# Directed Energy Deposition of IN 718 for Turbine Blade Repair

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Blade tips in gas turbine engines wear during use, decreasing the engine efficiency and increasing cost and fuel consumption. Our goal is to investigate the repair process for these blades using directed energy deposition (DED). For the repair, we test IN718 with 0, 1, and 3% ceramic reinforcement with high power and low power DED parameters. We characterize the process using optical microscopy, hardness measurements, tensile testing, and wear testing. We do not see differences in microstructure at different reinforcements, but we find evidence that 3% ceramic reinforced material is harder and stronger than 0 and 1% reinforced material.

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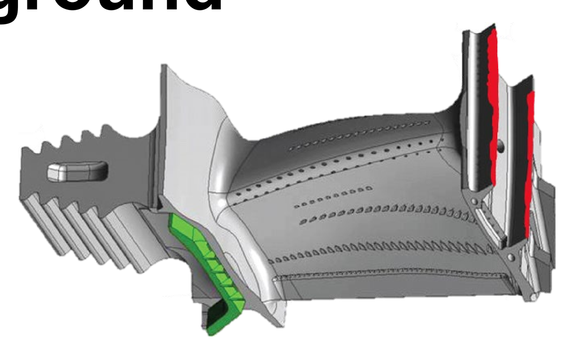
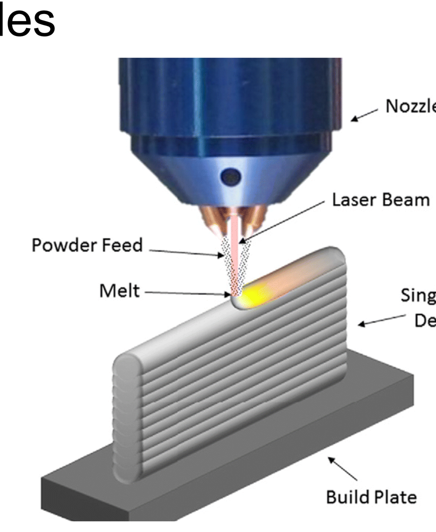
## Project Background

- Single crystal CMSX-4 blade tips wear in use, decreasing engine efficiency

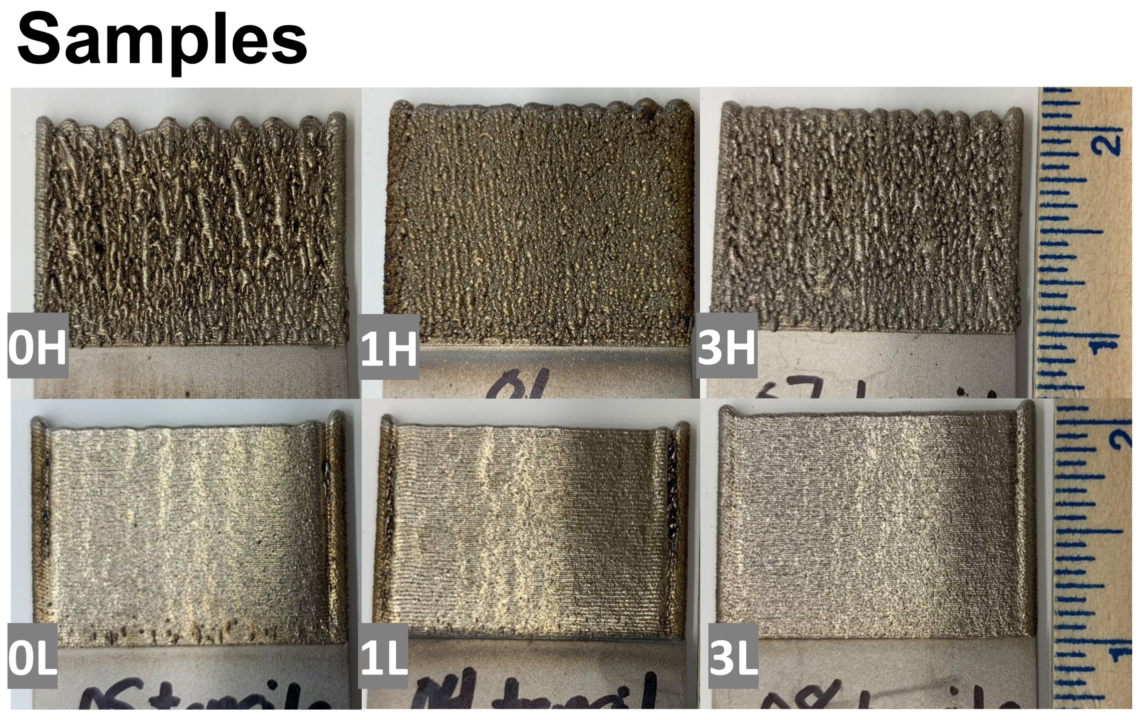



- Replacing blades is costly, motivating an interest to repair with Additive Manufacturing (AM)
- **Approach:** Use directed energy deposition of IN718 to repair turbine blades
- **Directed Energy Deposition:** AM technique often used to add material to an existing component, simultaneously melting and depositing material[1]




- **Material for Repair:** Nickel superalloy **IN 718**
- **Metal Matrix Composites:** adding ceramic particles to metals can improve hardness and wear resistance

## Samples




Printed samples. **0, 1,** and **3** refer to **% reinforcement**. **L = low-power sample; H = high-power sample**

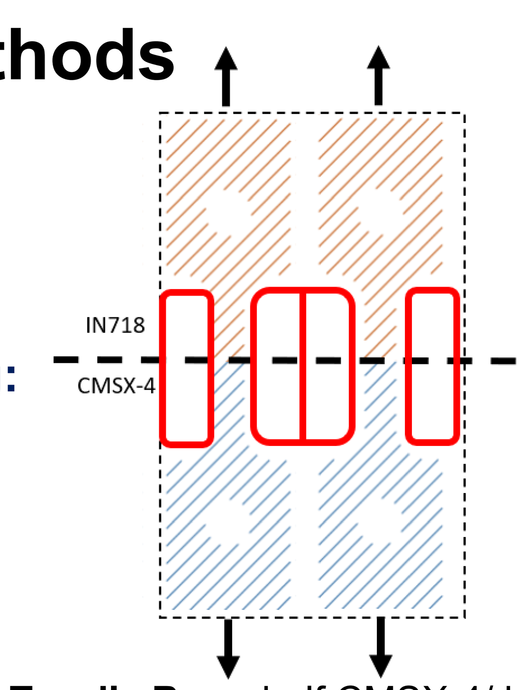
- Samples printed at lower power have more visible build lines and smoother surfaces
- Samples printed at higher power have more surface roughness and porosity through the thickness

## Experimental Methods

**Optical Microscopy**: analyze microstructure of samples

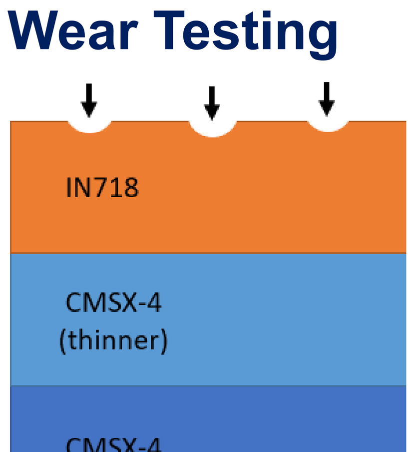
**Vickers Hardness Testing:** understand mechanical properties

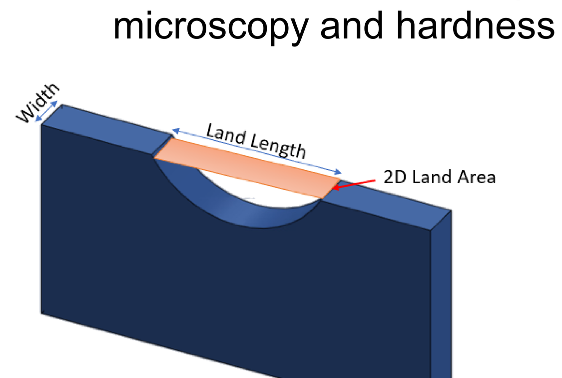
**Tensile Testing**: analyze interfacial strength




**Tensile Bars:** half CMSX-4/ half IN 718; red box used for optical microscopy and hardness

### Wear Testing

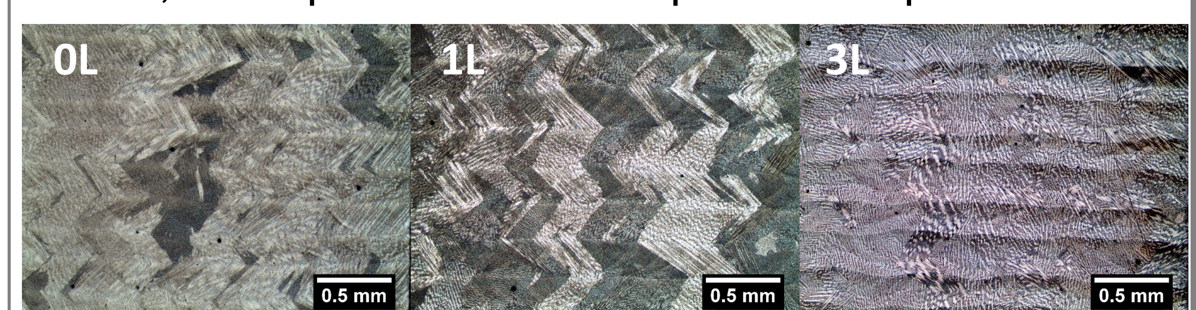


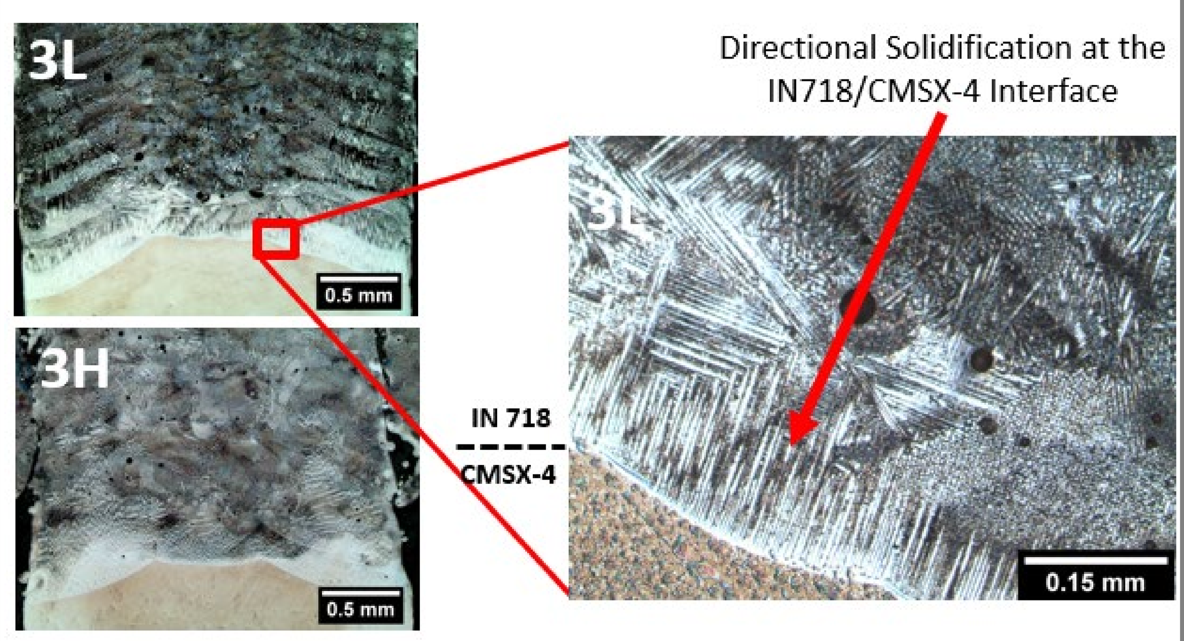

2D land area (land length x width) was used to normalize the data

## Microstructure

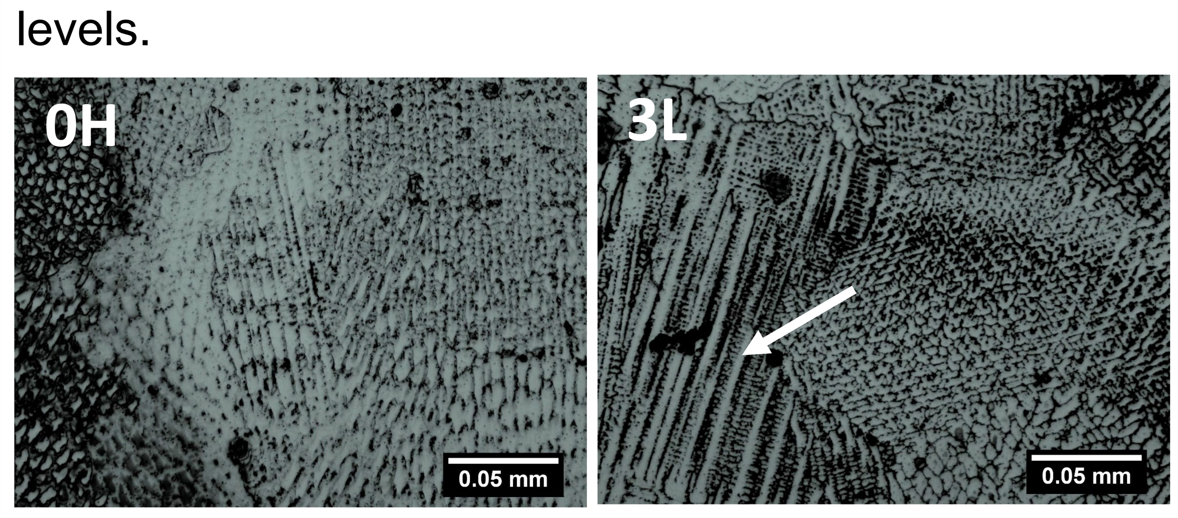
- Zig-zag pattern observed on face of DED printed IN 718; more prominent in low-power samples




- Optical microscopy of cross section showed a remelt region at the interface
- This region was larger in low-power samples and showed directional solidification



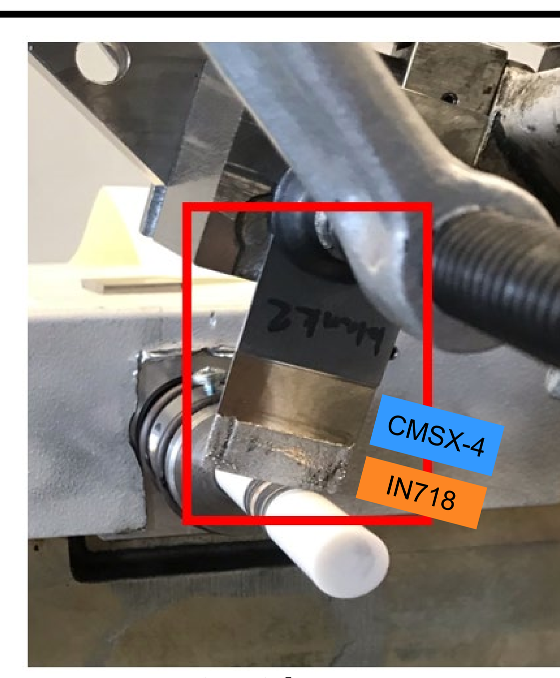

All samples showed columnar dendrites, with varying orientation. There were no significant differences in microstructure among each reinforcement and power levels.



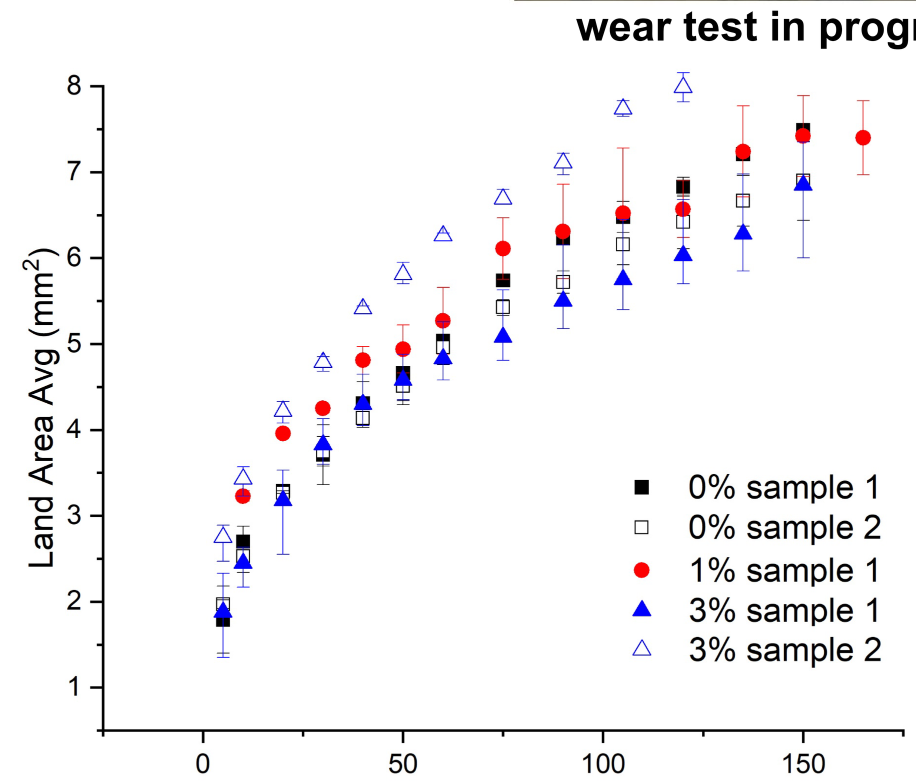

The average secondary dendrite arm spacing was 1.67 microns.

## Wear Testing

- 3 wear tests for each sample
- Samples worn with a ceramic rod
- No apparent correlation between % proprietary ceramic reinforcement and rate of wear

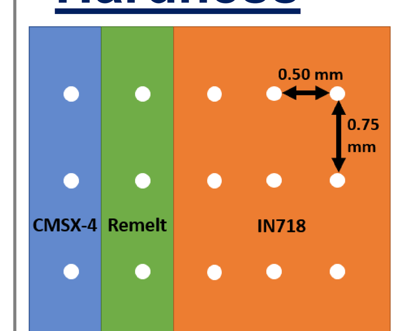



wear test in progress

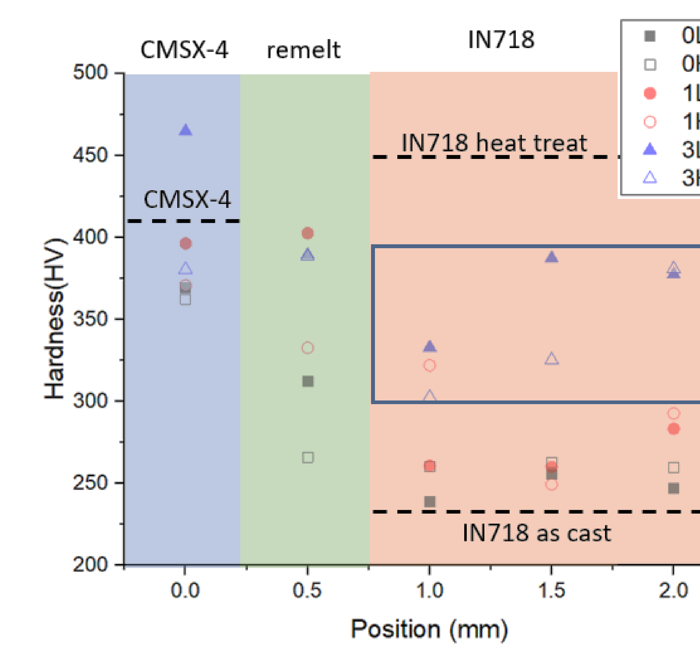



## Mechanical Properties

### Hardness

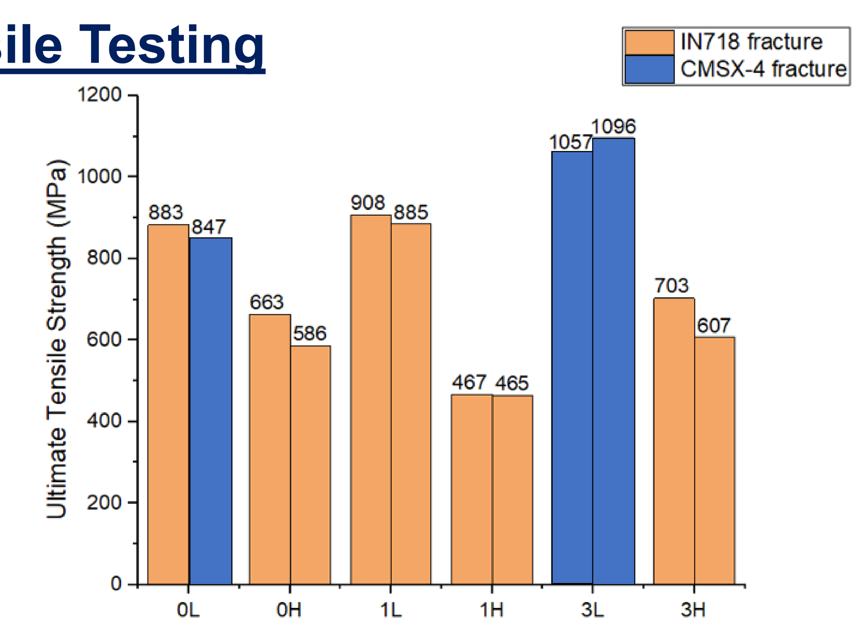



hardness indent locations in cross section of samples



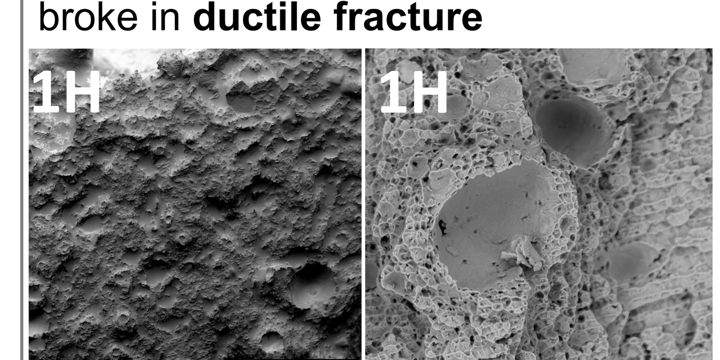

- Hardness of CMSX-4 is lower than handbook value[2]
- **3% reinforcement** samples had higher hardness
- Samples printed at **low power** generally had higher hardness than high-power samples

### Tensile Testing

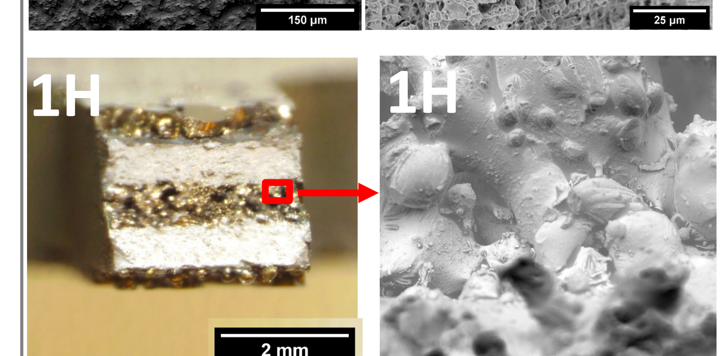



- No samples broke directly at interface, indicating bonding as strong as alloys themselves
- **3L** samples both broke in **CMSX-4**, indicating the 3% IN 718 material was stronger
- Low-power consistently stronger than high-power

Scanning Electron Microscopy (SEM) revealed that all samples broke in **ductile fracture**




**IN 718 Fracture**
**Left:** smooth, round indentations indicate porosity, likely the cause of fracture
**Right:** dimpling indicates ductile fracture




**Structure for 1H and 3H fracture surfaces**
**Left**: lack of cohesion in the center region; smaller cross-sectional area results in lower fracture strength
**Right**: SEM of porous region

## Recommendations

- Print at lower power parameters – the samples printed at lower power had both better hardness and tensile strength
- Continue investigating 3% reinforcement – this may be stronger and harder
- Do not investigate 1% because it was similar to 0%
- Use other characterization methods to search for ceramic particles and investigate remelt section with SEM/EDS

## References

1. Guan, X., Zhao, Y.F. *Int J Adv Manuf Technol* **107**, 1959–1982 (2020).
2. Aluru, R. Gale, W., et al. *Mater. Sci. Technol.* **24** 517-528 (2008).