Recyclability of 304L Stainless Steel in the Selective Laser Melting Process

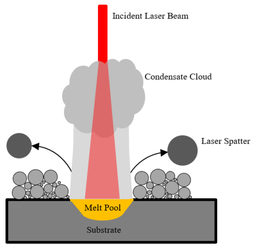
Austin T. Sutton[1] , Caitlin S. Kriewall[2], Ming C. Leu[1], Joseph W. Newkirk[2]
[1]Department of Mechanical and Aerospace Engineering
[2]Department of Materials Science and Engineering

Abstract

Selective laser melting (SLM) is an additive manufacturing (AM) process that uses a laser to bond layers of powder for creation of three-dimensional components. During part fabrication, a large amount of energy is induced into the melt pool causing laser spatter and condensate to be generated, both of which have the potential to settle in the surrounding powder-bed compromising its reusability. In this study, 304L stainless steel powder is subjected to five reuses in the SLM process to assess its recyclability through both powder and mechanical property characterization. All powder was characterized by particle size distribution and shape measurements, oxygen content with combustion analysis, and phase identification by x-ray diffraction. The evolution of powder properties with reuse was also correlated to tensile and Charpy impact behavior. The results show that reused powder coarsens and accrues more oxygen with each reuse causing no change in the tensile properties but a decrease in the toughness.

Background

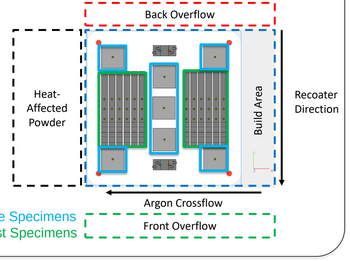
Two forms of ejecta in SLM:
1. Laser spatter
2. Condensate



- Local evaporation of the melt pool surface causes a recoil pressure that pushes on melt pool to eject molten material
- Vaporized material condenses in build chamber atmosphere to produce condensate
- Both laser spatter and condensate redeposit in the surrounding powder-bed compromising its reusability

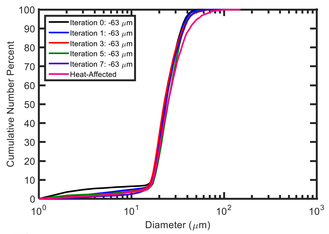
Methodology

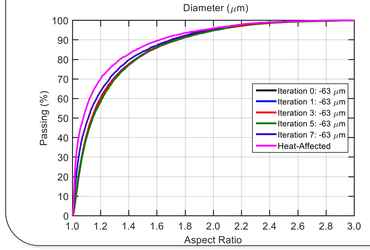
- 7 powder reuses were performed
- Powder was sampled from various areas
- Tensile and Charpy properties measured



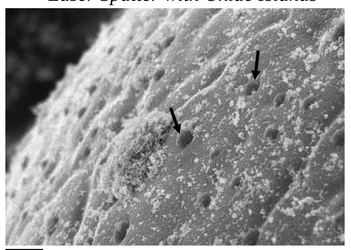
Evolution of Powder Properties

- Oxide islands and condensate present on the surface of laser spatter
- Particle size distribution coarsens with reuse
- Powder becomes more spherical when recycled

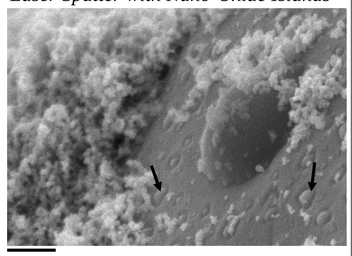




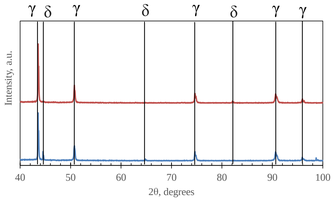
Laser Spatter with Oxide Islands

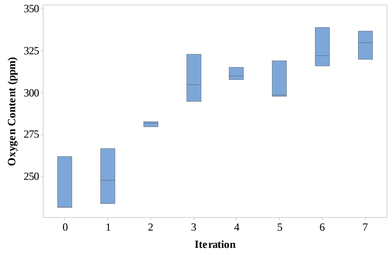


Laser Spatter with Nano-Oxide Islands



- Powder accrues oxygen with reuse due to formation of oxides on laser spatter

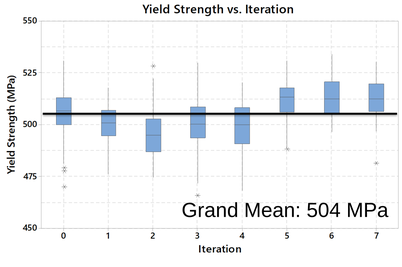


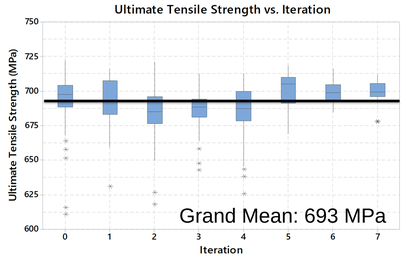


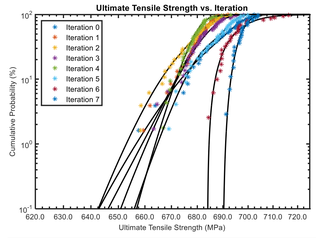
- Recycled powder has more delta ferrite indicating the accretion of laser spatter particles

Evolution of Tensile Properties

- No trends in either the yield or ultimate tensile strength with reuse
- While statistically significant trends were found, the differences observed are not practically significant

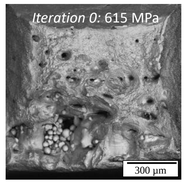


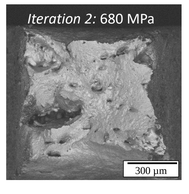


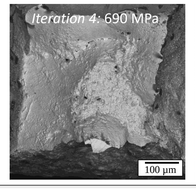


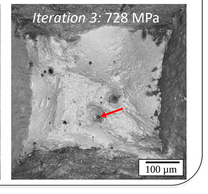
- Fracture surfaces show some tensile specimens with large pores and others with small porosity and inclusions
- Bimodal 3-Parameter Weibull distributions show no major differences with iteration

	Lower Distribution			Upper Distribution			
	Scale (MPa)	Shape (MPa)	Threshold (MPa)	Scale (MPa)	Shape (MPa)	Threshold (MPa)	α
Iteration 0	121	15.2	559	85.2	15.4	611	0.264
Iteration 1	133	17.9	548	92.2	19.2	592	0.219
Iteration 2	103	17.9	564	86.0	11.9	598	0.079
Iteration 3	97.4	18.1	581	95.9	15.2	591	0.128
Iteration 4	100	19.3	589	80.1	20.0	600	0.109
Iteration 5	87.3	18.1	592	78.2	18.0	615	0.274
Iteration 6	13.6	1.50	684	-	-	-	-
Iteration 7	8.57	2.28	690	-	-	-	-



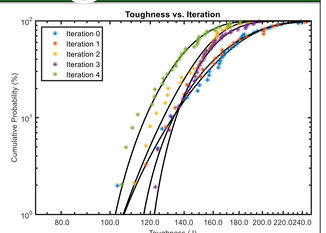


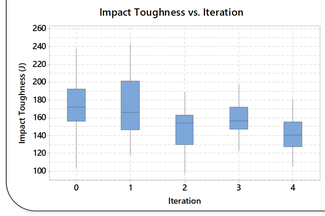




Impact Toughness

- Impact toughness decreases with reuse
- Toughness is sensitive to the oxygen content is expected to be the cause of degradation with reuse





	Scale (J)	Shape (J)	Threshold (J)
Iteration 0	103	3.38	80.1
Iteration 1	72.2	2.16	108
Iteration 2	88.8	4.95	71.1
Iteration 3	50.7	2.55	114
Iteration 4	58.6	3.01	89.7

- Distributions show a gradual decrease in toughness

Conclusions

- Powder Characterization
  - 304L SS powder coarsens and becomes more spherical with reuse
  - Powder-bed density increased with reuse
  - Oxygen content increased as powder was used
  - Apparent and tap densities increased with powder reuse
  - Recycled powder to be more flowable than virgin material
- Part Characterization
  - Tensile data showed no practically significant trends with reuse
  - Weibull distributions of tensile strength showed no change with reuse
  - Charpy testing revealed a statistically significant decrease in impact toughness with reuse
  - Part oxygen content was found to increase with reuse

Acknowledgement

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