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

UNMcNair & ROP Scholars Program

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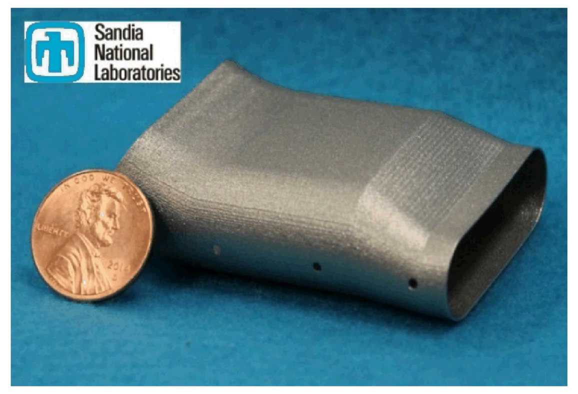
Introduction

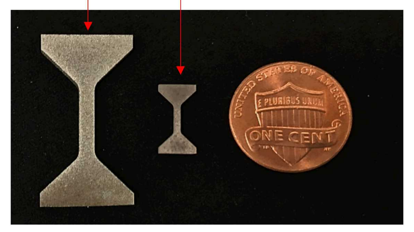
Additive manufacturing (AM) is the 3D printing of metals by adding one layer of particles on top of another. In AM a machine lasers and melt specific regions of a build plate that contain micro particles of steel to create an object. Once one layer is melted, the build plate will then be lowered by 1mm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



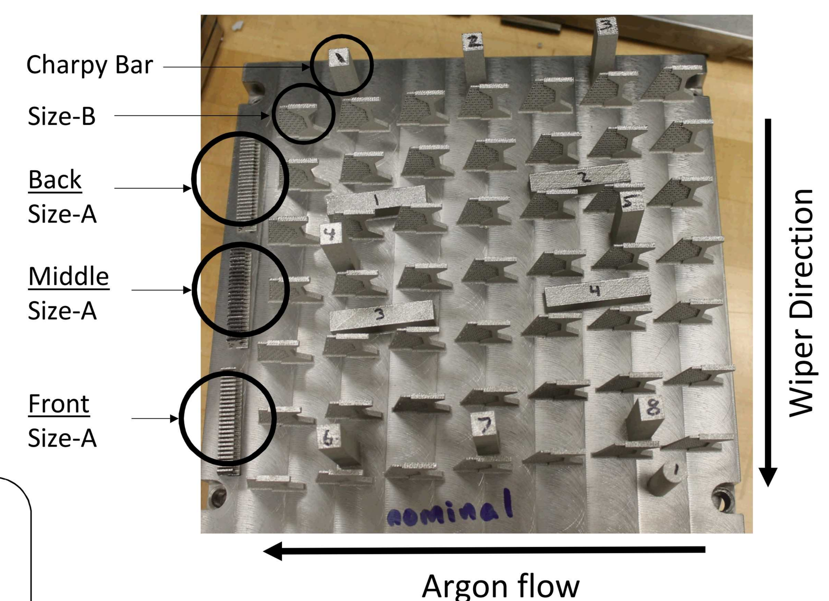
The purpose of this investigation is whether the Thermal Energy Density (TED) values can predict structural material behavior. Three build plates were printed at different laser power (GED) by Sigma Labs Inc to identify how the laser power affects each tensile and Charpy sample's mechanical properties. 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)

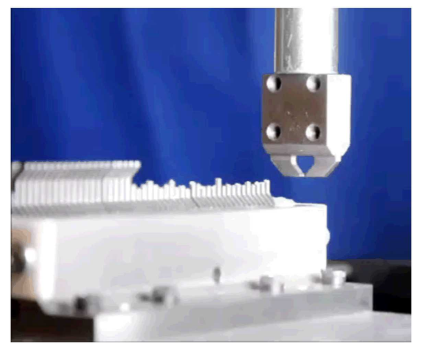


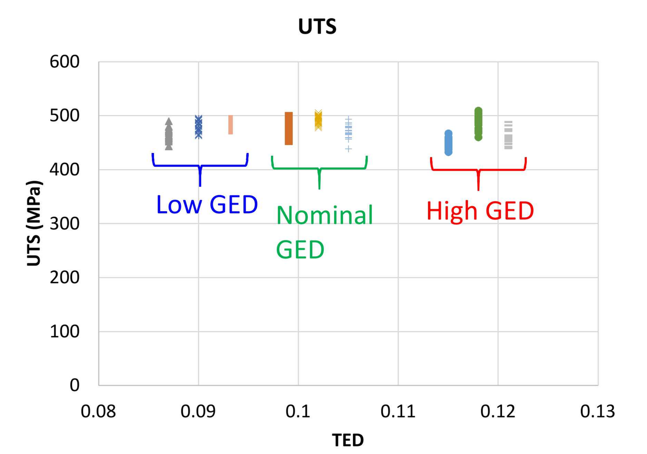
3 Build plates defined by laser power
~ 350 Tensile specimens printed: 126 Size-B & 225 Size-A
Build plates are defined by laser power: Low, Nominal, High
High Throughput Tensile Testing streamlines testing process by 10x

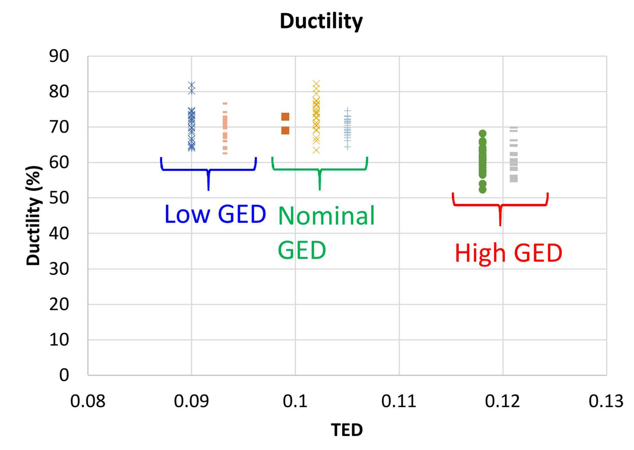
Tensile properties largely unaffected by GED/porosity Tensile Strength not affected by GED

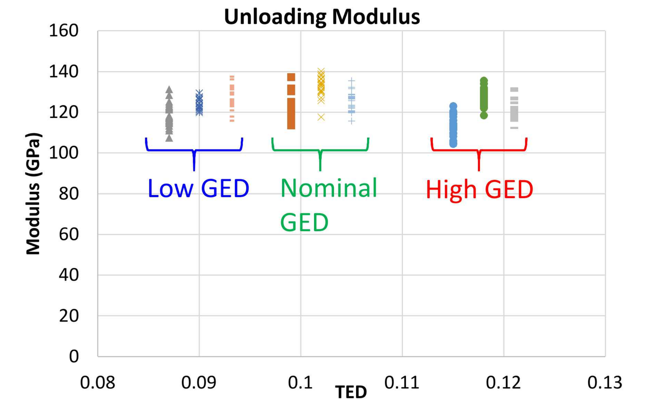
TED Values have little affect on the material properties

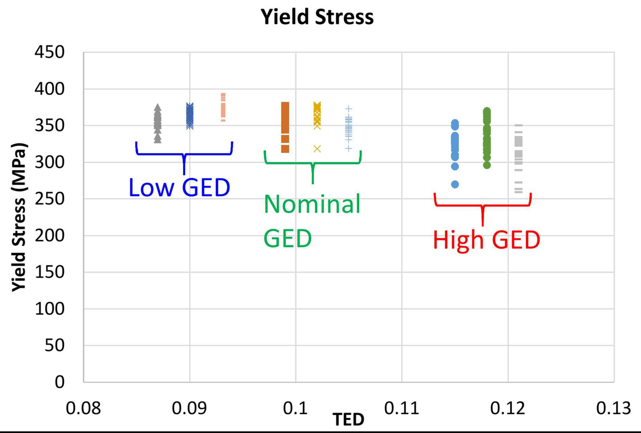
1. TED value has little affect on UTS of tensile bars.
2. Yield stress slightly decreases as the TED values increases.
3. TED values roughly no affect on the unloading modulus
4. Cross-sectional area slightly increases as TED value increases. Potential Result of surface roughness, porosity, and crust.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



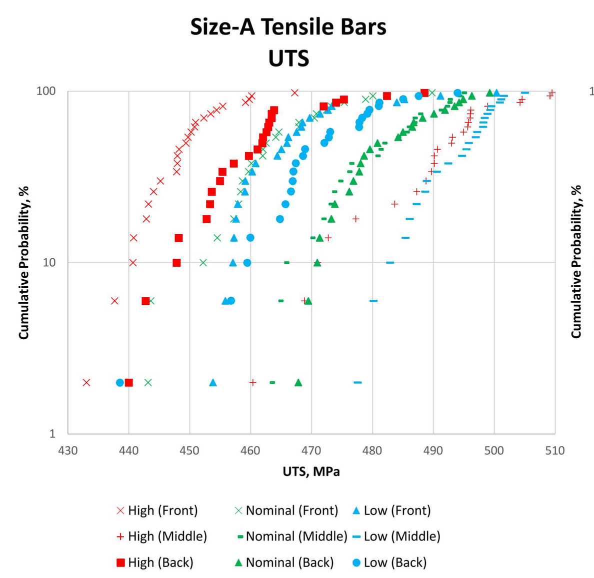


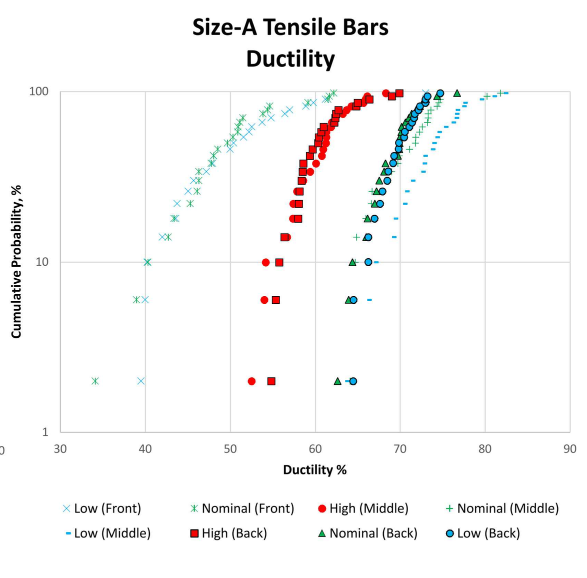






GED power and location on plate both affect properties



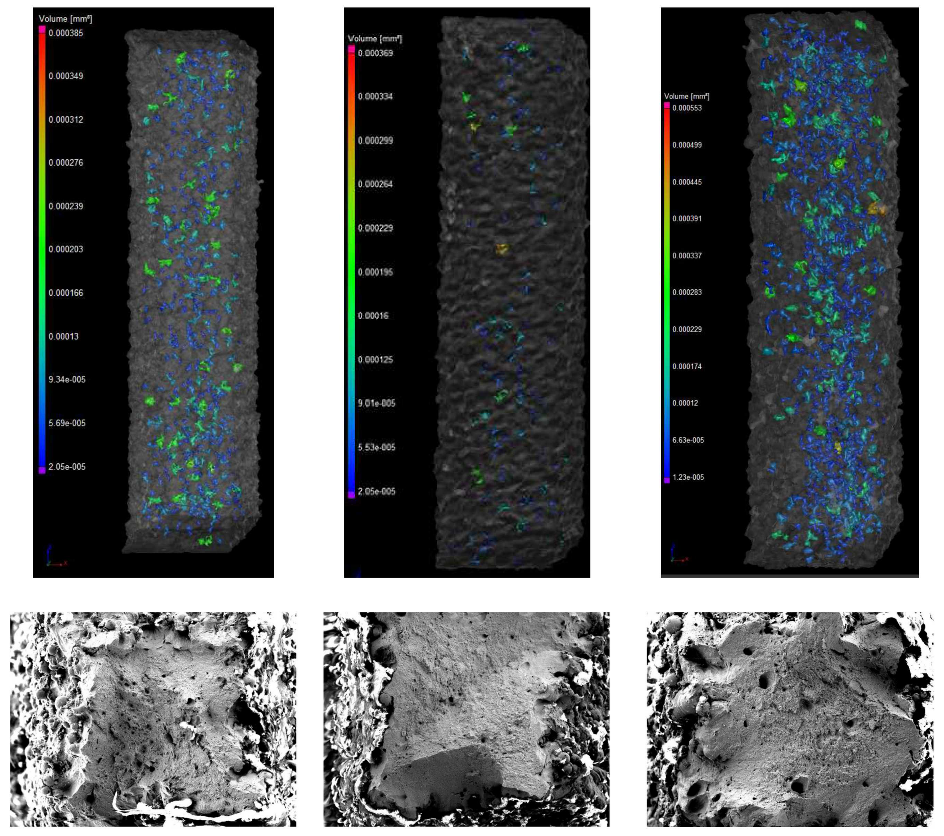


Size-A Tensile Bars

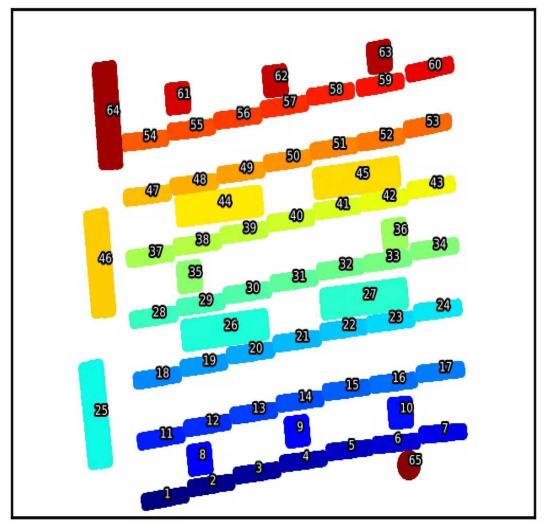
1. Low GED is strongest and most ductile
2. Location on build plate matters just as much as GED.
3. Middle rack of tensile bars for the "low" build plate has the highest ductility. "Low" and "high" middle rack of tensile bars has highest UTS.

Power density (GED) affects porosity

Low GED (-15%)   Nominal GED   High GED (15%)



Specimen Layout Map



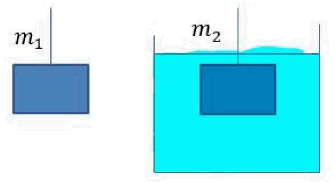
As the TED value increases so does the porosity within each sample. Low and nominal samples have the same average porosity with significant variability.

TED measures the energy density at each location.

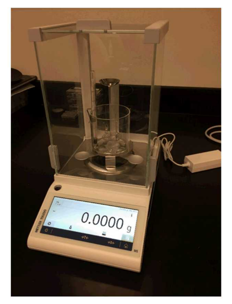
TED predicts density

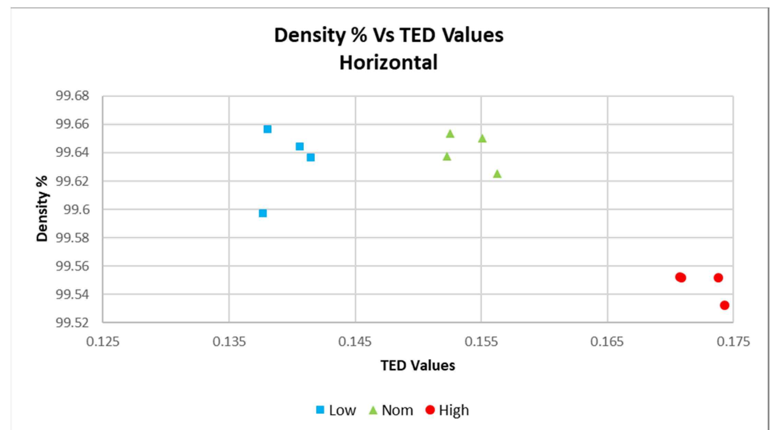
TED Values affect the density of each sample

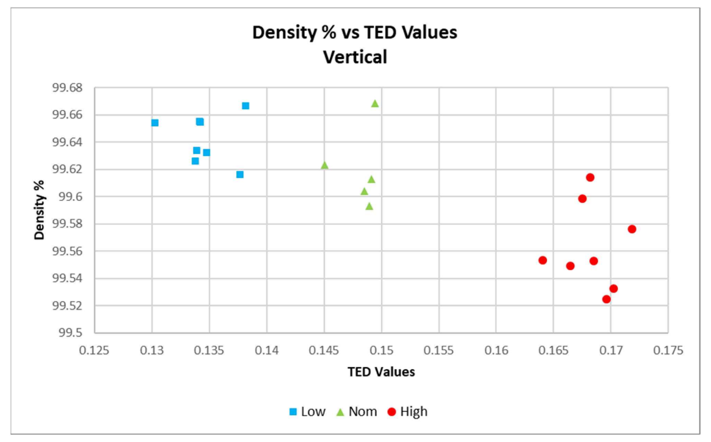
1. Density decreases as TED value increases.
2. Low and Nominal samples have approximately the same density
3. Density drops off around TED~0.16
4. TED value has a large influence on the density of each sample depending on the build plate.
5. Each sample's weight while submerged only differed by 0.001g at most from one another.
6. Resulted in each sample being 99.5% to 99.68% dense with a potential error of +/- 0.1%



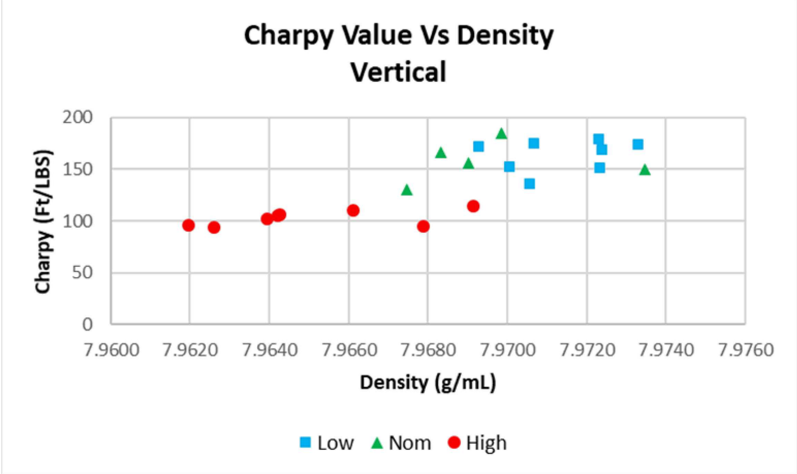
$$\rho_{solid} = \rho_{water}\left(\frac{m_1}{m_1 - m_2}\right)$$

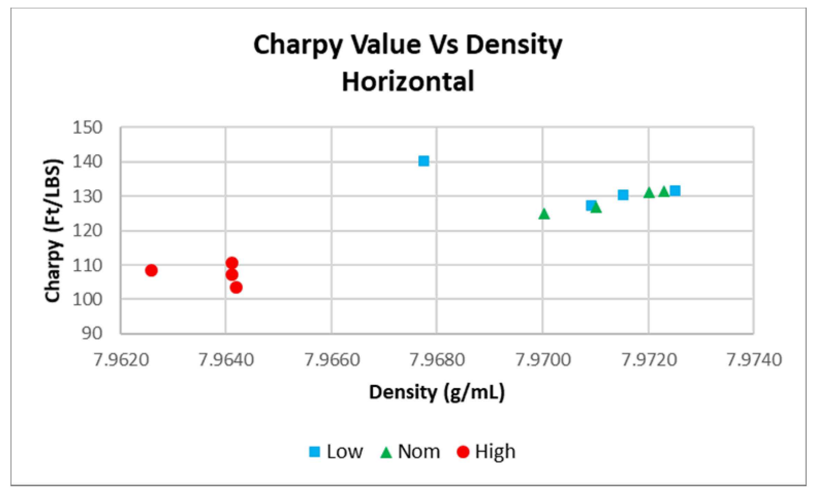






Density predicts Charpy toughness





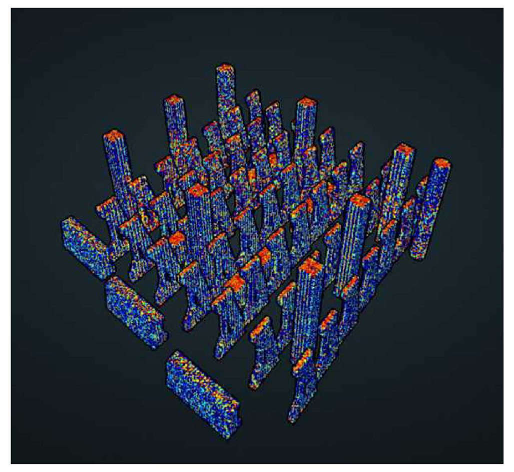
TED predicts Charpy toughness

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

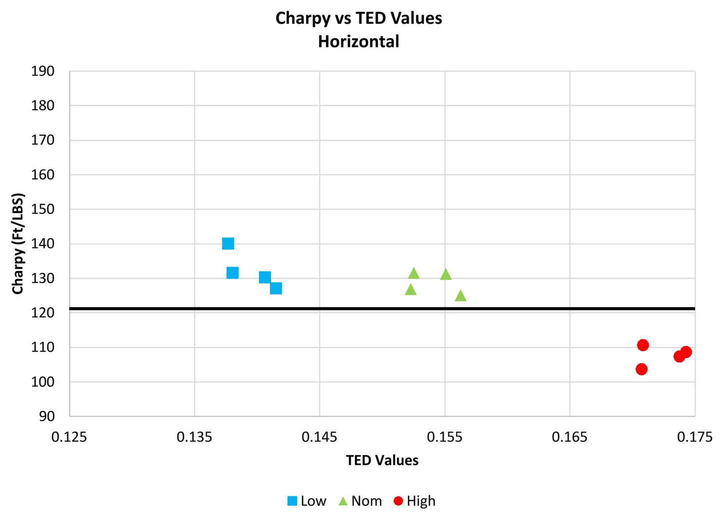
TED Values affect the Charpy Value of each Charpy Bar

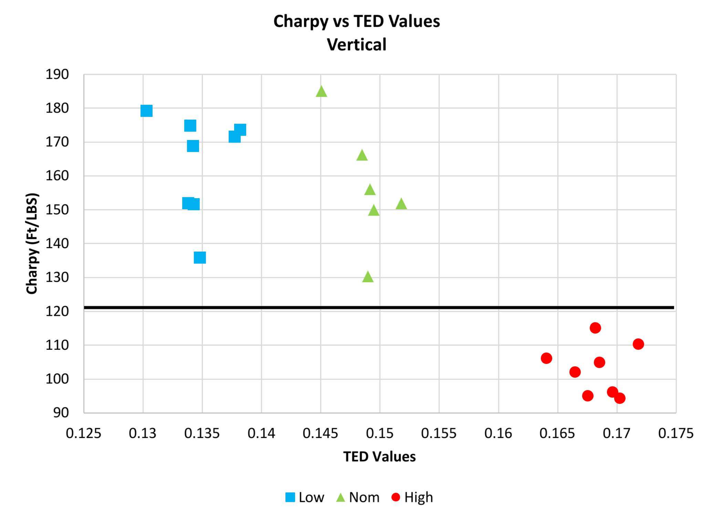
1. Charpy value decreases as TED Value increases
2. Results from an increase in porosity which decreases the volume of each Charpy sample.
3. Low and Nominal Samples have approximately the same Charpy value for both the Horizonal and Vertical plots.
4. Charpy toughness drops off at TED ~ 0.16

TED Value Diagram



Charpy Impact Tester





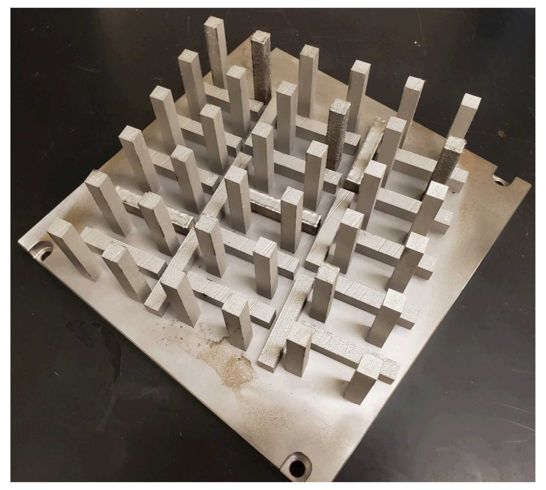
SUMMARY:

Conclusion:

- TED values are predict density
- Density predicts Charpy toughness
- TED predicts Charpy toughness
- 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

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