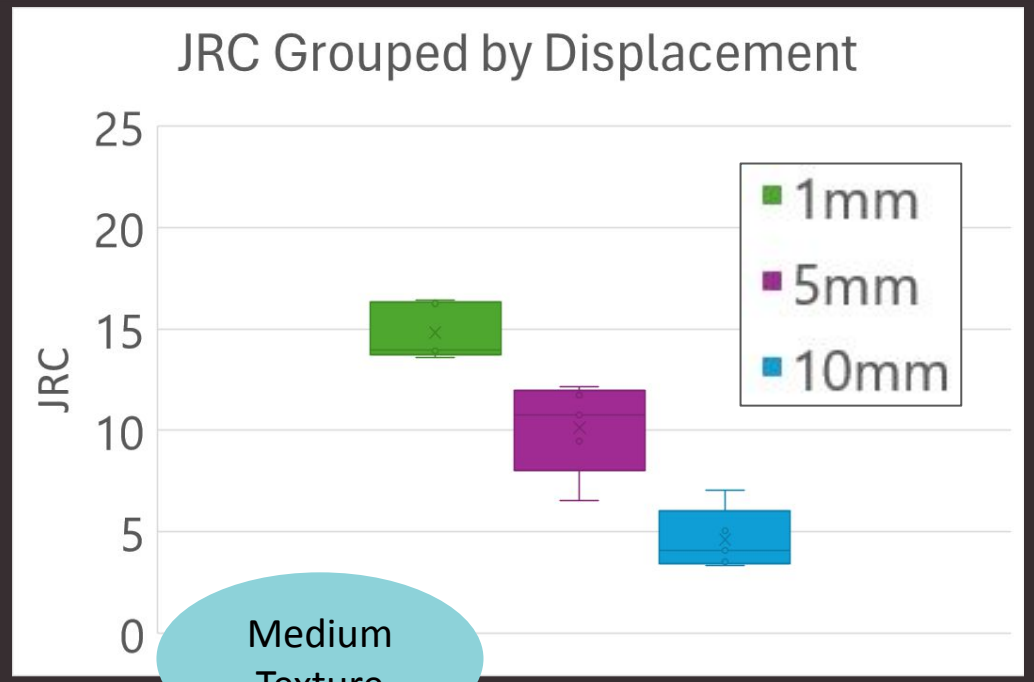
Simulated Rock

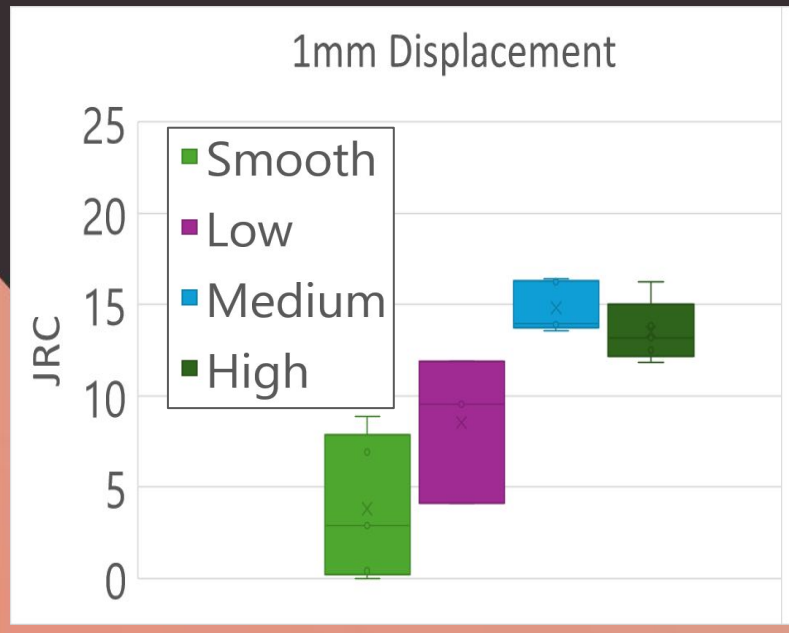


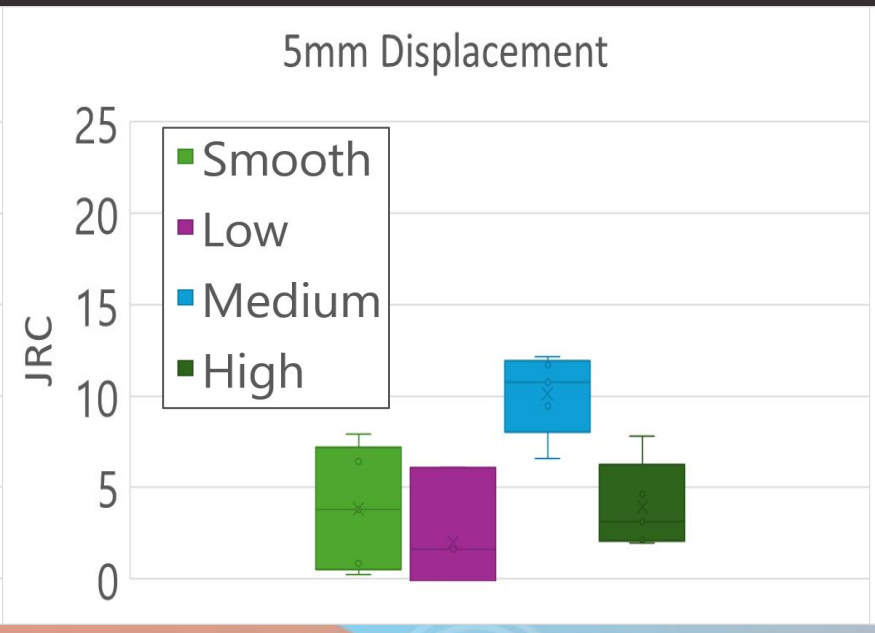
Rock Type	UCS (MPa)	E (GPa)
Oregon Basalt	112 - 308	54 - 92
Meng-di-gou Granite	120	34.1
Miocene Limestone dry	0.86 - 38.8	0.43 - 21
Miocene Limestone sat	0.63 - 27.6	0.28 - 13.3
Xushou, Jiangsu Sandstone	78 - 82	6.61 - 6.82
Johpur Sandstone	39.9 - 56.7	44.3 - 58.5
Dolerite	83 - 96	50 - 66
Shale	25.3 - 39.7	15.8 - 21.2
Green Marble	38.4 - 46.2	50.3 - 60.8
Quartz	123.2 - 143.7	89 - 100.4



Example DS Results 7-day Seawater

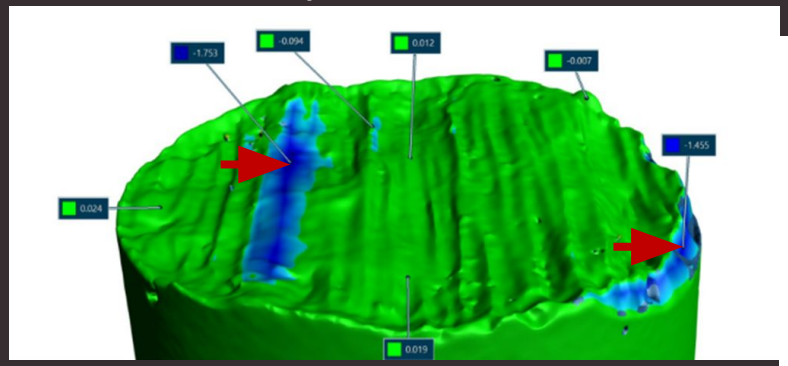






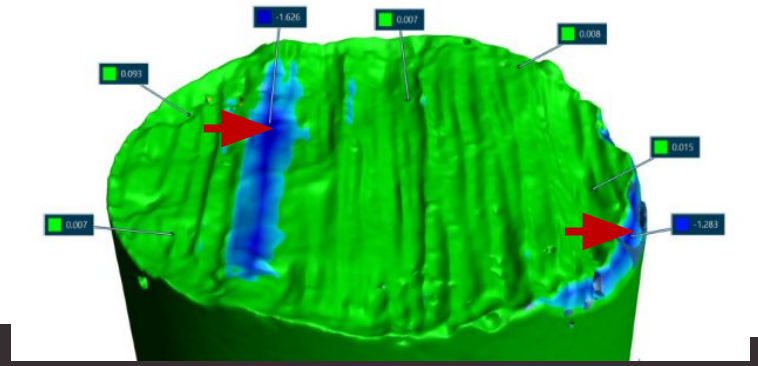
Grout Shape Change with Displacement

After 3mm displacement



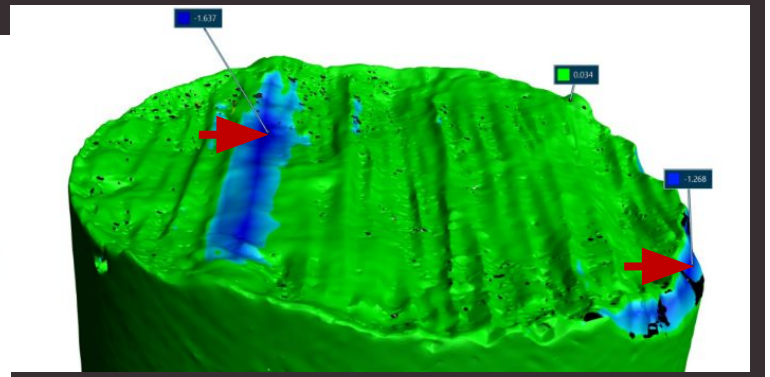
Left: -1.573mm
Δ = -1.573mm
Right: -1.455mm
Δ = -1.455mm

After 6mm displacement

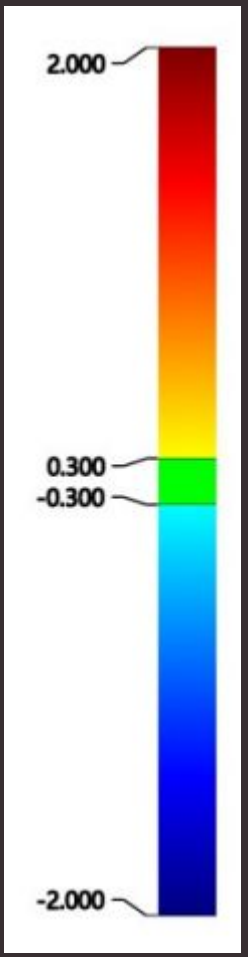


Left: -1.626mm
Δ = -0.053mm
Right: -1.283mm
Δ = +0.172mm

After 12.7mm displacement



Left: -1.637mm
Δ = -0.011mm
Right: -1.268mm
Δ = +0.015mm



Conclusions

- Seawater accelerates cure time of grout (cost impact)
- UCS grout w/c = 0.45 (plastic consistency) is greater than UCS grout w/c = 0.6 (flowable consistency)
- 4°C decelerates cure time of grout vs 20°C (cost impact)
- Increasing displacement yields: 1) decreased JRC 2) decreased friction angle 3) decrease shear resistance
- Peak shear resistance observed at 1mm displacement
- The synthetic rock used in this investigation approximates sandstone
- Based on models generated by Neda Jamaleddin, bar failure occurs before shear resistance failure between grout and rock

Acknowledgements

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