Performance Characterization of Additively Manufactured Turbine Repair Components

PURDUE UNIVERSITY

Materials Engineering

Analiese Long, Rachel Nederhoed, Adam Smith, Sam Inman

Faculty Advisors: Prof. Michael Titus

Industrial Sponsors: AIM-MRO: Ben Foster and Brian Frazier, GE Aviation: Michael Andersen

Brazing repair of turbine engine components is a significantly less expensive alternative to outright replacement. Braze repair material is currently tape cast (TC), which limits the geometries able to be repaired. However, a method of additive manufacturing (AM) would allow for increased complexity given that these components behave in the same manner as their TC counterparts in application. Powder blends of cobalt and nickel based superalloys were analyzed to compare the properties and thus anticipated behavior of TC and AM alloys.

This work is sponsored by AIM-MRO and GE Aviation, Cincinnati, OH

AIM MRO GE Aviation

Project Background

Super-alloys mixed with braze powders will contain phases that melt at slightly lower temperatures, allowing for components to form alloyed interfaces with base metals. This is an efficient and cost effective repair method. The braze alloys studied in this project are a Ni-based Superalloy (NBS) and a Co-based Superalloy (CBS) blended with a high temperature MPS alloy.

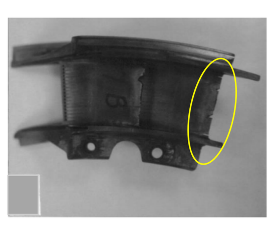

Figure 1: High pressure turbine nozzle in need of repair

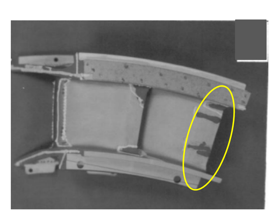

Figure 2: Repaired turbine braze part

Repair components are currently tape cast (TC) as shown in Figure 3, which limits complexity, but is a more efficient and well understood process. Binder Jet additive manufacturing (AM) is a powder based 3D printing method that uses liquid binders and a post printing sintering cycle, reducing internal stress and allowing for increased complexity demonstrated in Figure

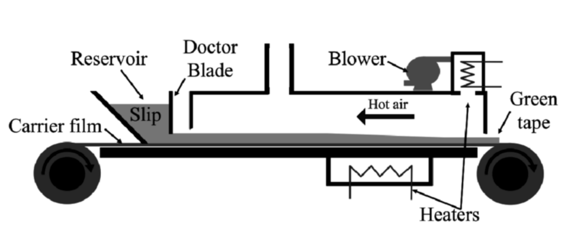

Figure 3: Tape Cast (TC) method.

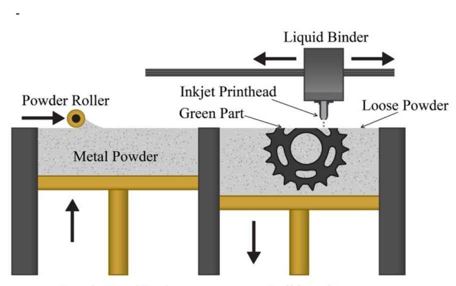

Figure 4: Additive Manufacturing (AM) method.

Additive and cast NBS and CBS samples were analyzed for mechanical, compositional, and microstructural similarities and variations to develop a comprehensive profile and behavioral prediction of additively manufactured repair components.

Experimental Procedure

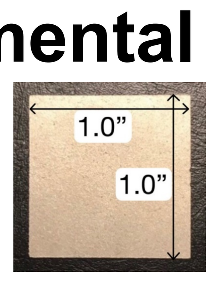

Figure 5: Sample coupon received from company sponsors.

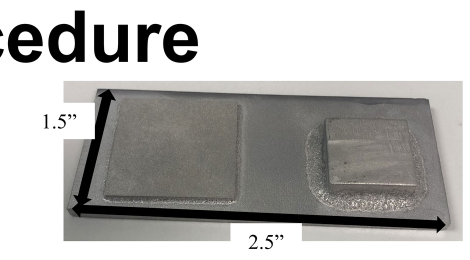

Figure 6: Sample brazed with TC and AM pieces received.

Density

- Bulk density measured with calipers
- Apparent density measured with Archimedes method

Hardness

- 100 gram load
- Brazed samples 15 randomly spaced indentations
- Non-brazed indentations systematically split at 200 μm

Scanning Electron Microcopy (SEM)

- Energy Dispersive Spectroscopy (EDS) determined spot chemistry of microstructure
- Analyzed with ImageJ to determine porosity

Glow Discharge Spectrometry (GDS)

- LECO 850 A
- Three burns in three locations for two of each sample

Differential Scanning Calorimetry (DSC)

- 400 °C to 1400 °C ramp, 1 hour hold, reverse ramp

Acknowledgements

The team would like to thank the following, without whom our work could not be complete:

- Mark Gruninger: Purdue MSE Industrial Consortia
- David Brice and Matt Binkley: Purdue MSE
- Haynes International for providing GDS standards

Results

Mechanical Properties

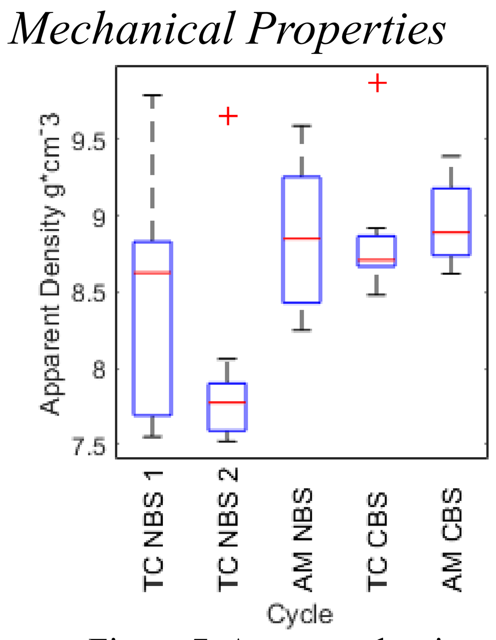

Figure 7: Apparent density

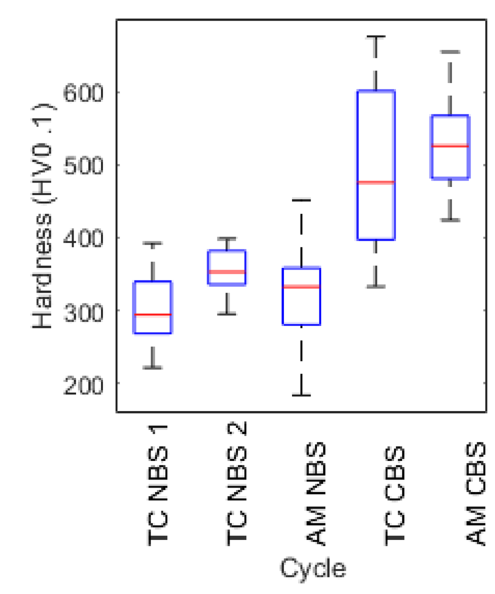

Figure 8: Vickers Microhardness

Deviations between processing methods are of similar magnitude to deviations between sintering cycles of the same for both hardness and density.

Scanning Electron Microscopy

The pie charts below (Figures 11 and 14) summarize the composition of two main phases present in Figures 9, 10, 12, and 13. The two phases analyzed are the light particles and the dark background matrix.

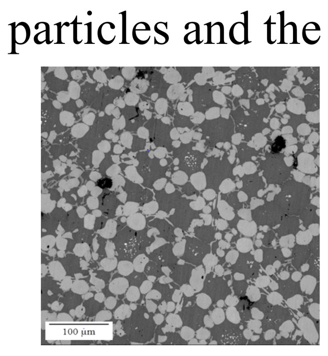

Figure 9: CBS TC image taken with SEM.

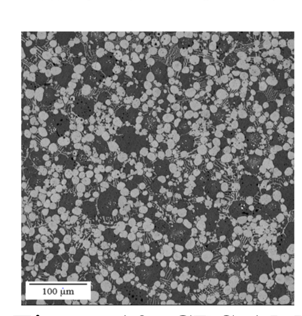

Figure 10: CBS AM image taken with SEM.

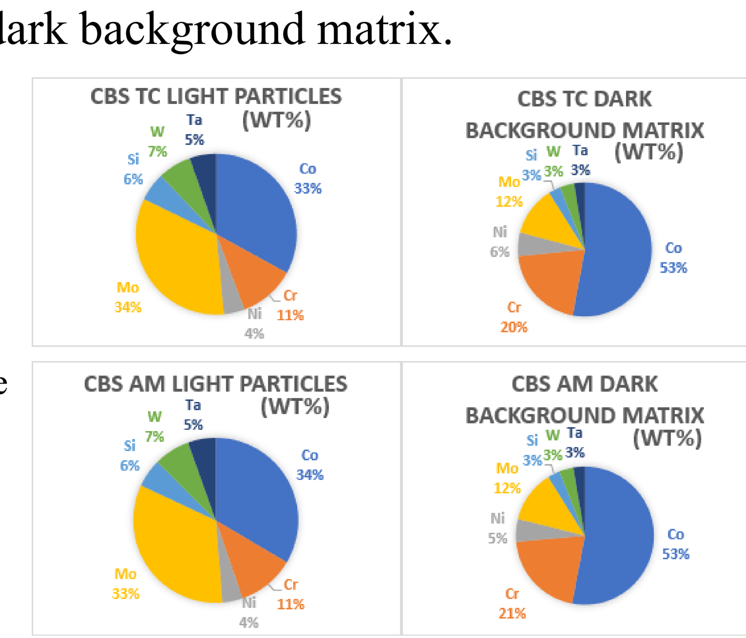

Figure 11: Spot chemistry breakdowns from the EDS for CBS TC and AM. Both the lighter particles and the dark background matrix were analyzed.

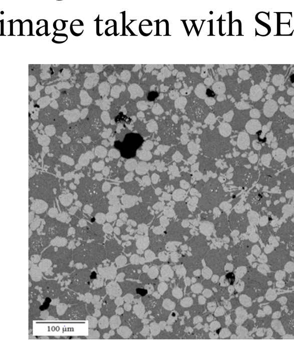

Figure 11: NBS TC image taken with SEM.

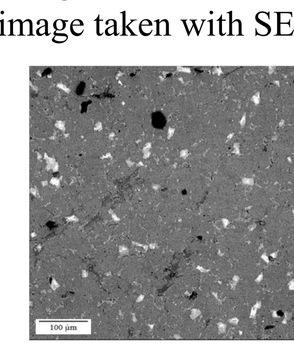

Figure 12: NBS AM image taken with SEM.

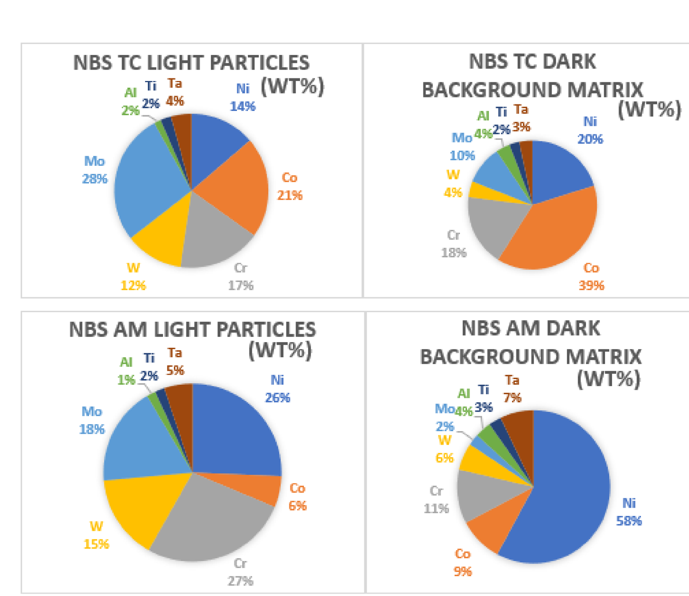

Figure 14: Spot chemistry breakdowns from EDS for NBS TC and AM. Both the lighter particles and the dark background matrix were analyzed.

Porosity

Porosity increased from TC to AM for both alloy types.

Table I: Porosity (%)

Sample	NBS	CBS
TC	1.57	0.68
AM	1.98	0.77

Glow Discharge Spectrometry

NBS exhibited a statistically significant increase in carbon content and increased variation across processing methods (from TC to AM). In contrast, CBS exhibited a non significant decrease in carbon content and decreased variation.

Table II: Carbon Content (wt. %)

Sample	NBS	CBS
TC	0.334 ± 0.043	0.354 ± 0.146
AM	0.392 ± 0.074	0.284 ± 0.013

Brazed Mechanical Properties

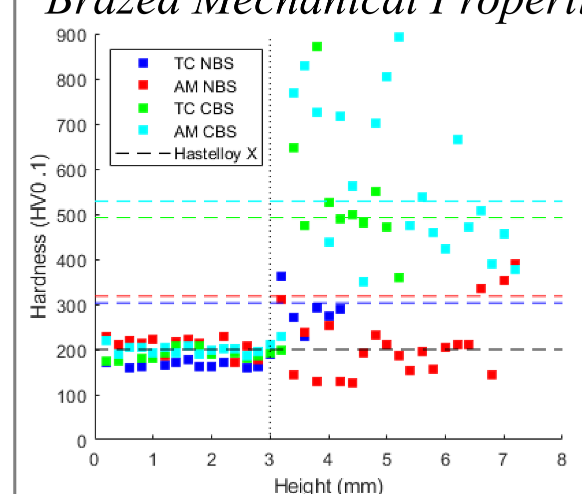

Figure 15: Brazed microhardness with corresponding non-brazed sample means and interface location

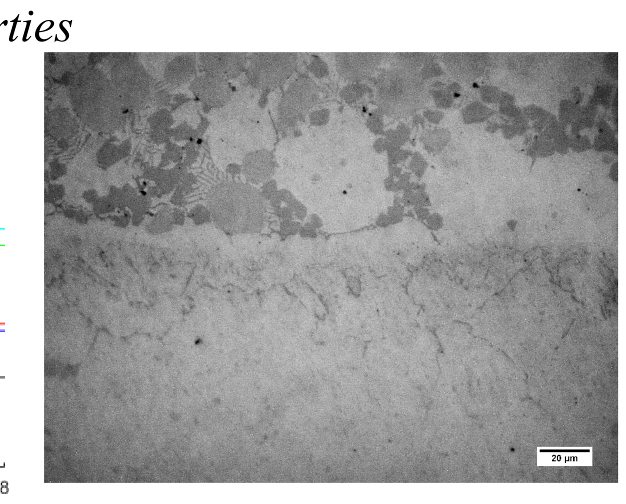

Figure 16: CBS (top) brazed to Hastelloy X (bottom) interface under optical microscopy

For brazed samples of both samples and processing methods, there was significantly more scatter with no directional trends beyond the interface seen at approximately 3 mm.

Brazed Differential Scanning Calorimetry

DSC scans are shown in Figure 17. An extra phase exists in the TC NBS that appears absent in the AM NBS, but onset melting temperatures are comparable between TC and AM processes.

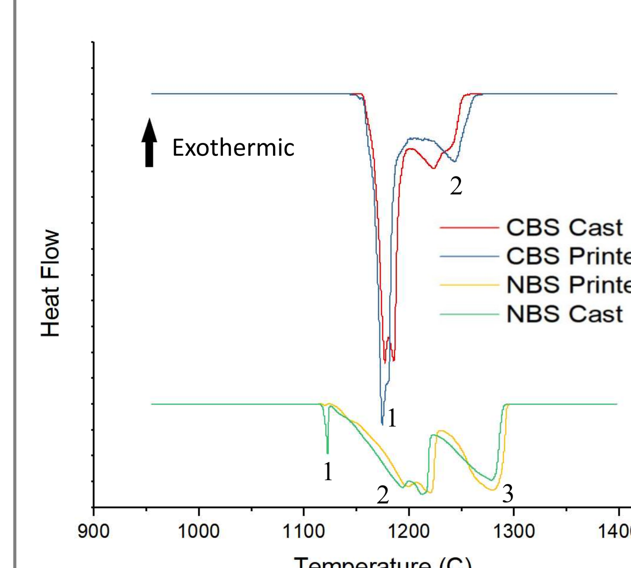

Figure 17: CBS (top) and NBS (bottom) heat flow as a function of temperature

Table III: Onset melting temperatures (ºC) of NBS and CBS.

Alloy System		Peak 1	Peak 2	Peak 3
CBS	TC	1154	1165	-
	AM	1154	1161	-
NBS	TC	1110	1135	1219
	AM	-	1109	1222

Discussion

- Deviations of similar magnitude suggest hardness and density of both AM alloys to be in the previously established control range
- Besides disparity at the interface, there was no significant trend in hardness. This suggests all effects of brazing diffusion occur within the 200 micron test spacing, as confirmed by Figure 16
- For all sample types, the non-brazed samples and brazed regions had similar hardness distributions
- CBS (both AM and TC) consisted of phases of similar composition
- TC CBS displayed a slightly depressed melting temperature
- AM and TC NBS exhibited much larger variation in microstructural chemistry
- Comparable C content and reduced variability in the AM CBS suggests improved process control
- Increase in wt. % C and increased variation, as well as a change in the number of phases present suggests that AM NBS may not behave in the same manner as its cast counterpart

Recommendations

- Inconsistencies within the NBS analysis suggest the AM process requires additional testing prior to implementation.
- AM CBS is anticipated to behave in similar manners as TC due to any variation being within the parameters established by the TC process.