

Investigation of Silicone Masking Materials for Air Plasma Spray of Environmental Barrier Coating Applications

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Abstract: This project evaluates the performance of silicon-based masking materials used in Air Plasma Spray processes for high-temperature aerospace applications, where thermal and environmental barrier coatings are applied to reduce thermal gradients. The materials are subjected to repeated thermal cycling near degradation temperatures to assess chemical stability, mechanical integrity, and reusability over cycles. Findings reveal key material-performance relationships, providing actionable data for Rolls-Royce to select materials that improve reusability and overall process efficiency.

This work is sponsored by
Rolls-Royce Corporation,
Indianapolis, IN



Background & Objective

Air Plasma Spray (APS) is a standard industry practice for creating TBCs on alloys found in turbine engines to provide thermal dissipation. By expanding plasma-forming gas to instantaneously melt ceramic powder, APS forms layers that provide sufficient thermal dissipation for turbine engines to operate safely. Masking materials are the only barrier between critical components that do not require multiple spray layers over their surfaces.

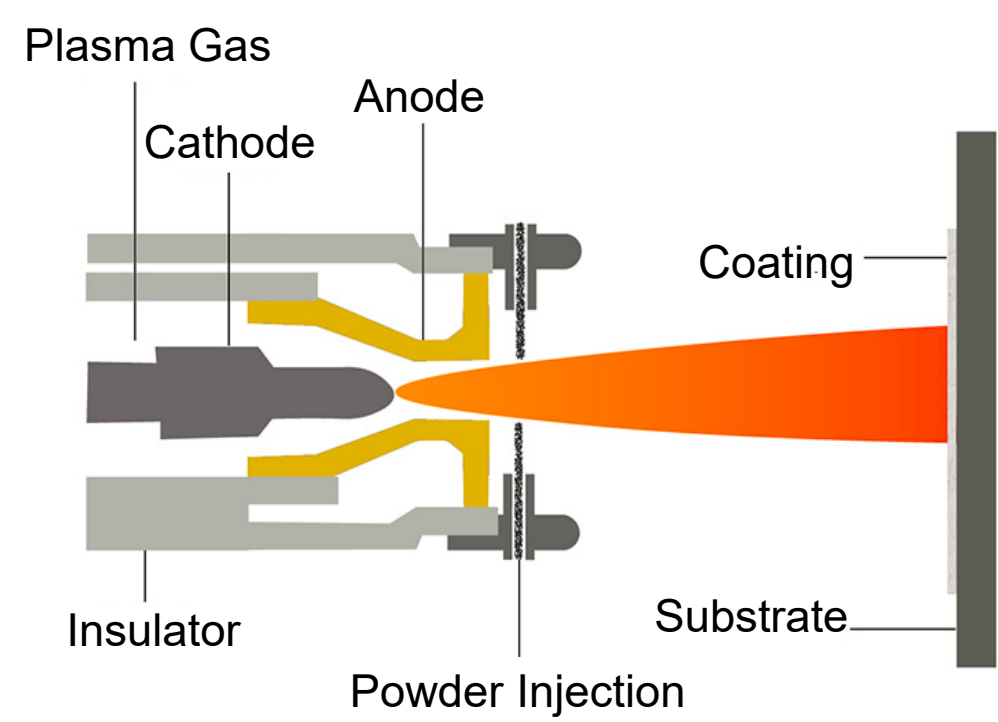
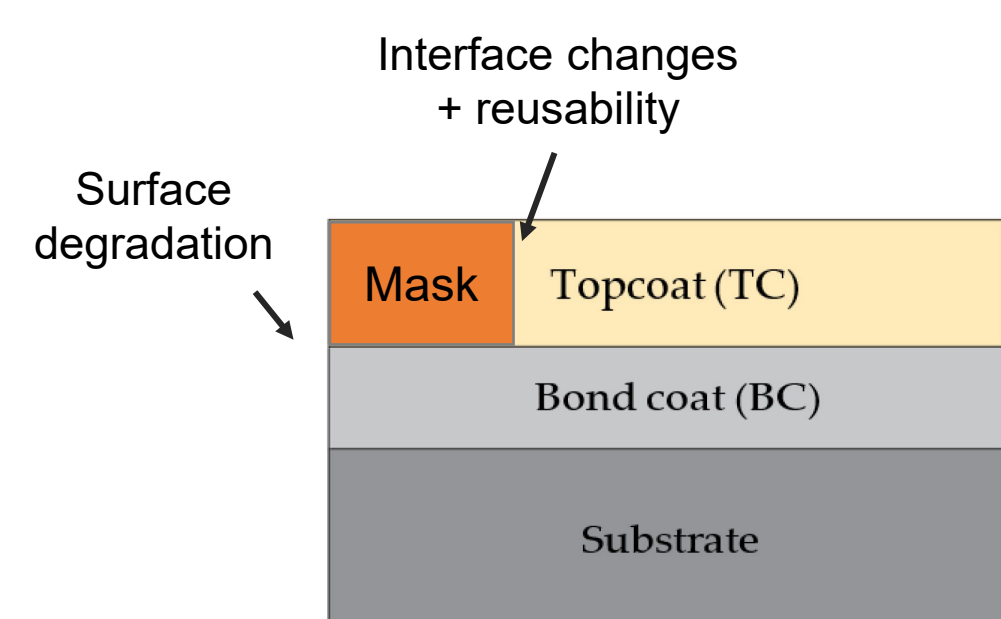


Diagram of Air Plasma Spray Components

The energy intensive nature of the APS process works against the mask in actively destroying the material through heat, erosion, and potential chemical interactions. Consequently, developing a reusable, robust, and cost-efficient mask is a great technical challenge for Rolls-Royce. The combination of heat and particle impact often causes the mask to degrade, tear, embrittle, or fuse to the component surface or the freshly sprayed thermal barrier coatings (TBC). Difficult or destructive mask removal can damage the newly applied coating or the underlying substrate.



Coat-mask surface interaction

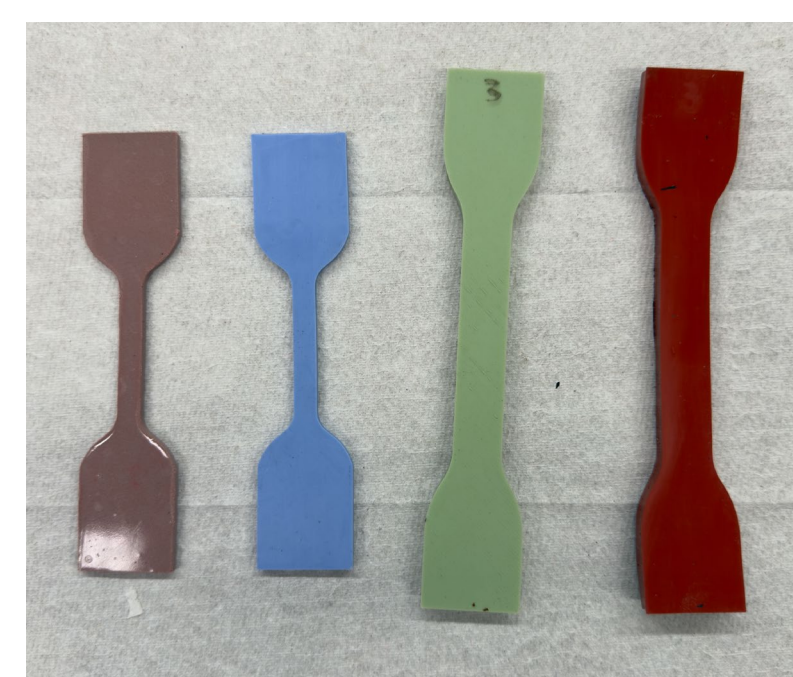
Goal: Mimic APS thermal environment to find optimal masking material to establish performance of chemical and mechanical reliability and reusability over at least ten cycles.

Procedure

Materials Investigated

Four silicone masking materials:

- HVOF grade (Brown, AIMTEK)
- Base SIL grade (Blue, AIMTEK)
- P-50 (Green, Rolls-Royce)
- High Temp SIL (Red, Rolls-Royce)



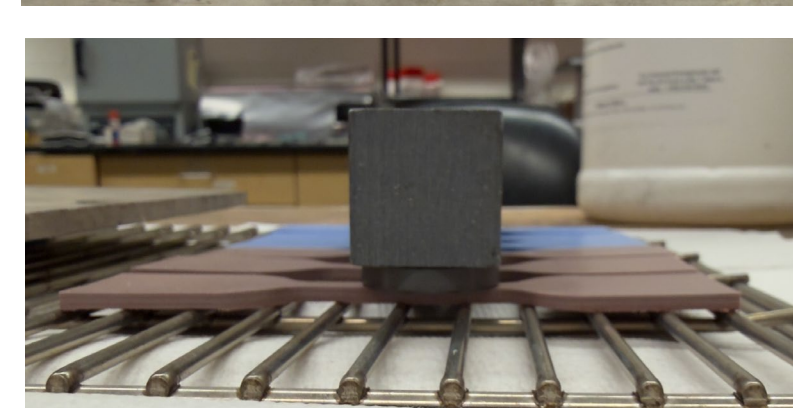
Sample Preparation

- Silicone punched into circular pucks (ASTM D395-T1) and dog bone specimens (ASTM D412-A) via lever press
- YbDS powder cold-pressed at 4 US tons, sintered at 1500°C for 10 hours to form ceramic pellets
- Reaction Bonded Silicon Carbide pucks provided directly by Rolls-Royce

Test Configurations

(5 per material, 20 total combinations)

1. Blank mask
2. Mask + YbDS pellet
3. Mask + SiC puck
4. Mask + YbDS pellet weighted (~250 g)
5. Mask + SiC puck weighted (~450 g)



Thermal Cycling

Quincy Lab 10GC Gravity Convection Oven; 215°C for 2-hour intervals, 10 cycles per combination. Brown and Blue additionally cycled at 250°C.

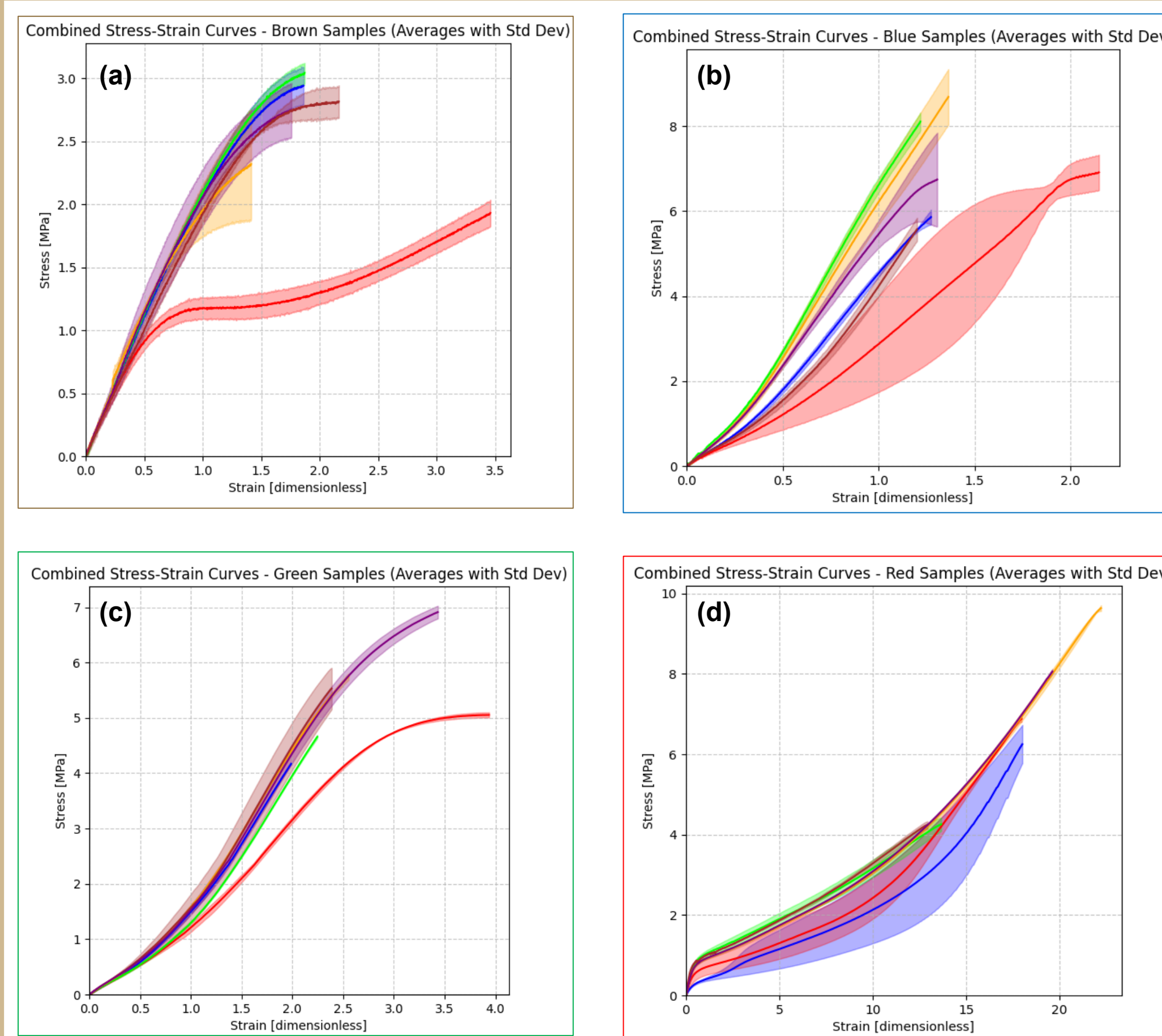
Post-Cycle Characterization

- Shore A hardness (durometer per ASTM D2240)
- Dimensional changes (digital calipers; diameter and thickness)
- Surface inspection (optical microscopy (OM))

Tensile Testing

ADMET MTEST Quattro per ASTM D412-16 at cycle 0 and cycle 10; 3 dog bone specimens per cycled and uncycled condition

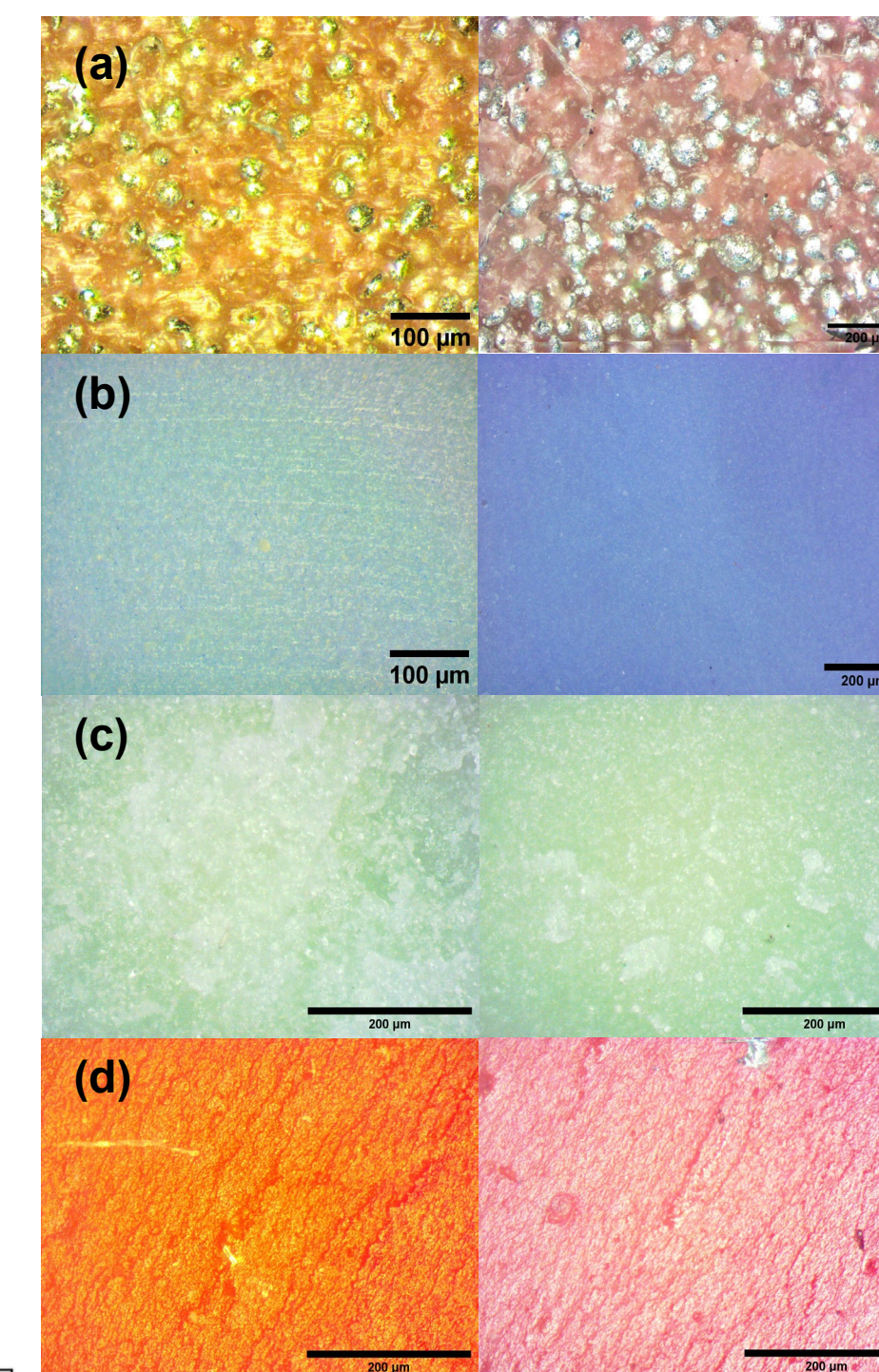
Results



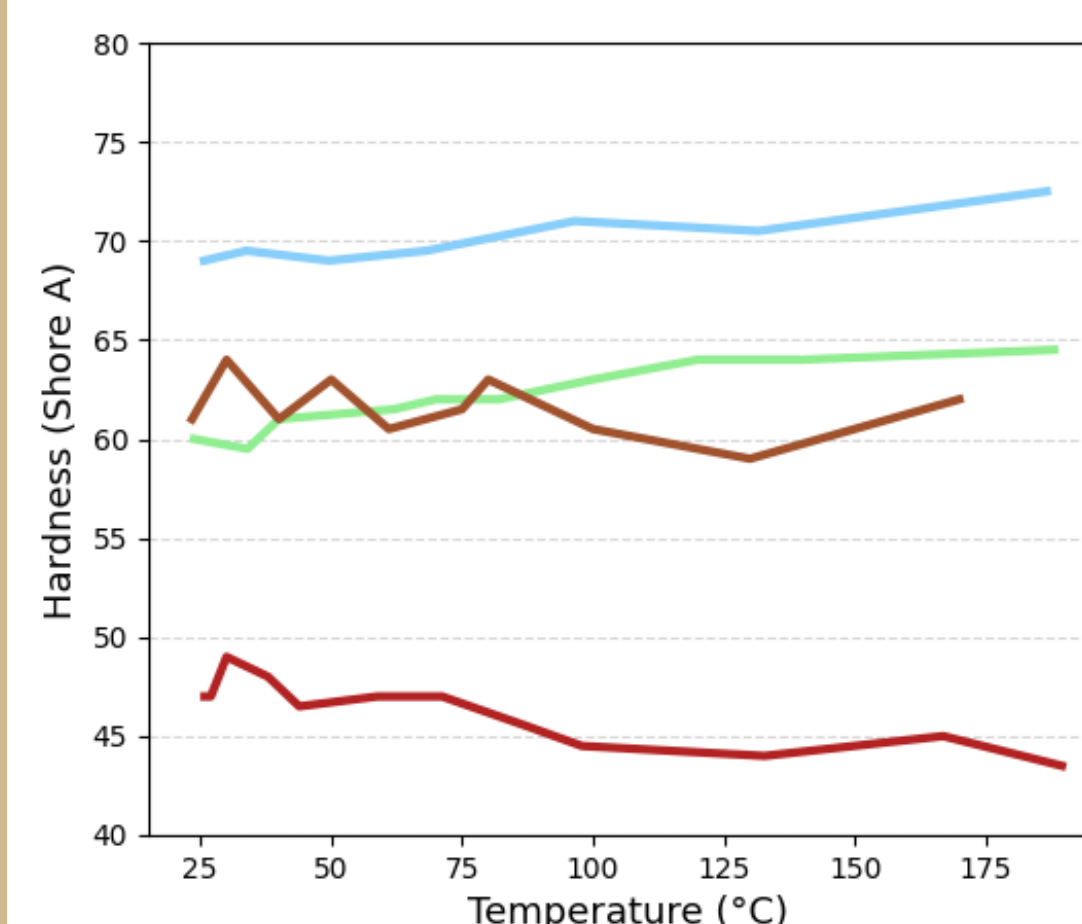
As Received (Not thermal cycled) Blank Material YbDS
YbDS Weighted SiC SiC Weighted

Tensile results of brown (a), blue (b), green (c), and red (d) silicone. Combined plots with standard deviation of each unique test configuration. All but the red silicone lost ductility from thermal cycling.

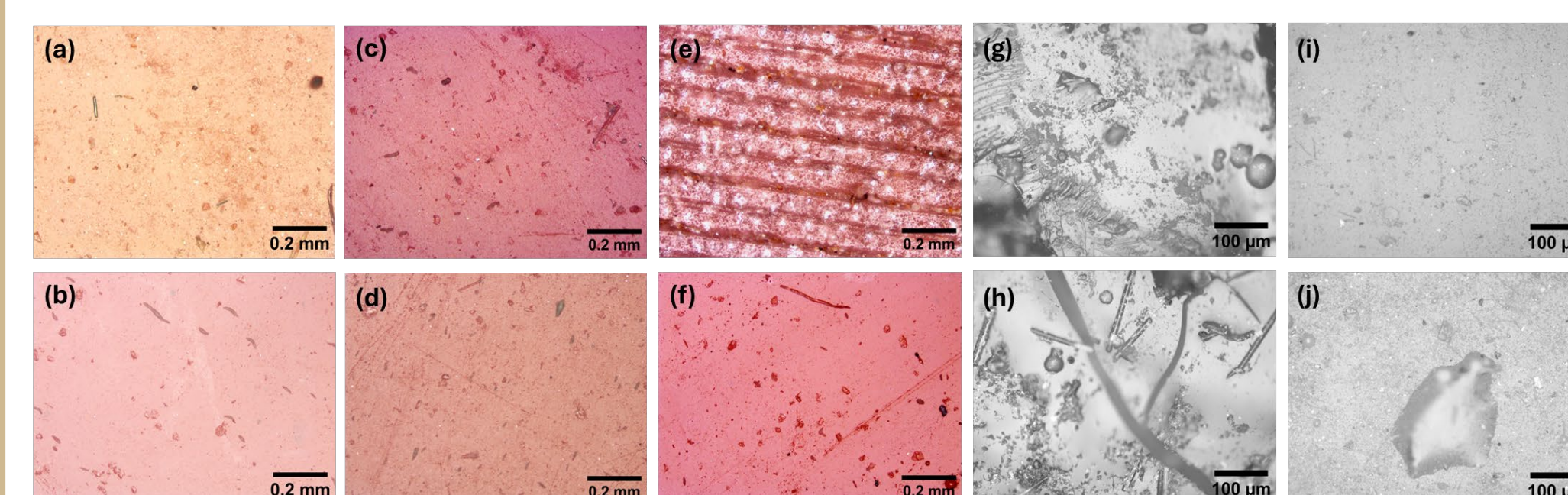
The brown silicone, HVOF, contains fillings of 1%-5% Quartz and <1% of Titanium Dioxide. It is the only silicone tested with fillings as seen by the noticeably different cross section view.



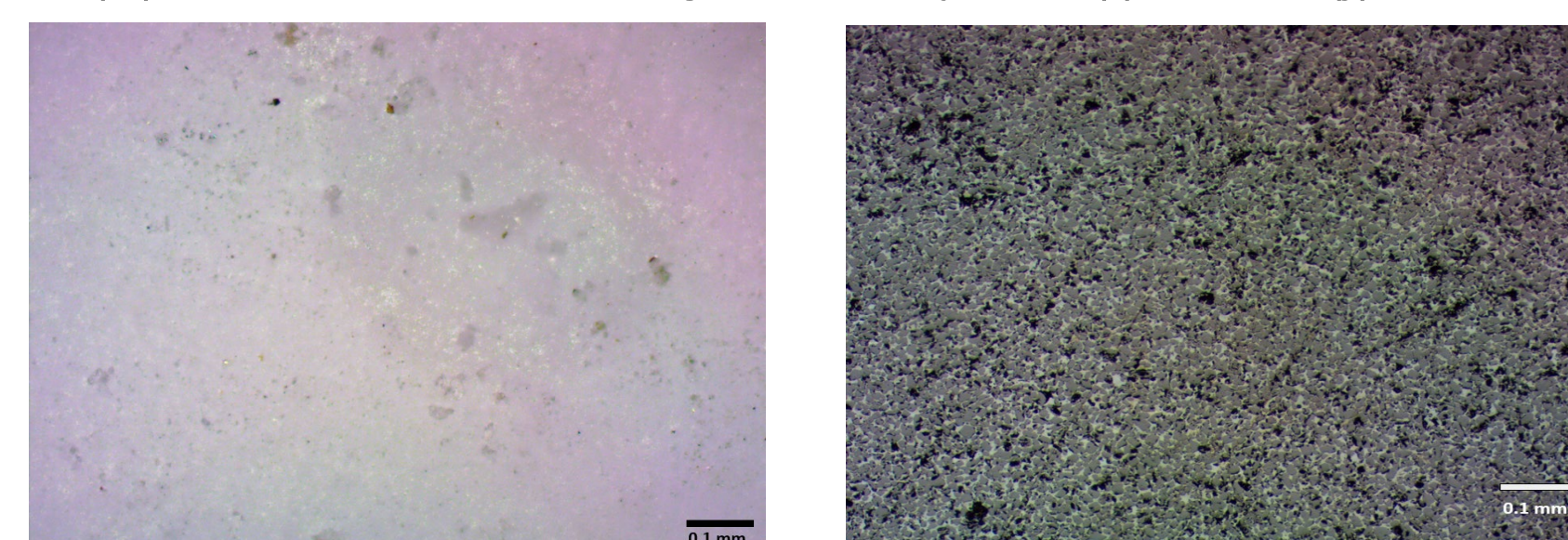
Cross section fracture surface of brown (a), blue (b), green (c), and red (d) tensile samples. Left images are as received material. Right images are of samples after 10 thermal cycles. No thermal degradation observed, which would be seen as amorphous white lines in cross section.



Hardness of each sample as a function of temperature. Samples were heated to 200°C and cooled to room temperature. Blue and Green both increased with temperature, while Red decreased, and brown did not change.



Optical Microscopy images of red masks at 10x magnification of bare samples at cycles (a) 5 and (b) 11, SiC weighted at cycles (c) 3 and (d) 9, SiC unweighted at (e) 3 and (f) 6, YbDS weighted at cycles (g) 3 and (h) 9, and YbDS unweighted at cycles (i) 3 and (j) 9.



(Left) YbDS and (Right) optical microscopy images at 10x magnification after 10 thermal cycles showing no indication of change to surface or any evidence of residual substrate material after subsequent cycling, a key measure of the chemical compatibility of substrate-mask relationship.

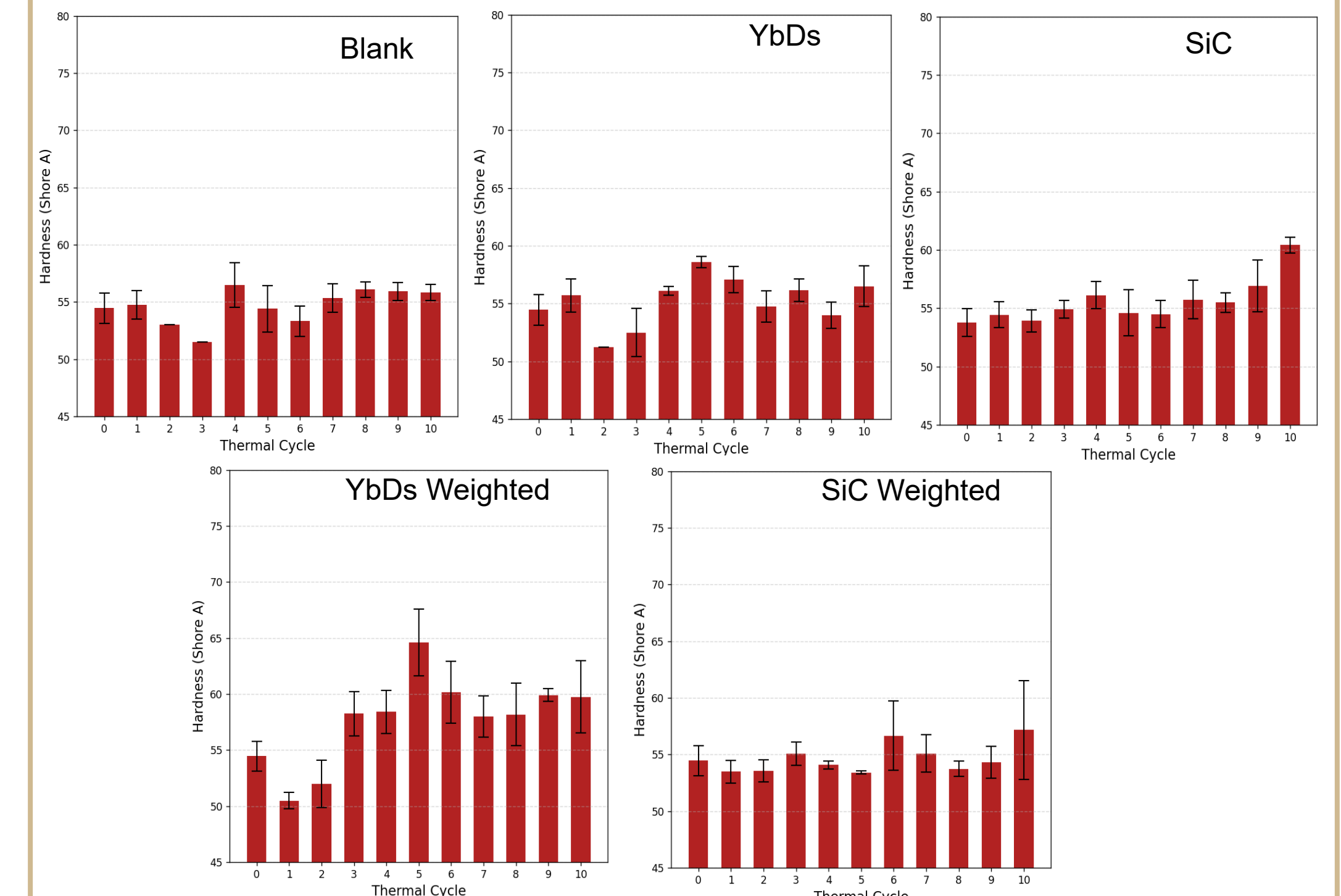
Conclusion

Assumptions: Due to constraints of our oven testing could not be done over 250°C. Additionally, the environment for thermal cycling does not mimic the intense heat fluxes experienced by the silicone masking material in real air plasma spraying. Also, a realistic force (weight) could not be applied in testing.

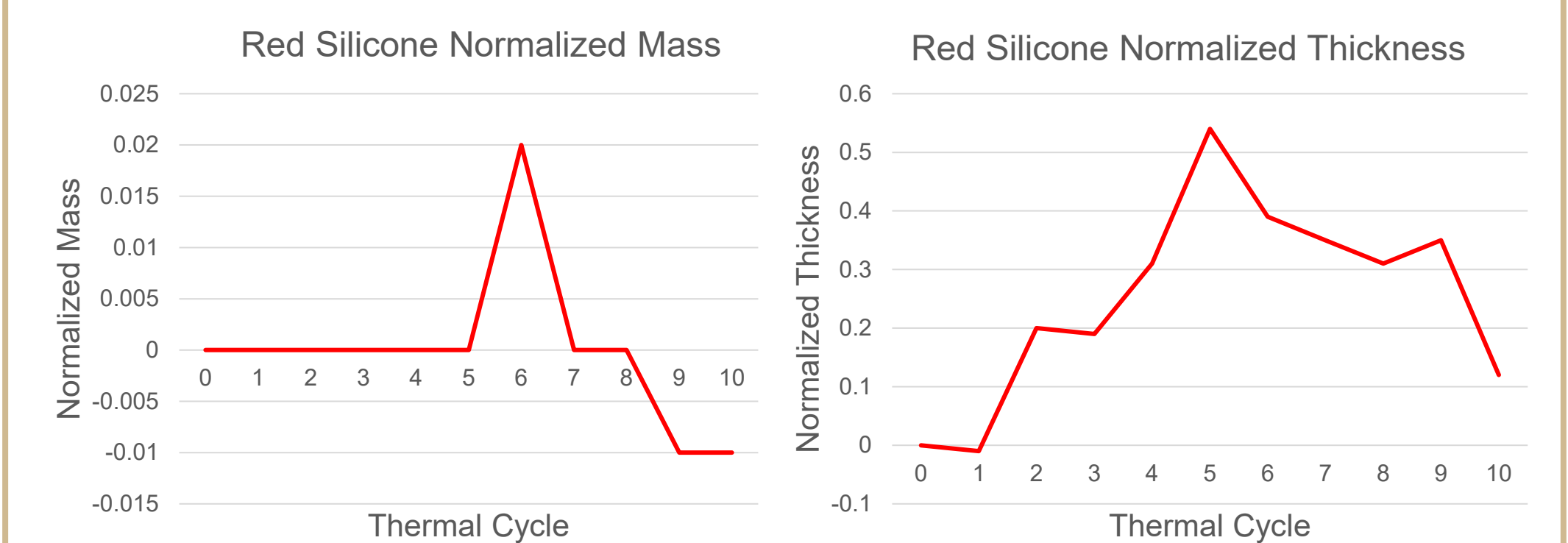
Discussion: The substrates did not indicate chemical or physical change during the entire cycling, reinforcing the conclusion that no apparent chemical reactions took place on the surface of the substrate or mask. No residual material was found on either mask or substrate after cycling. The hardness measurements consequently did not change or vary after 10 thermal cycles. The largest change seen was in the mechanical response for every mask except red.

Recommendation: The Red silicone is the best silicone, due to its superior tensile strength, ductility, and maintained properties after thermal cycling. This silicone's hardness is independent of temperature, and like all the silicones, left no residue or smudging on the substrate materials, YbDs or SiC.

Future Testing: To better understand thermal degradation of silicone masking materials higher temperatures and longer cycles are required. Our specimens experienced 215°C and 250°C for 20 hours. No significant changes occurred in mechanical response between these two temperatures. To simulate the air plasma spray process better, higher heat fluxes and force must be applied the silicone mask while in contact with the substrate materials.



Hardness plots of red silicone for each testing combination. There was low variation in Shore-A hardness values proving consistent hardness measurements for the material throughout testing.



Mass of red silicone sample during thermal cycling. No considerable change seen with a range of 0.03 g. This silicone did not thermally degrade by losing mass. Thermal degradation often is presented by loss of mass and dimensionality with range of 0.6 mm.

Thickness of red silicone during thermal cycling. Due to the soft nature of silicone, calipers may have been less precise due to squishing from caliper pinchers. Still, not noticeable change in dimensionality with range of 0.6 mm.

References

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