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Effects of recycled powder on build integrity in metal based additive manufacturing

Katherine Wellmon[1]; Joshua Yee, PhD[2]; Nancy Yang[2]; Julie M. Schoenung[1]
[1]University of California, Irvine; [2]Sandia National Laboratories

Abstract

Metal based additive manufacturing has struggled to become a widely utilized process partially due to the need to improve the economic impact of these techniques. For Direct Energy Deposition (DED), 90% of feedstock powder is unused. The convention is often for this powder to be discarded to prevent negative effects on build quality if reused due to the possible morphological and microstructural changes in the powder resulting from interactions with the laser. However, recent studies have shown that the morphology of the powder can be maintained for multiple deposition cycles if properly processed. In this study, 316L stainless steel powder is used as feedstock in a Laser Engineered Net Shaping (LENS®) machine. The effects of the recycled powder, including the particle morphology, agglomeration, composition and microstructure, on the quality of the build are investigated through scanning electron microscopy, particle size analysis, and mechanical testing.

Background

LENS® additive manufacturing utilizes powder feedstock to build 3-dimensional parts through direct laser deposition. Injection nozzles deliver powder to the melt pool of the high-power laser beam as shown in Figure 1. The part is built up layer by layer with increments in the z height of the laser. Powder that does not contribute to the laser melt pool and can be collected from the stage can potentially be reused in another deposition.

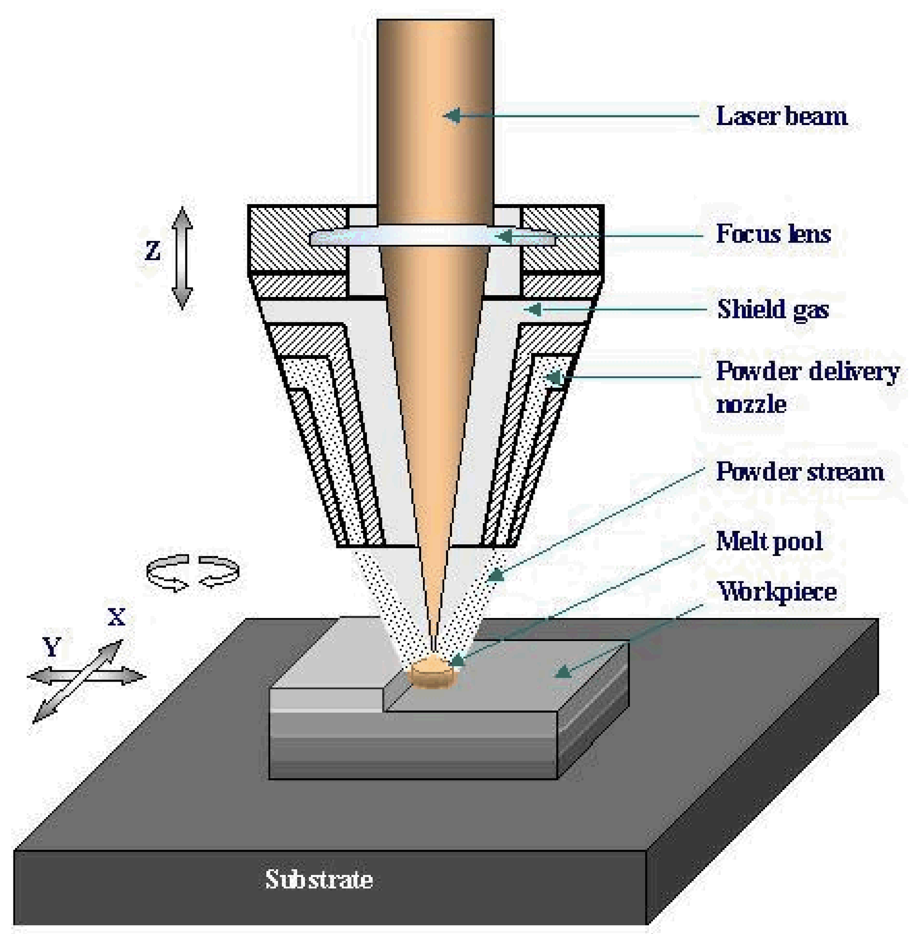

Figure 1. LENS machine laser and powder feed nozzles illustrating layer by layer deposition on substrate [1].

Literature shows that only small variations of powder properties can occur through 10 cycles of reuse[2]. In the present work, efforts are focused on relating these property changes to physical properties of deposited parts.

Approach

The DED process is unique to powder composition, causing the reuse of different powders to have varying outcomes. Over processing of powder between depositions can compromise physical properties of the particles that can affect the final build. Powder morphology, Powder Size Distribution (PSD), flowability, and microstructure were examined through three cycles of deposition. After each deposition, powder was collected from the stage, sieved to remove particles ≥ 150 µm, analyzed, and reused for the next cycle. Parts were built with consistent deposition parameters from as-received (C0), cycle one (C1), and cycle two (C2) powder. To test the integrity of the build from each cycle; density, hardness, and compression measurements were conducted.

Characterization

- Scanning electron microscopy (SEM) was used to analyze the morphology and microstructure of powders and deposited parts.
- Sieve shaker machines were used to separate and analyze powders for size distribution.
- Powder flowability was tested using a carney flow meter method.
- Density measurements were conducted using the Archimedean method.
- Vickers hardness method was used to measure build hardness.
- Instron 8801 universal testing machine was used to compress samples of each deposition cycle that were prepared by cutting the parts into rectangular cuboids with an EDM.

Results

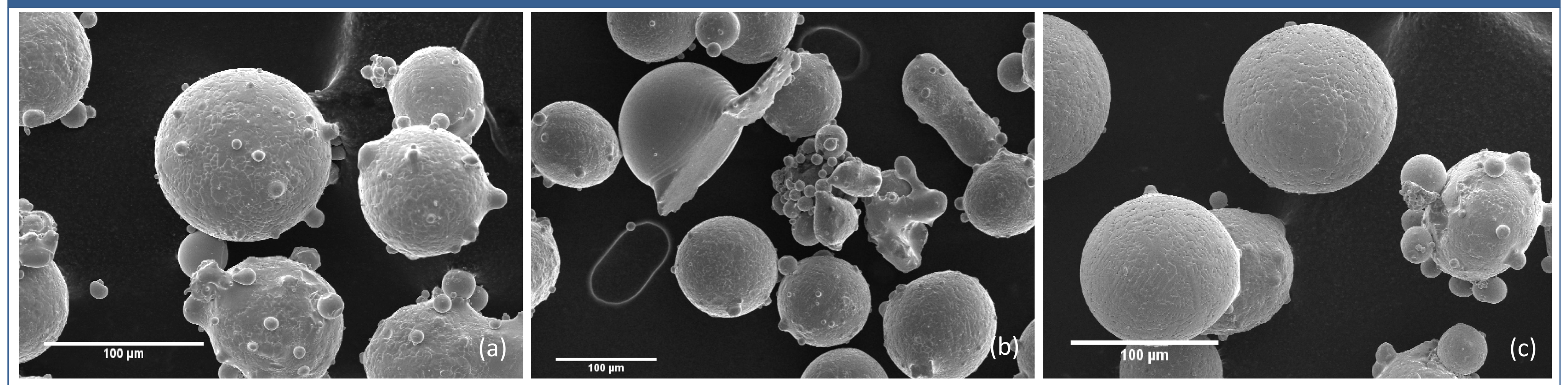

Figure 2. Morphology of (a) C0, (b) C1, and (c) C2 powders. Reused powder has more agglomerates with non spherical particles and particles that remain spheres have less satellites.

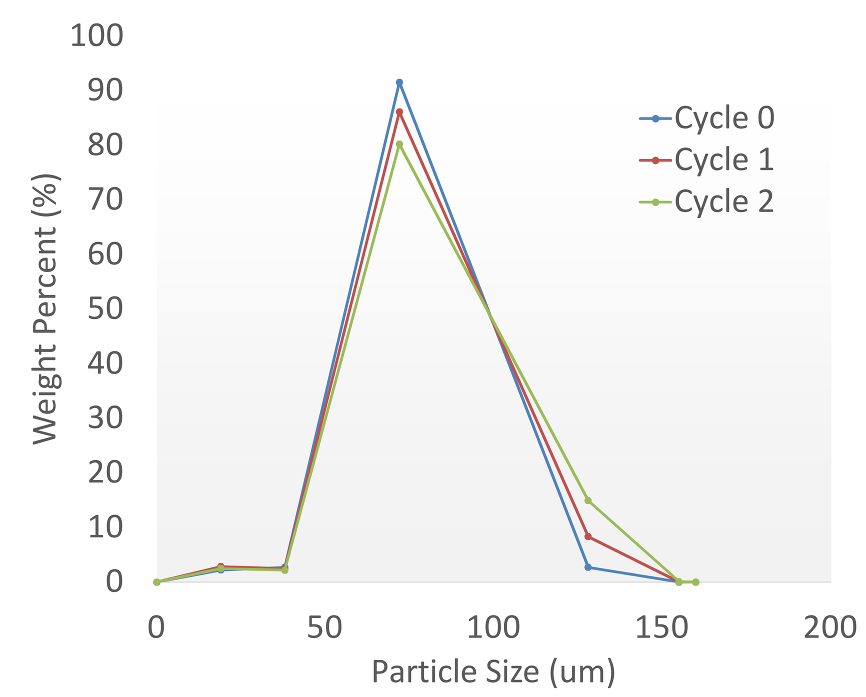

Figure 3. Powder Size Distribution (PSD) shows increase in number of particles larger than 106 µm and particles smaller than 45 µm.

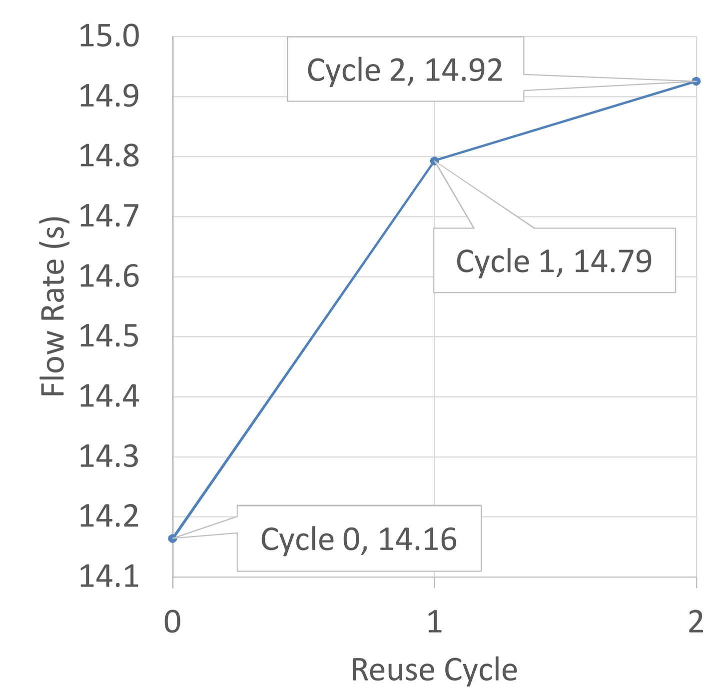

Figure 4. Powder flow rate of the powder increases with the number of reuse cycles.

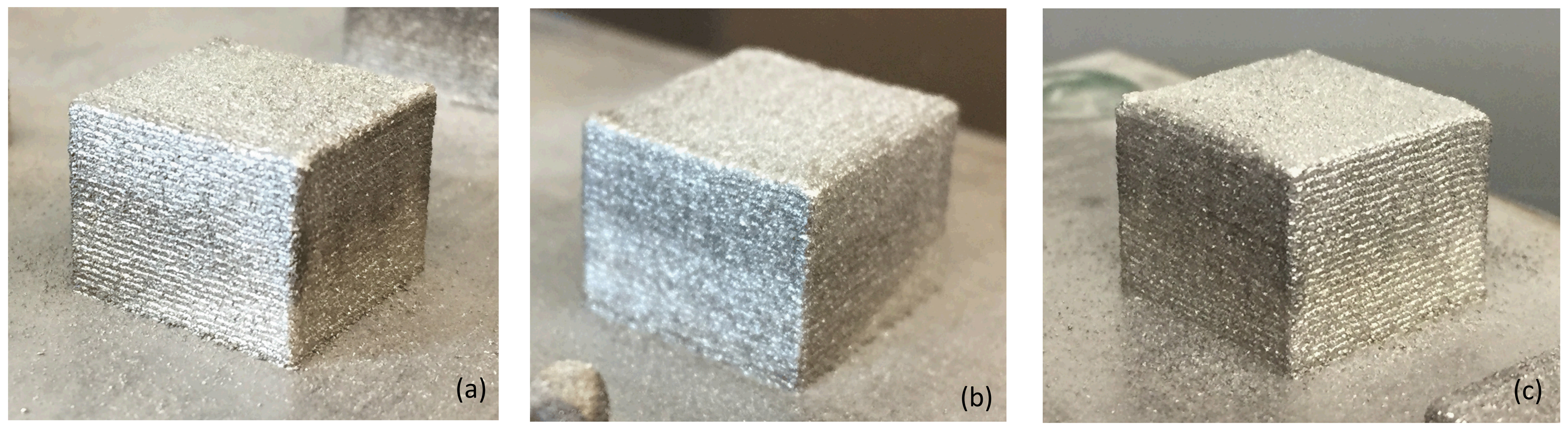

Figure 5. Deposited parts made with powders: (a) C0, (b) C1, (c) C2. Surface finish and size of the builds are consistent through each cycle. Each build's width is 15.9 mm with approximate volume of 3.21 cm³.

Table 1. Archimedean density measurements of C0, C1, C2 builds. Density increases as powder is reused. All builds are >99% dense comparing to 316L stainless steel standard density of 7.95 g/cm³ [3].

Cycle	Build Density [g/cm³]
C0	7.939
C1	7.952
C2	7.955

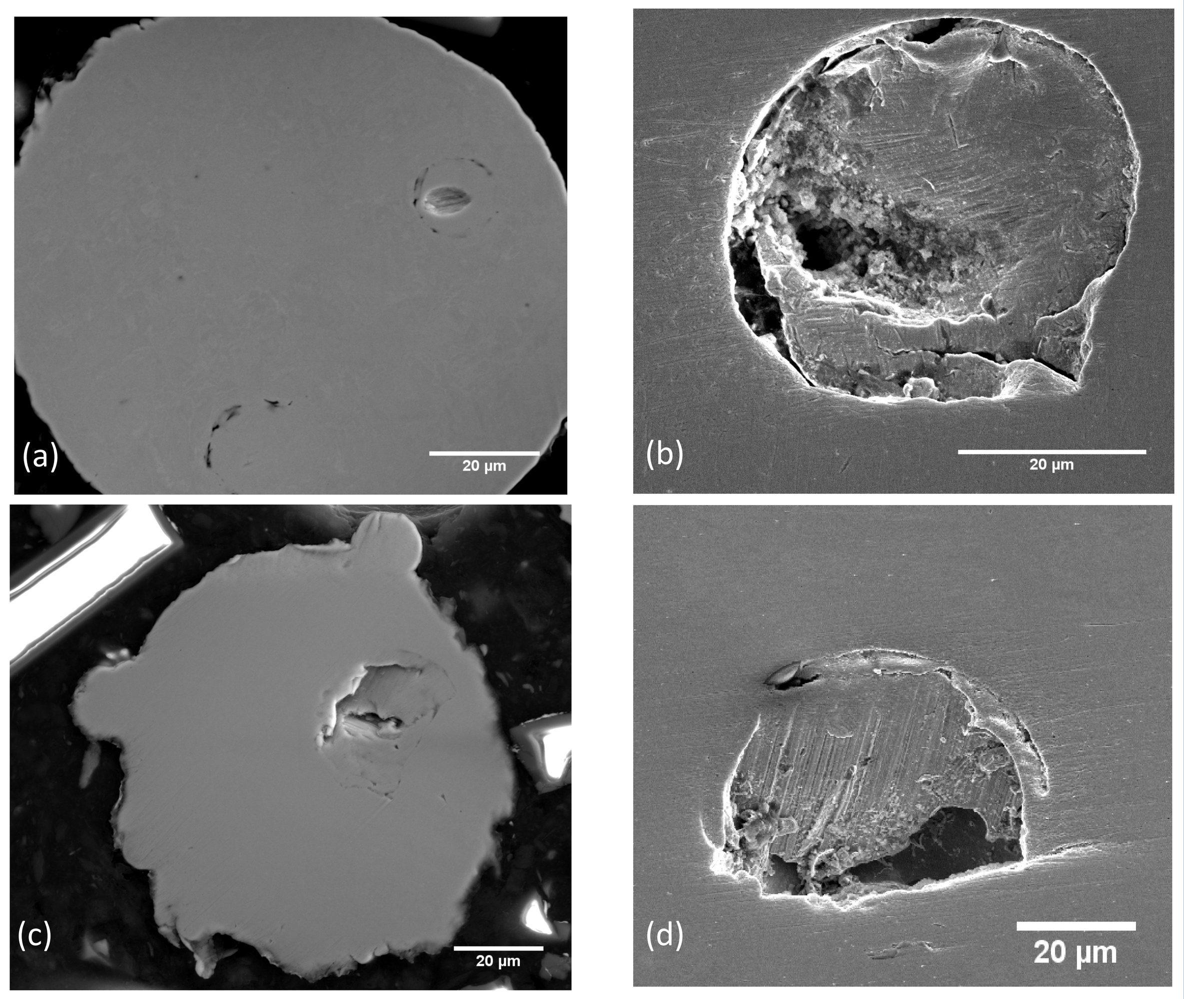

Figure 6. Micrographs of powder cross sections for (a) C1 and (c) C2 and build cross sections for (b) C1 and (d) C2 show similar features that were maintained through the deposition process.

Results

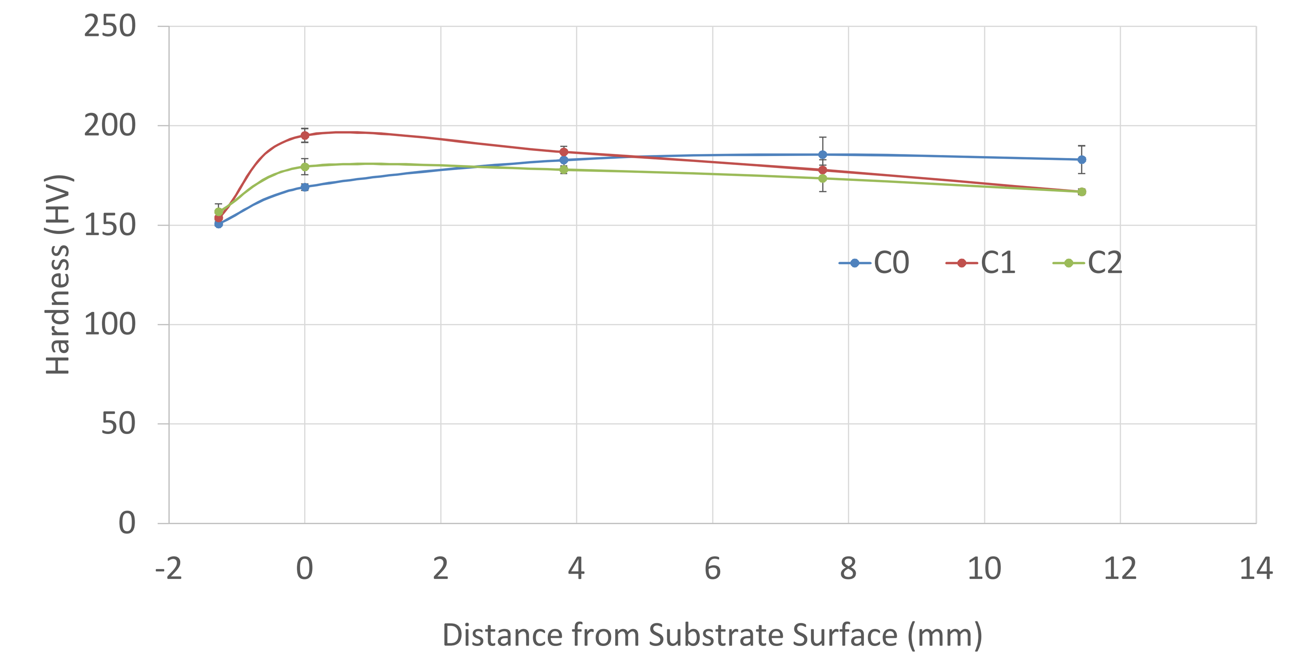

Figure 7. Vickers hardness from substrate (0 mm) to top of build (11.5 mm).

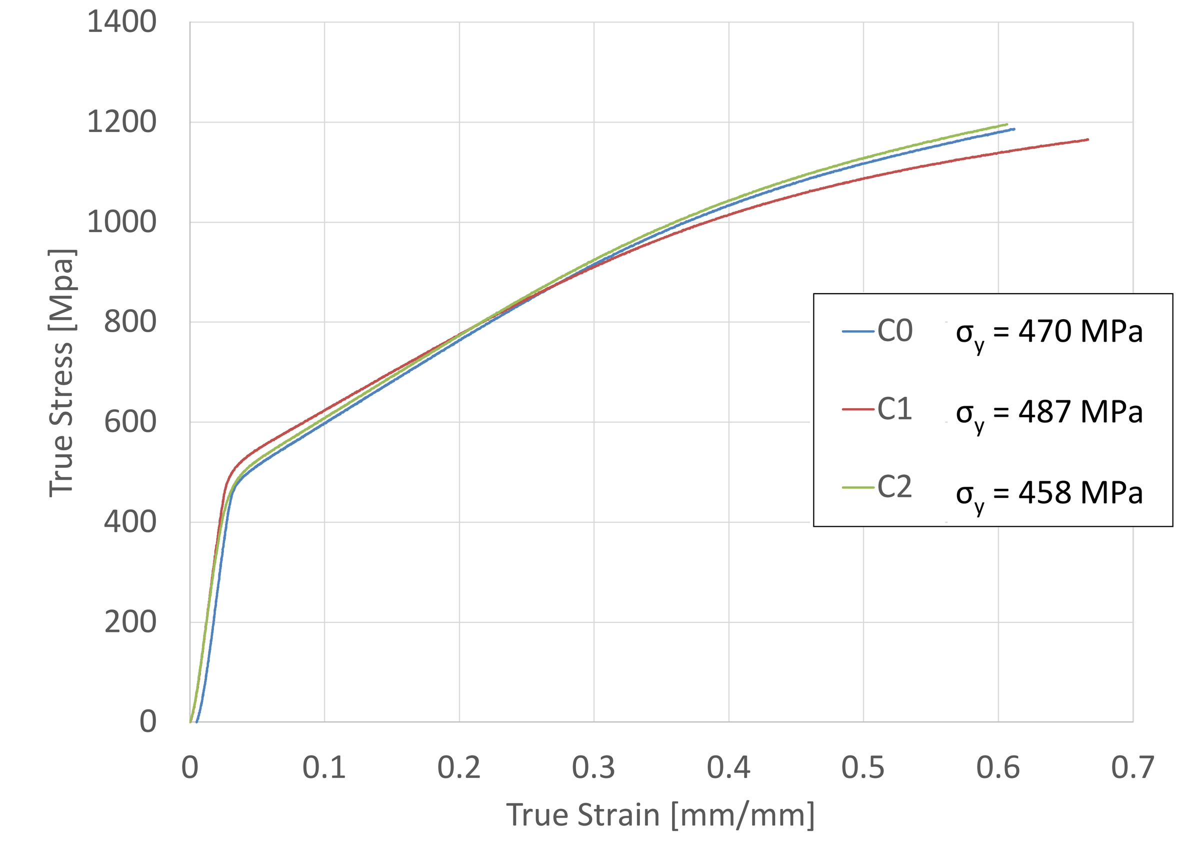

Figure 8. Compression tests show small variations in compression yield strength between cycles.

Conclusions & Future Work

For the first three cycles of this study, some trends can be seen in the properties of the powder that directly relate to properties in builds. As the reuse of the powder continues, there is an increasing number of particles larger than 106 µm resulting from agglomerations as well as smaller than 38 µm from dislodged satellites. The change in PSD and morphology contributes to small increases in build density. Flowability of the powder is shown to increase slightly from the AR powder to the C2 powder, also a result of changing PSD. The surface finish and volume of the deposited parts remain constent through reuse of powders and mechanical properties show small variations. These results are consistent with published studies of reusing powder for additive manufacturing production. This research will continue to track trends in powder and deposition parts through 9 reuse cycles.

Acknowledgements & References

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References:

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