Thermal Cycling Rig Design for High Heat-Flux Environment in Ox-rich Turbopump

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I. Motivation

High-pressure, oxygen-rich environments increase risk of a metal-fire in the ox-rich turbopump of a staged combustion rocket engine. A triple-phase composite environmental barrier coating (EBC) has shown to provide resistance to particle-impact ignition, a dominant failure mode in the turbine of these turbopumps.

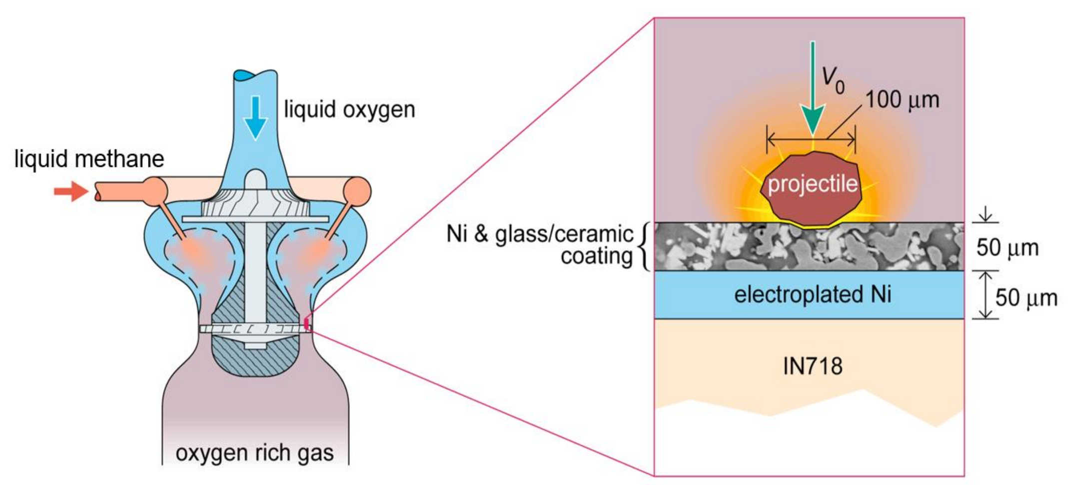


Figure 1: Schematic of an oxygen-rich turbopump assembly.

II. Background

Thermal transients at engine start-up and shut-down can cause the coating to delaminate.

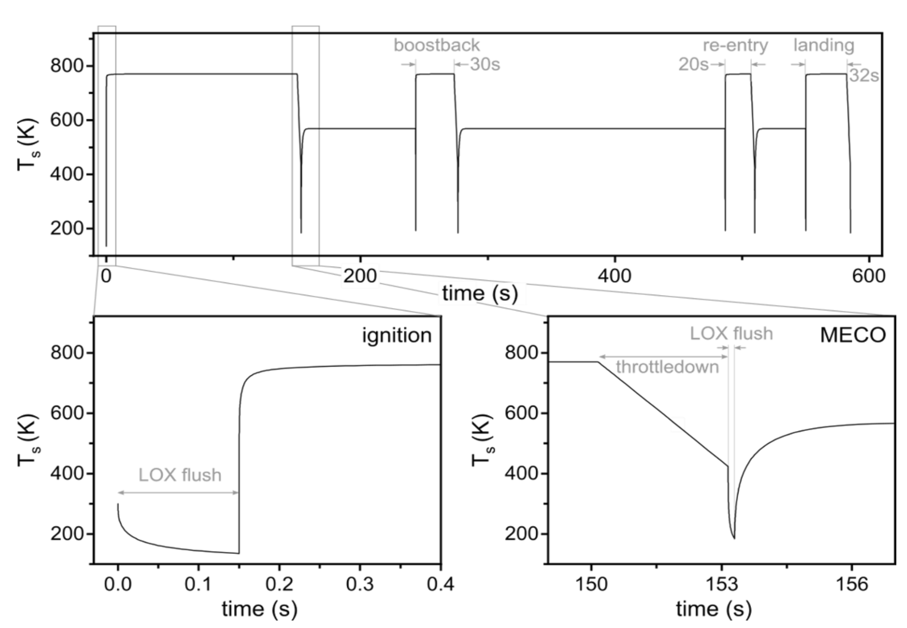


Figure 2: Predicted surface temperature of an EBC-coated surface in an ox-rich turbine of a reusable rocket engine during a single flight.

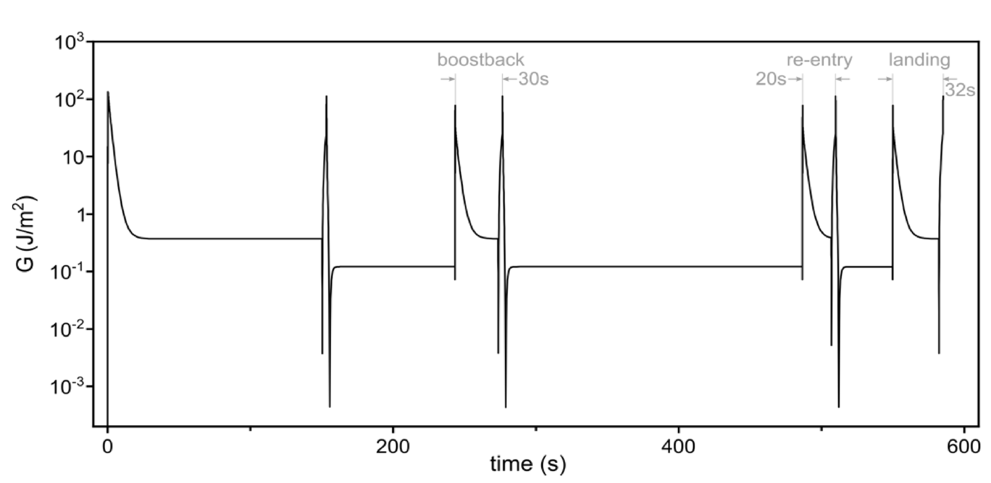
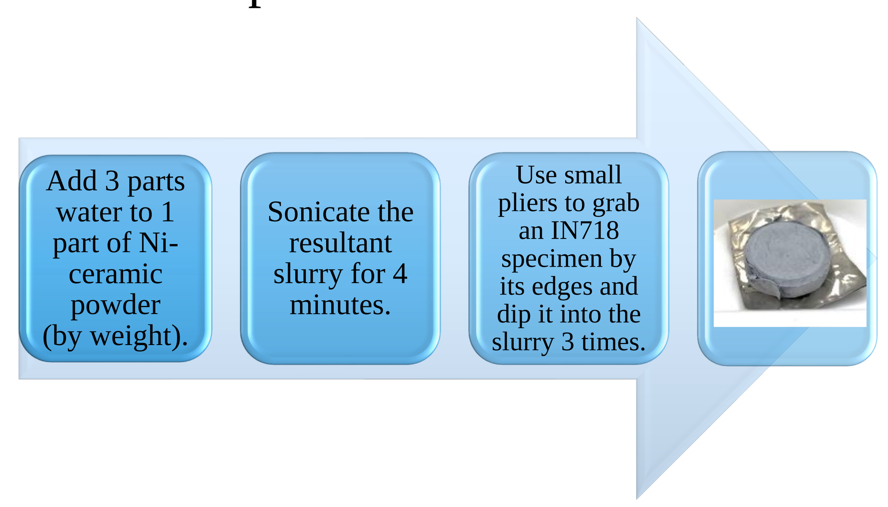


Figure 3: Strain energy release rate for the crack propagation at the interface of the ox-compatible coat and the nickel (Ni) coat during a single flight.

III. EBC Deposition and Preferential Etching

A. EBC Deposition



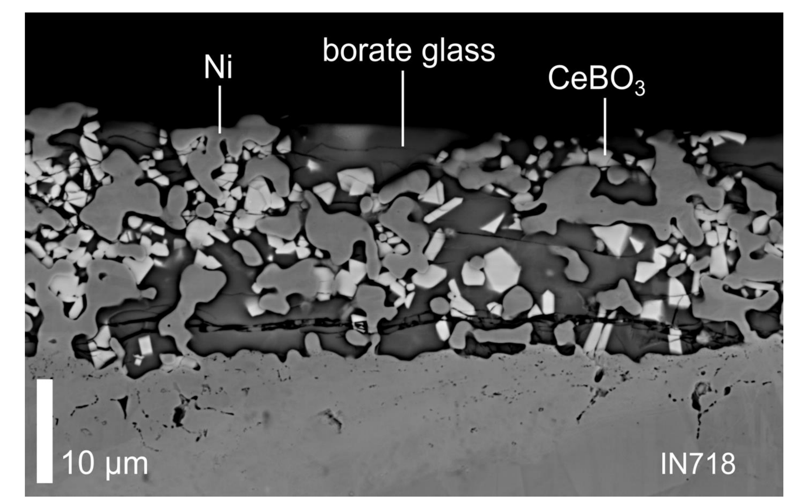


Figure 4: SEM image displaying the constituent materials of the EBC (10 µm thickness).

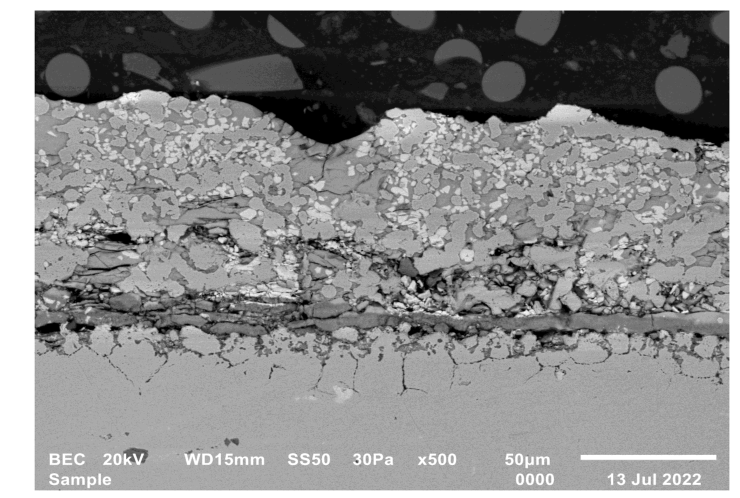


Figure 5: SEM image of IN718 sample after coating deposition (50 µm thickness).

B. EBC Preferential Etching

Step 1	Add 100 mL of distilled water to a plastic bottle.
Step 2	Add 50 g of $FeCl_3$ powder in a separate dry container.
Step 3	Use a plastic spoon to add small portions of the powder into the water bottle.
Step 4	Stir to dissolve the solution as you add more $FeCl_3$ powder.
Step 5	Let the solution cool down and dip the EBC pellet for 96 hours after immersing it in the solution.

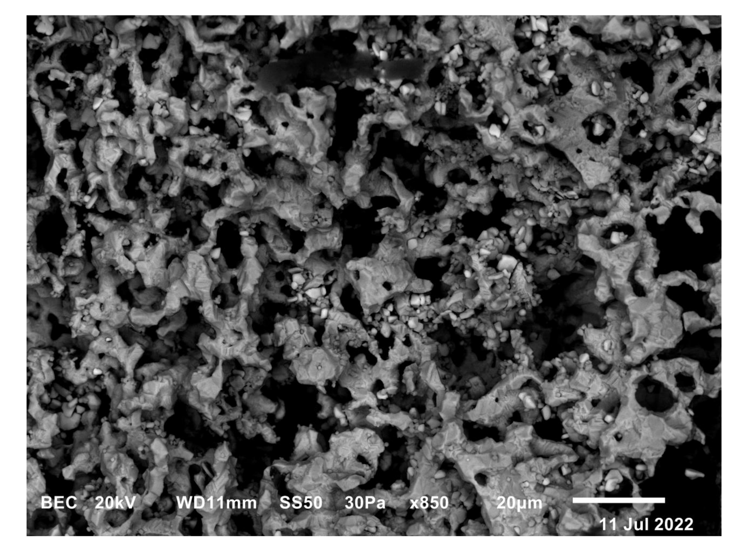


Figure 6: Post-etching SEM analysis shows a self-supporting network of Ni.

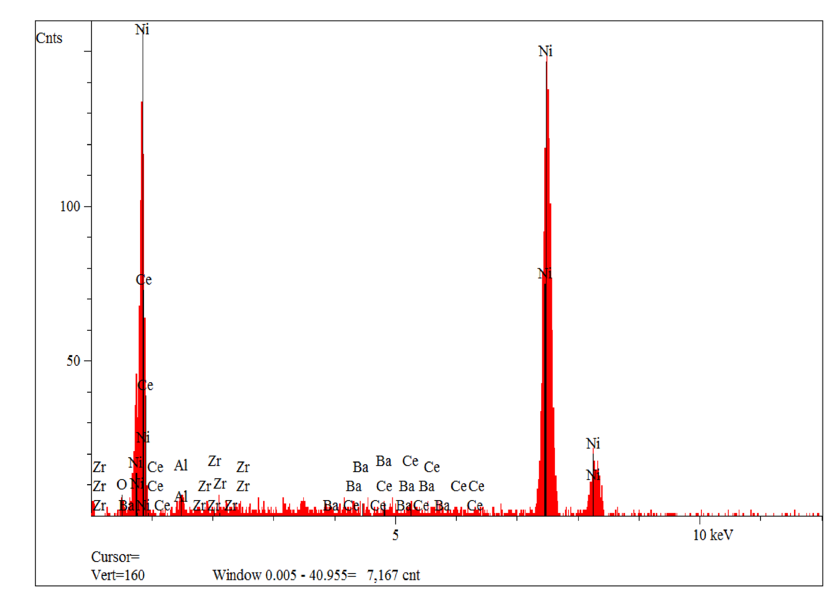


Figure 7: EDS analysis of the etched EBC pellet after using an Iron Chloride ($FeCl_3$) solution.

IV. EBC Thermal Cycling Rig Design

Purpose: Subject an EBC-coated disk specimen to the thermal cycling conditions of a reusable rocket engine.

- The sample, mounted at one end of a tubular steel arm, is rotated between a liquid nitrogen (LN) container and a flame torch.
- Hot flame subjects the sample to a hot-shock that simulates the start-up of the engine.
- LN reproduces cold shock conditions at shut down.
- A step-servo motor and gear-box assembly is used to actuate the rig.
- A programming code specifies the motion profile that replicates rocket engine thermal transients.

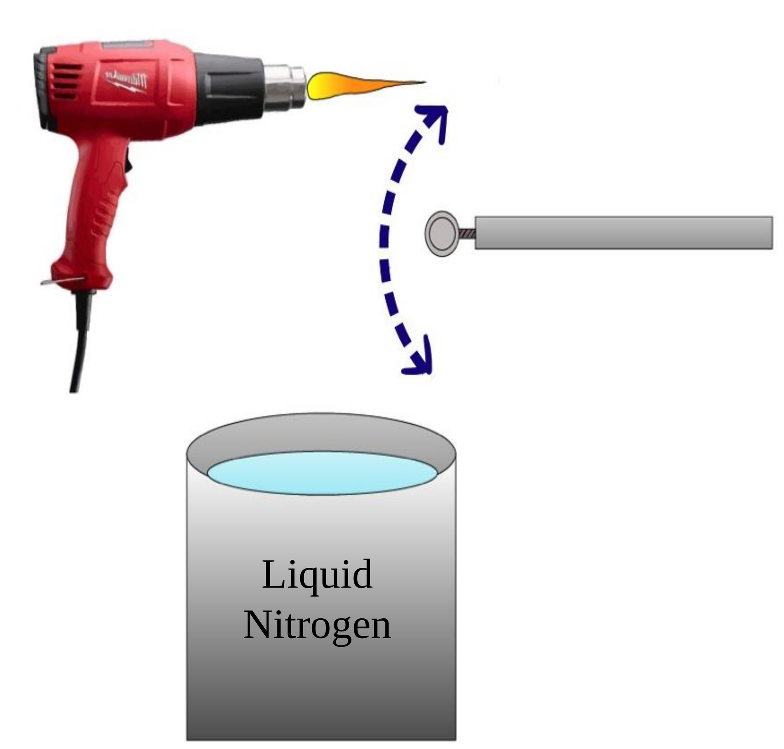


Figure 8: Schematic of the cyclic motion of the thermal shock rig between hot air gun and liquid nitrogen (LN).

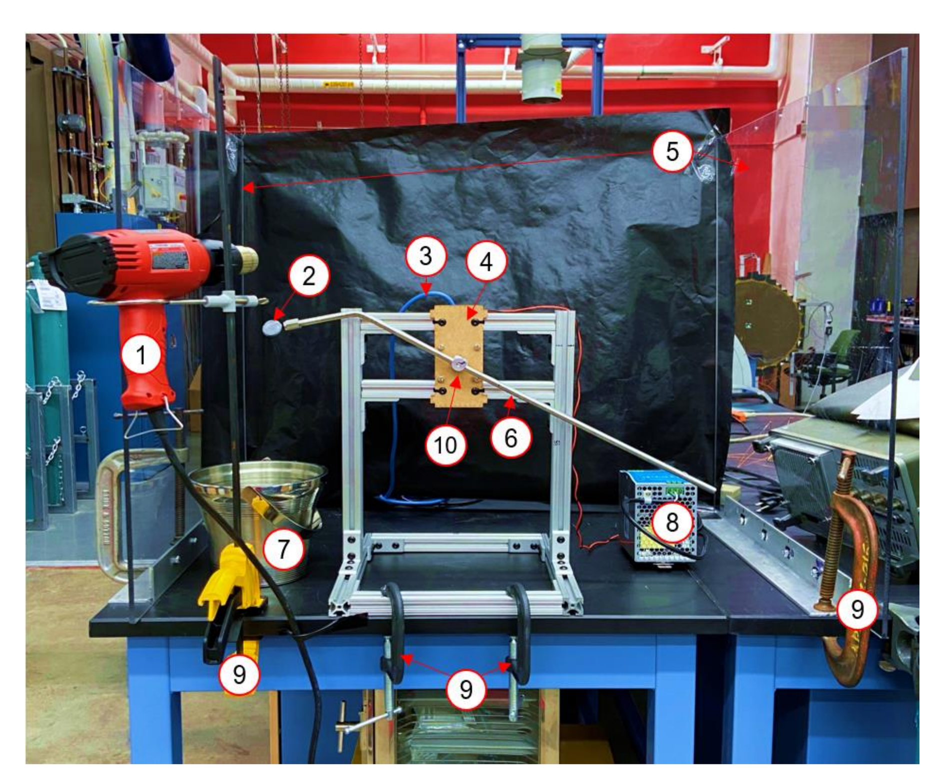


Figure 9: Final setup of EBC thermal cycling rig.

Table 1: Breakdown of components within the thermal cycling rig design shown in **Figure 9**.

Component's number	Name of Component
1	11.6-Amp 120-Volt Dual Temperature Heat Gun
2	EBC-coated IN718 specimen
3	Ethernet cable
4	Mounting board of SSM23IP-2EG Step Motor
5	Polycarbonate protective shield
6	Lever arm (rig)
7	Liquid nitrogen (LN) container
8	NDR-480-48 Mean Well Power Supply
9	Clamps
10	Coupler

V. Conclusions

- Deposited protective EBC of thicknesses greater than 50 μm using multiple coating deposition cycles.
- Interpenetrating phase structure revealed by etching indicates presence of ductile-toughening effect in the EBC.
- Designed a rig to test EBC coated IN718 samples under thermal cycling conditions of a reusable rocket engine.

VI. Future Work

- Conduct thermal shock experiments in the final setup until simulating 1000 flights.
- Install a gear box in the thermal shock rig system in order to fix the inertial mismatch between the motor and the load (rig and EBC specimen).
- Identify the optimal angle and speed to submit the EBC sample into thermal shock.
- Characterize the EBC sample to further assess its performance throughout thermal cycling.
- Identify a method that prevents oxidation between the metal-ceramic-glass composite coating, Ni bond-coat, and IN718 sample.

VII. Acknowledgements

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VIII. References

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