Optimizing the Post-Processing of Additively Manufactured Parts

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Introduction

The AMW on Greenville Campus

▪Greenville Advanced Manufacturing Works uses additive manufacturing for complex components

▪Process development on current processes for UTSR

GOAL: Determine efficacy of and improvements to post-processing techniques of additively manufactured parts

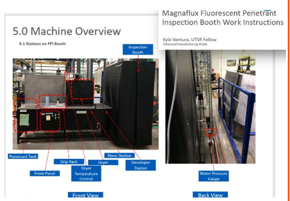
Fluorescent Penetrant Inspection

▪Setting up a Fluorescent Penetrant Inspection (FPI) booth was one of the firsts tasks I was given

▪Required Signoff from multiple parties, needed:

- ▪Readiness for production use
- ▪Engineering safety controls in place
- ▪Instructions written for operation

▪Water splash guard installed, and a GFCI outlet for blacklight



Work Instruction Excerpt from Magnaflux FPI Booth

Creation of Quality Indicators

▪Performing FPI on additively manufactured (AM) parts is difficult because of the rough surface of as printed parts

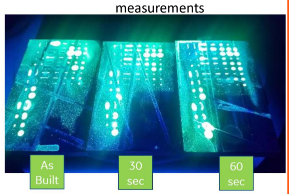
▪The goal of this project was to understand cost/cycle of surface treatments to enable FPI of AM parts

Surface Profilometer used for roughness measurements

▪Coupons were designed in Siemens NX and then printed to mimic AM parts

▪Surface treatments or media blasting were used to decrease surface roughness

▪325 Ra was normal for as built panels, whereas 200 Ra was the roughness for panels after surface treatment



Quality indicators coupons after FPI

Post-Build Heat Treatment

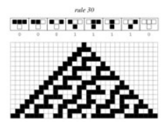
A computational and experimental study

▪Post-processing of AM superalloys often involves heat treatment to get optimal properties

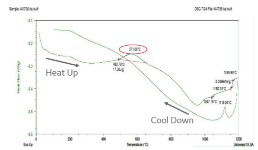
▪Goal of this project was to create a model to describe the precipitation of γ' in IN-738

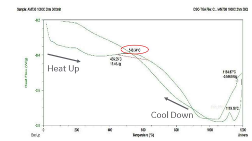
▪The intent was to use cellular automata to model the diffusion of elements in the as-printed components

▪Simulations were run against experiments to determine if they model reality



A relatively simple one-dimensional cellular automaton



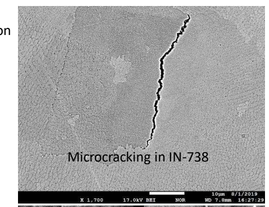


▪ Differential Scanning Calorimetry was used to determine phase transformation temperatures, especially after thermal exposure

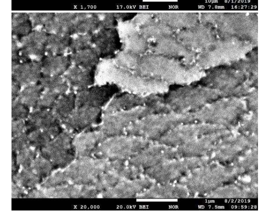
▪Thermo-Calc was used to determine what phases could be expected

▪DSC curves show transformations around 575°C, matching up with Thermo-Calc

▪Scanning Electron Microscopy performed to examine phases present in samples heat-treated at 575°C



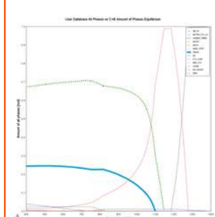
Microcracking in IN-738

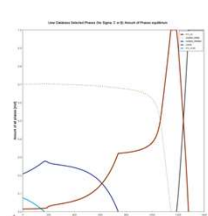


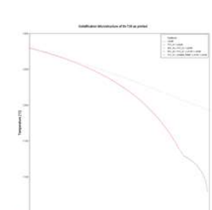
Secondary Phases in IN-738

▪Thermo-Calc Scheil solidification predictions show that the first phase to appear is γ, followed by a BCC phase, then finally γ'

- ▪This implies a very small amount of γ' in the as solidified structure







Build Time Estimation

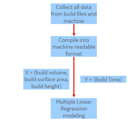
▪A build time estimator was programmed in python using sci-kit learn's multiple linear regression function

▪Inputs:

- ▪Constant:
  - ▪Machine,
  - ▪material,
  - ▪parameter set
- ▪Variables:
  - ▪Build Volume
  - ▪Surface Area
  - ▪Z-Height

▪Multiple linear regression used to predict build time in hours

▪R^2 Value reported to be 0.99



Software diagram of the model built

Actual Time (hrs) Model Prediction (hrs)

```
array([[50.1],              array([[48.88564868],
       [12.3],                     [ 9.34889401],
       [65.3],         vs.         [66.03927854],
       [ 2.5],                     [ 5.55770688],
       [ nan],                     [33.42619   ],
       [57. ]])                    [57.36847189]])
```

Actual build time vs model prediction in hours

Powder Capsule Redesign

▪This project was one that needed to be done to improve the builds that the team was performing. The powder capsule is used to document what the state of the powder was for a build, so that analysis does not need to be performed every time. This is done by building a 3D wall around the powder, such that the powder has no egress from the structure. This allows the history of the powder used to build the part to be easily saved and catalogued for later analysis.

Conclusions

▪There were multiple conclusions from this variety of projects

▪3D printing very small features is difficult

▪We understand that there are a few different events taking place during the heat treatment that bear more scrutiny

▪Transformations at 575°C and 1065°C may be of interest for heat treatment – perhaps bounds for the heat treatment process

▪From Thermo-Calc, A large amount of γ' and other TCP phases are expected to appear at equilibrium

- ▪However, this is often hard to determine as kinetics of these phases are very slow

References

- M. S. A. Karunaratne, S. L. Ogden, S. D. Kenny & R. C. Thomson (2009) A multicomponent diffusion model for prediction of microstructural evolution in coated Ni based superalloy systems, Materials Science and Technology, 25:2, 287-299, DOI: 10.1179/174328408X355415