Optimizing the Additive Repair of Turbine Blades Using Directed Energy Deposition

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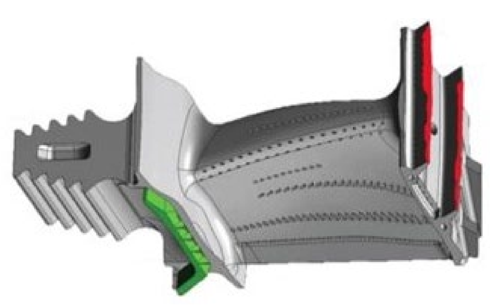
Rolls Royce is developing Directed Energy Deposition (DED) as an additive repair method for their seal fins, which are located on the end of the turbine blades. The base material of the turbine blade and seal fin is a cast and hardened single crystal nickel-based superalloy, CMSX-4, and the additive material is IN718 – RAM3. Our project focuses on the effect of the DED process parameters on the properties of the repaired part. We conducted hardness tests, wear tests, optical microscopy, and SEM on the samples with various laser scan speeds and powers. In the ranges studied, we found that the samples with a higher power and middle to lower speed provided the best additive deposition because they had the highest hardness (over 20 HRC), no significant structural flaws, and were near the sample with the lowest wear rate.

This work is sponsored by Rolls-Royce

Background

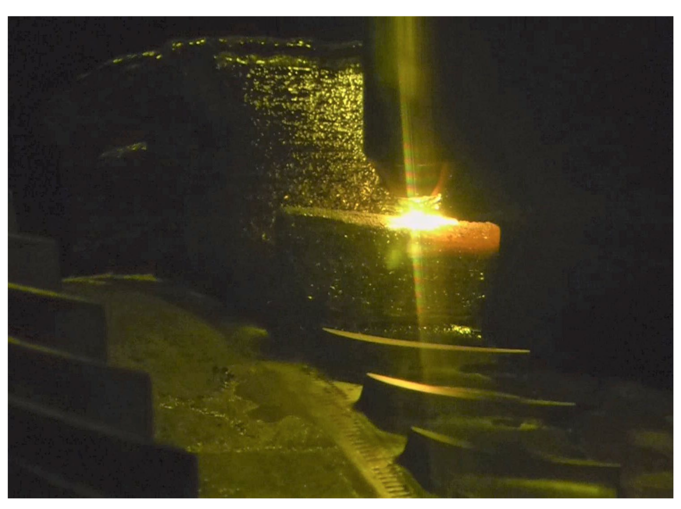
Problem

Tips of CMSX-4 turbine blades wear during use, which decreases engine efficiency



Proposed Solution

Use Directed Energy Deposition (DED) to replace worn material



Directed Energy Deposition

Additive manufacturing process used to selectively add material onto an existing part

Repair Material

Powdered nickel superalloy, IN718–RAM3, which uses an in-situ chemical reaction to form a Metal Matrix Composite

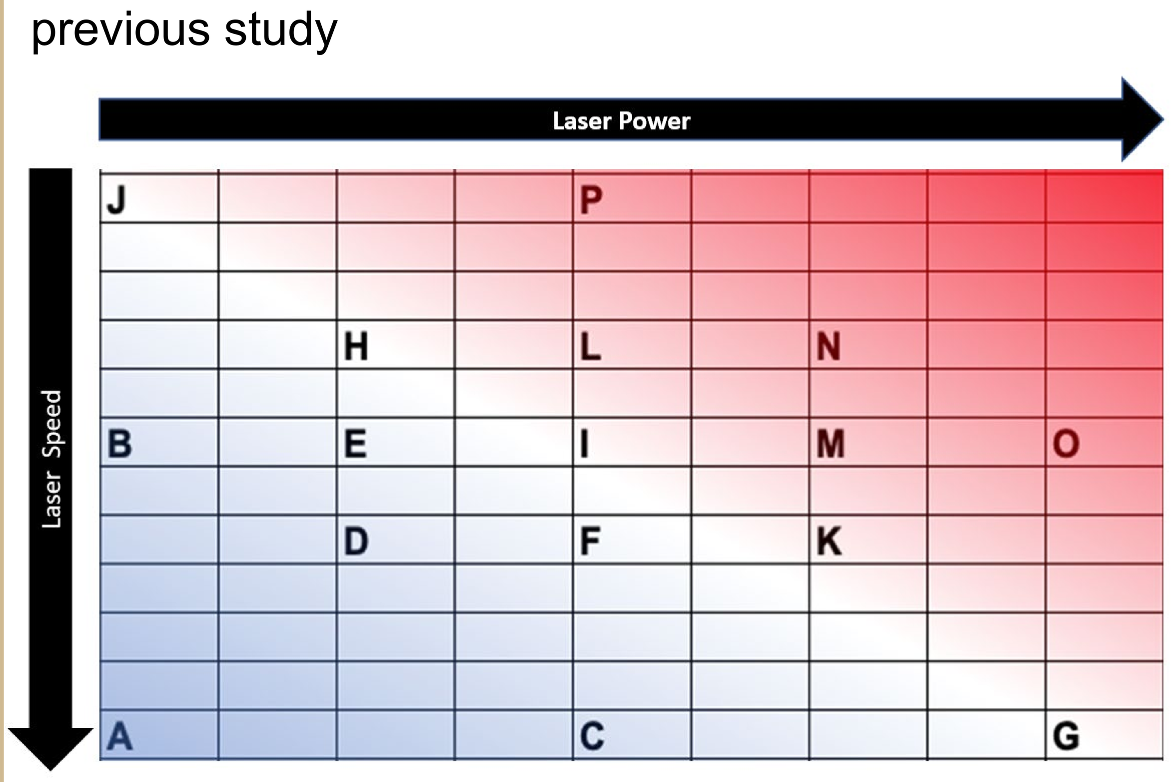
Goal of the Project

Determine which heat parameters provide the best additive build by varying the laser power and speed

Samples

Selection

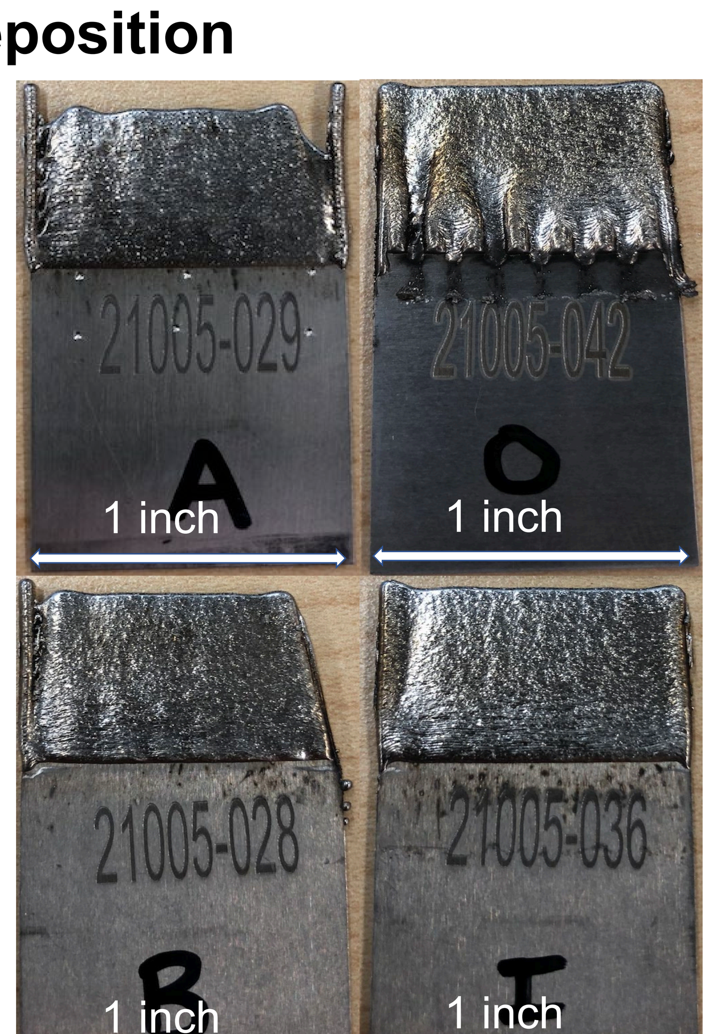
Samples were deposited at various power and speed values. Case I is the baseline case, suggested from a previous study



Variations in Deposition

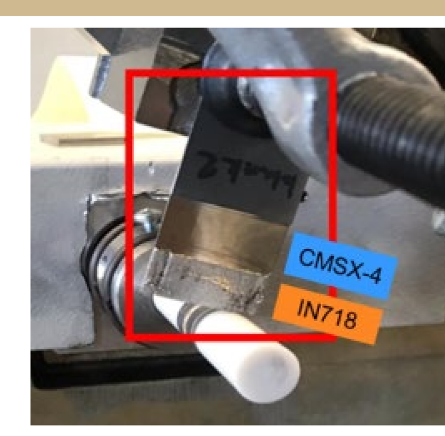
The process conditions produced different structures, with defects such as horns (in A) and waves (in O)

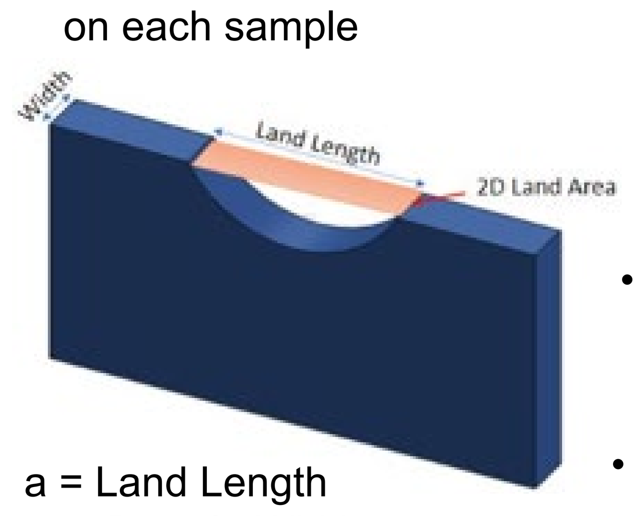
The samples were then subjectively ranked from best to worst build based on these characteristics



Wear Testing

- Coupons worn with a ceramic rod at a specified load
- Two wear tests were performed on each sample

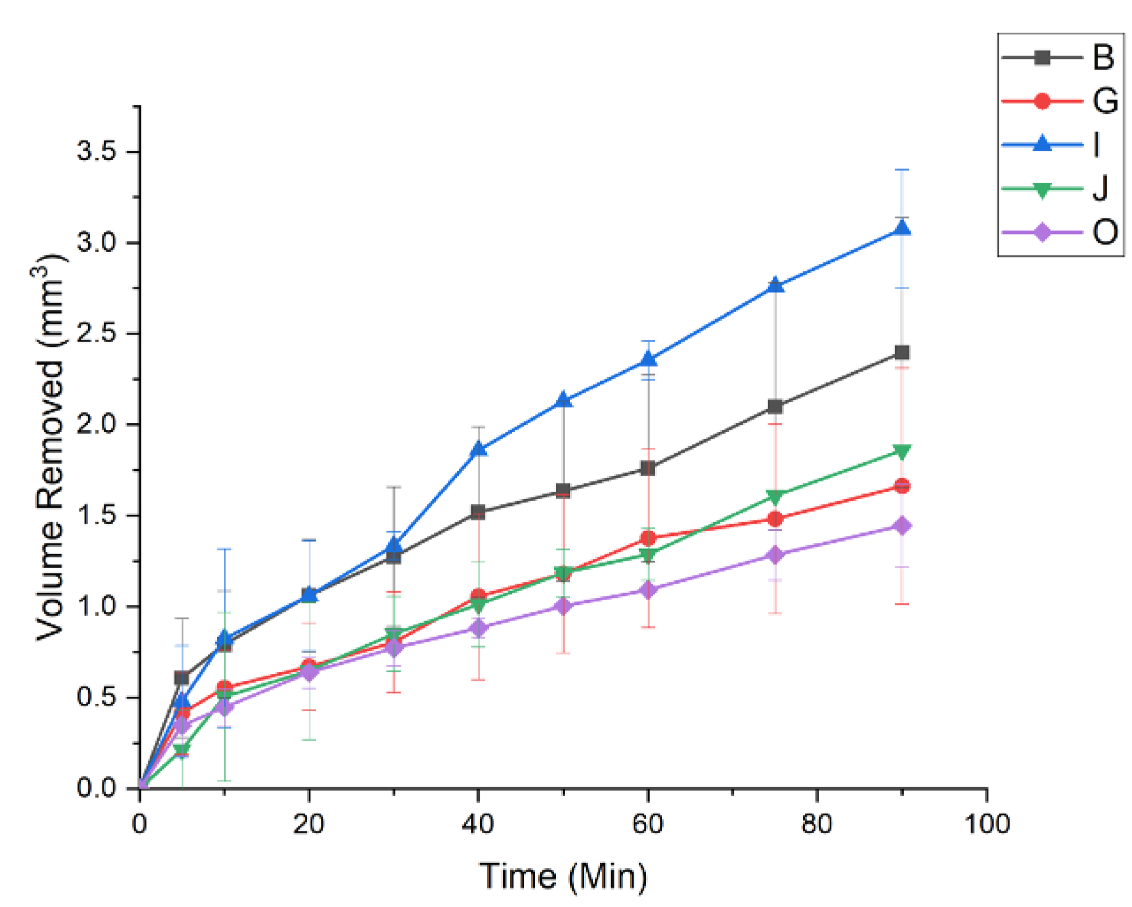




- Land length was measured periodically during each 2-hour test
- Worn volume calculated from measured land length and width

a = Land Length
w = Sample Width
R = Ceramic Rod Radius

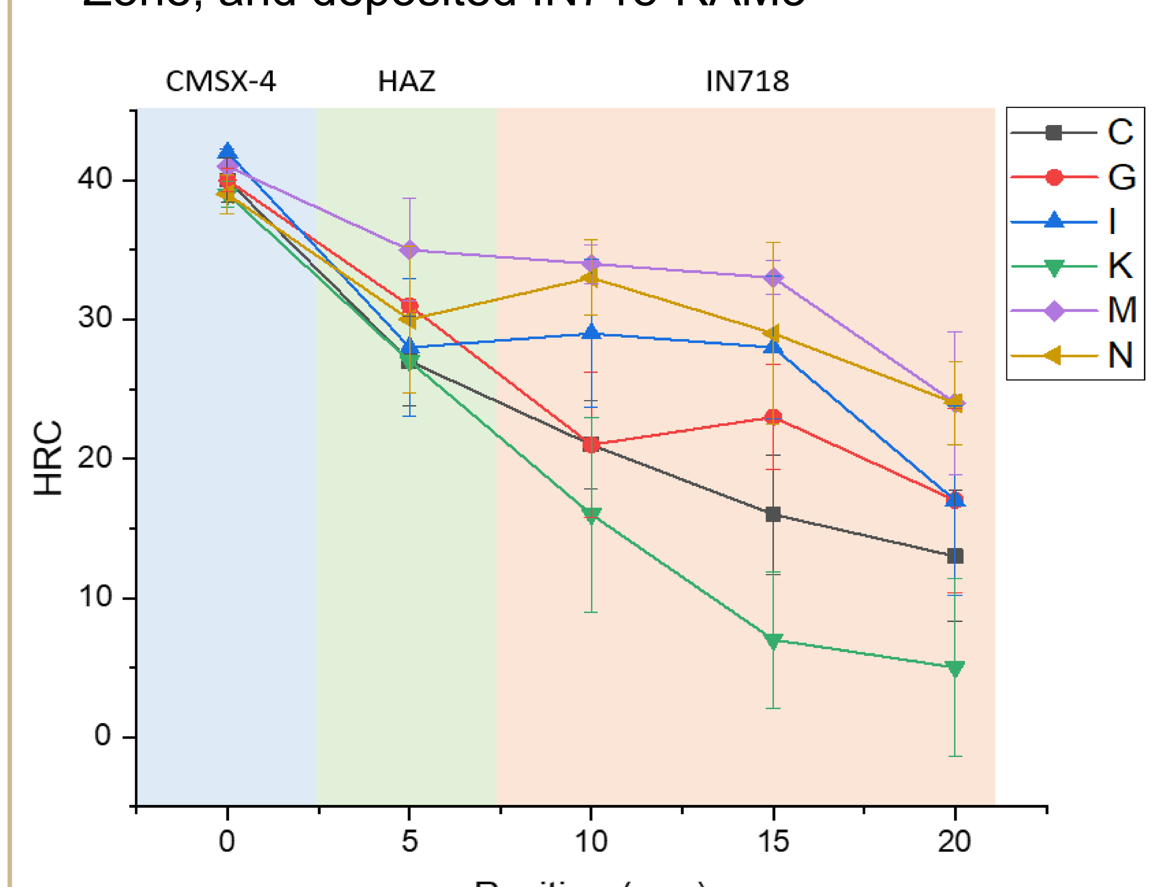
$$Volume\ Removed = w\left[\frac{1}{2}R^2\left(\sin^{-1}\left(\frac{a}{2R}\right) - \sin\left(\sin^{-1}\left(\frac{a}{2R}\right)\right)\right)\right]$$



- The wear rate was fastest at the beginning of a test and decreased over time
- Sample O displayed the best wear resistance
- No statistically significant relationship between heat parameters was found

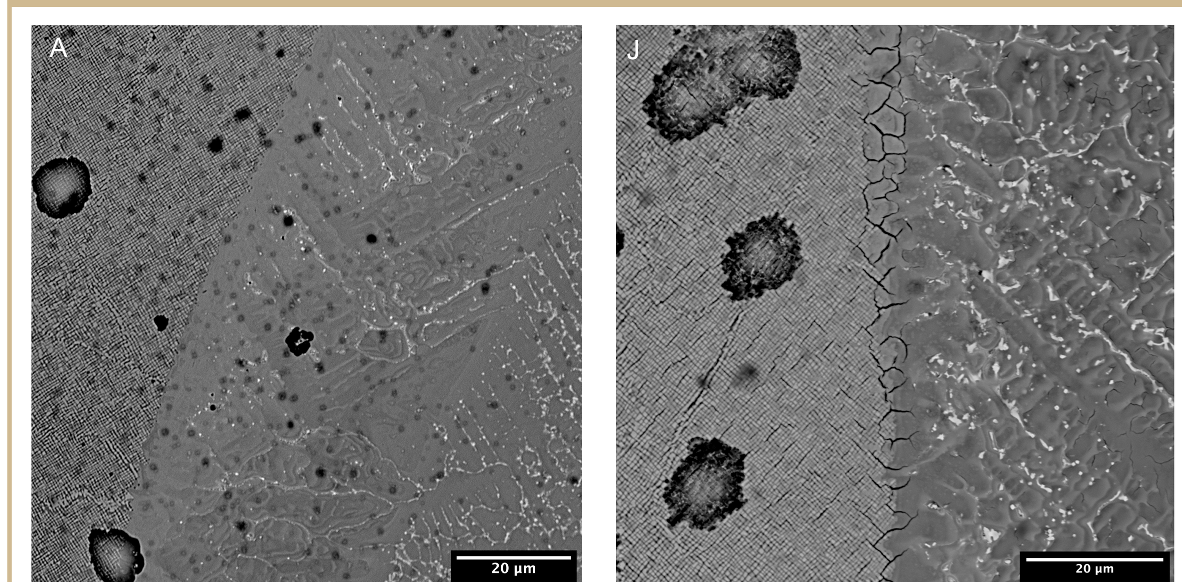
Hardness Testing

- Hardness profiles (HRC) were taken near the repair interface, through CMSX-4, Heat Affected Zone, and deposited IN718-RAM3

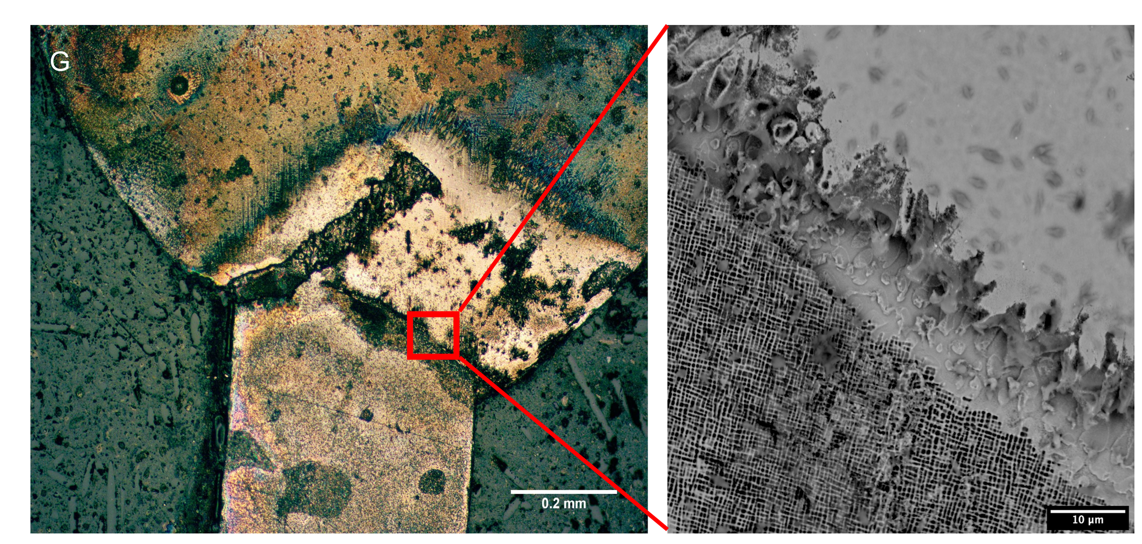


- Sample M had the highest hardness values
- The top of the IN718-RAM3 build showed the lowest hardness values across all samples
- Hardness decreases in the HAZ as the heat from the deposition affects the single crystal microstructure

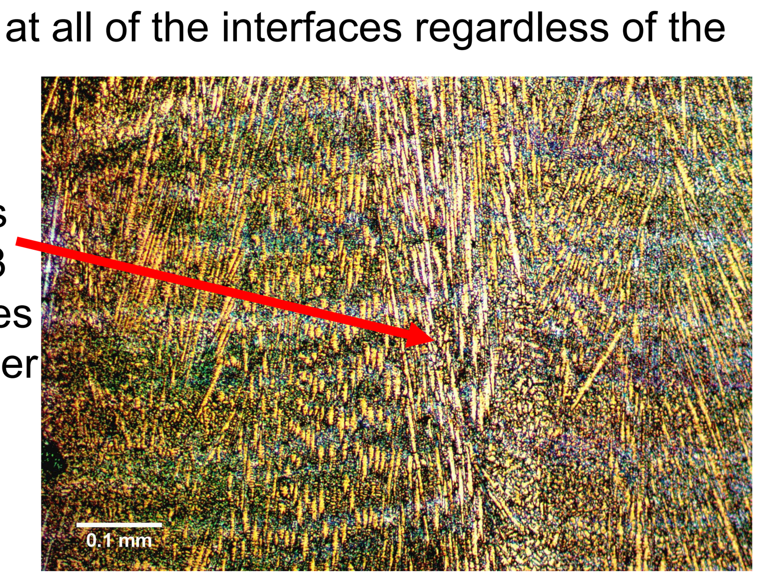
Microstructure



- Sample A has minimal cracking compared to the abundance of cracks all along the interface in sample J
- More pronounced cracks and other defects are observed at the IN718-RAM 3 & CMSX-4 interface as the overall heat input increases



- Porosity was found at all of the interfaces regardless of the heat parameters



- All samples show columnar dendrites in the IN718-RAM3
- Size of the dendrites increase as the laser speed decreases

Recommendations

Desired: high hardness, low wear, and low build defects

- Samples N & M show the best results, as they have the highest hardness values, few or no structural defects, and are near the sample with the lowest wear (O)
- Compared to the base case (I), increasing power and having the same or lower speed provides better deposition

References

- The Jet engine (5th ed.). (1986). Rolls-Royce.
- Farnell, Mackinzie, et al. Purdue University, West Lafayette, IN, 2021, *Directed Energy Deposition of Dissimilar Metals for Repair of Gas Turbine Engine Blade Tips.*