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Relating Build Parameters, Density, and Structural Properties in Additively Manufactured 316L Stainless Steel

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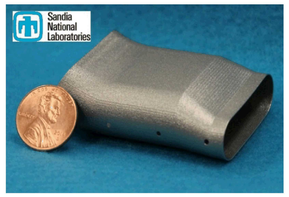
Introduction

Additive manufacturing (AM) is the 3D printing of metals by adding one layer of particles on top of another. In AM a machine lasers and melt specific regions of a build plate that contain micro particles of steel to create an object. Once one layer is melted, the build plate will then be lowered by 1mm so that the machine can roll a new layer of micro particles onto the build plate.

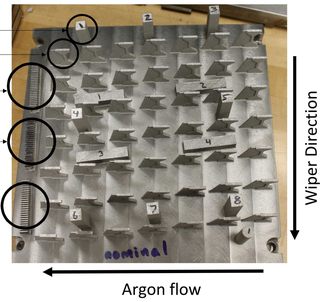


The purpose of this investigation is whether the Thermal Energy Density (TED) values can predict structural material behavior. Three build plates were printed at different laser power (GED) by Sigma Labs Inc to identify how the laser power affects each tensile and Charpy sample's mechanical properties. Charpy Impact Testing is conducted on Charpy bars that are printed vertically and horizontally. High Throughput Tensile Testing is conducted on Size-A and Size B .

Laser Powder Bed Fusion and High Throughput Tensile Testing (HTTP)

Size-B Tensile Bars Size-A Tensile Bars

2.5 x 2.5 mm, 1 x 1 mm
(dimension of cross-sectional area of gauge length)

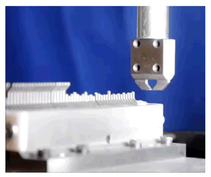


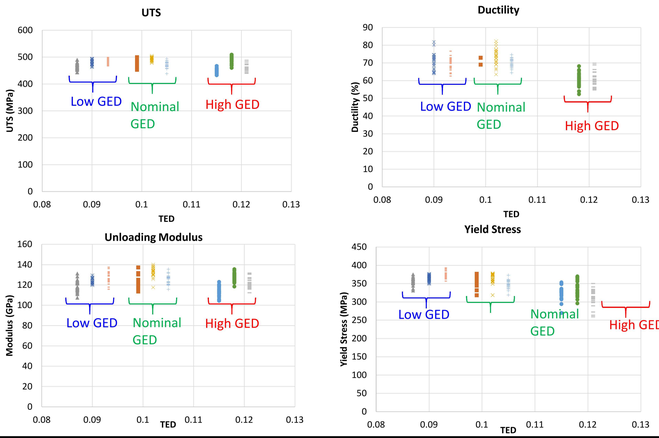
3 Build plates defined by laser power
~ 350 Tensile specimens printed: 126 Size-B & 225 Size-A
Build plates are defined by laser power: Low, Nominal, High
High Throughput Tensile Testing streamlines testing process by 10x

Tensile properties largely unaffected by GED/porosity
Tensile Strength not affected by GED

TED Values have little affect on the material properties

1. TED value has little affect on UTS of tensile bars.
2. Yield stress slightly decreases as the TED values increases.
3. TED values roughly no affect on the unloading modulus
4. Cross-sectional area slightly increases as TED value increases. Potential Result of surface roughness, porosity, and crust.
5. TED value has no affect on ductility





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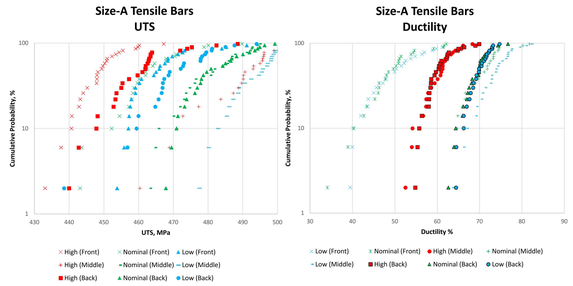
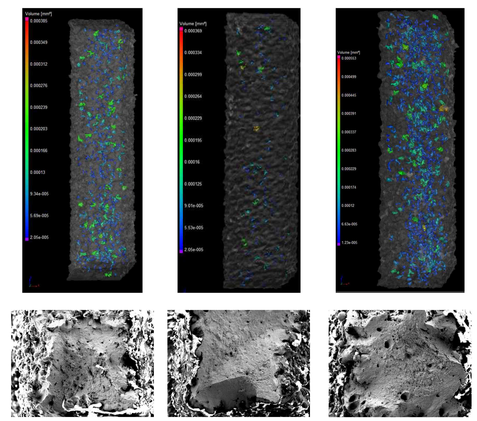
GED power and location on plate both affect properties



Size-A Tensile Bars

1. Low GED is strongest and most ductile
2. Location on build plate matters just as much as GED.
3. Middle rack of tensile bars for the "low" build plate has the highest UTS and ductility

Changing power density (GED) away from nominal increases porosity



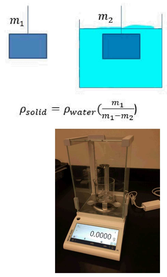
Charpy Sample #	Low build plate (TED) average	Nominal build plate (TED) average	High build plate (TED) average
8-10 (Vertical)	0.1329	0.1479	0.1674
26-27 (Horizontal)	0.1392	0.1537	0.1725
35-36 (Vertical)	0.1361	0.1507	0.1683

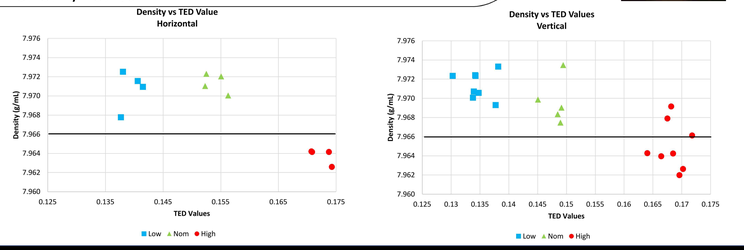
Both the Horizontal and Vertical Charpy bar's porosities can be predicted using the TED values. As the TED value increases so does the porosity within each sample. Low and nominal samples do not differ much in terms of porosity. TED measures the power density at each location.

TED predicts density

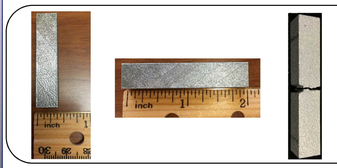
TED Values affect the density of each sample

1. Density decreases as TED value increases.
2. Low and Nominal samples have approximately the same density for both the vertical and horizonal plot.
3. Density decreases around 7.966(g/mL)
4. TED value has a large influence on the density of each sample depending on the build plate.
5. Each sample's weight while submerged only differed by 0.001g at most from one another.
6. Resulted in each sample being 99% dense with a potential error of +/- 0.1%





TED predicts Charpy Toughness

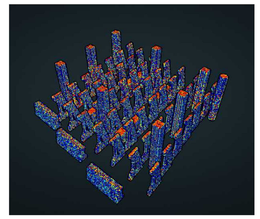


Charpy bars were manufactured by Sigma Labs Inc. Each sample was separated from each build plate using electrically discharged melting and were notched at using a V-Notch broaching machine.

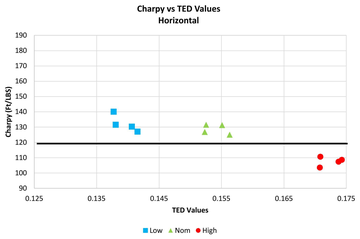
TED Values affect the Charpy Value of each Charpy Bar

1. Charpy value decreases as TED Value increases
2. Results from an increase in porosity which decreases the volume of each Charpy sample.
3. Low and Nominal Samples have approximately the same Charpy value for both the Horizonal and Vertical plots.
4. Charpy toughness drops off at TED ~ 0.16

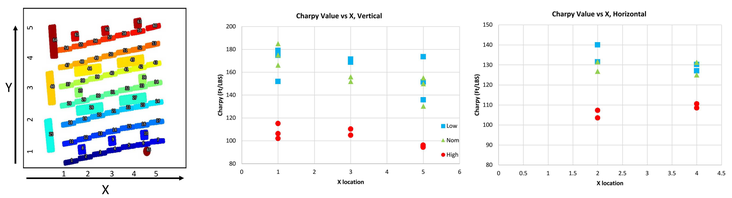
TED Value Diagram



Charpy Impact Tester



Charpy toughness is consistent spatially across build plate



Comparing the Charpy values to their build plate location shows some dependency. Both for the vertical and horizontal Charpy values, all the Charpy values slightly decrease as the location number increases from left to right. This same trend can be seen when comparing horizontal and vertical Charpy values to the Y location on the build plate.

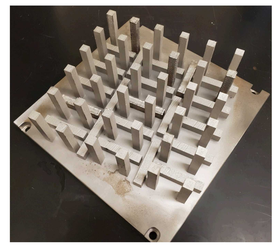
SUMMARY:

Conclusion:

- TED values are predictive of density
- Charpy toughness is affected by density
- Can predict Charpy toughness using TED values
- Why do tensile bars show location dependency but Charpy do not?

Future Projects:

- Building a process map of build parameters and structural properties in additively manufactured 316L Stainless Steel.



Charpy Build plate for next study