Analyzing Reuse of Powder Metal for Additive Manufacturing

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Submitted to:

GE Power- Gas Turbines Materials Processes Engineering

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2016 Southwest Research Institute- UTSR Program

1. Abstract

Powder metal samples were tested at various stages of reuse to investigate the changes in their physical properties. Powder metals are used in a laser powder bed additive manufacturing process to produce, as one example, gas turbine components. Samples of powder metal (PM) were tested for their property to flow, and then analyzed for their resultant change in morphology and size distribution, and how these changes affect their reuse for industrial applications.

2. Introduction

Powder metal is used in many additive manufacturing methods. In particular it is useful for the manufacturing of gas turbine components because of the distinct benefits that come from high performance powder metal alloys. For example: the high melting temperature and creep resistance. Many powder metal alloys formed into 3D components have desirable geometries and complexities that traditional manufacturing methods simply cannot achieve in a single process. The added speed of production and turnaround time for additive manufactured components combined with the capability of creating complex parts has a distinct advantage over any commercially available casting and machining techniques. During a laser powder bed process, the powder metal is shaped into three-dimensional parts used in gas turbines. A selected area of the powder metal is “fused” layer by layer with a computer guided laser until a part is produced. The laser “fuses” or micro-welds each layer of the selected powder metal until a usable part is obtained in a process called selective laser sintering (SLS).

Figure 1 shows an example of the complexity of parts produced by this technique of additive manufacturing.

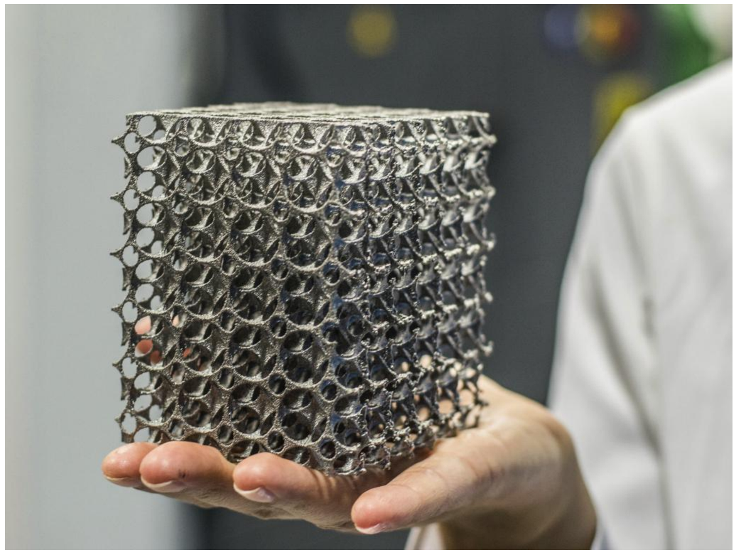

Figure 1. Additive Manufacturing capability and complexity [1]

This research was performed at General Electric's Power – Gas Turbine division in Greenville, SC in collaboration with the Materials and Processes Engineering team. The Materials and Processes engineering (MPE) team support GE Power in the area of materials characterization, and development and process development for gas turbine components. MPE also specializes in the advancement of Selective Laser Sintering processes.

A variety of studies on the reuse of powder metal have been published. Renishaw examined the limits on recycling metal additive manufacturing powder [2]. Ardila et. al. investigated the effect of selective laser sintering when applied to recycled powder of IN718 [3]. Each study highlights the observed change in mechanical and chemical properties of recycled metal powder, and how with modifications to the manufacturing process, the useful characters of these materials can be preserved. Further, both studies address the impact on the overall reduction of cost and material savings when powder metal is re-used as opposed to disposal.

This study is focused on the character of recycled powder metal to flow. The flow ability of powder metal is important to characterize because it relates directly to the reliability and efficiency of how powders are dispensed during an additive manufacturing process. Further, the flow ability of recycled material is correlated with changes in the chemical properties of the powders particles. The change in shape affects the efficiency of the micro-weld, and to the resultant parts being fabricated. Most significantly, impurities present in the recycled material can cause manufacturing defects. A pure alloy is desired and minimizing impurities greatly maintain the desired mechanical properties.

The ability of the powder metals to be reused is in the best interest of the industry, because of the potential for the company to save money and waste less material. Likewise, it is important to understand how the powder behaves at various stages of use so that predictions on the quality of the additive manufactured parts can be estimated. With much of the powder not being used during a build, there is significant benefit for the ability to recycle the unused powder remaining in the machine.

3. Experiment

The experimental approach to this study involved of evaluation of samples of powder metal at various stages of reuse. The samples gathered for this experiment were taken from a laser powder bed manufacturing machine. The machine had unused powder after each cycle, and the leftover powder was taken for sampling. The samples obtained were taken from a new batch of powder, short use, medium use and long term use. Each of the powder samples were analyzed for their ability to flow using a standard testing method. The data collected was also analyzed using 2-sample t-test and main effect plots to show what factors influence powder flow.

Samples were also analyzed for changes in their size distribution and shape morphology at the various stages of reuse. This was done by mounting the samples to be looked at under an scanning electron microscope (SEM) and creating magnified images that reveal individual powder particles. The images were investigated for their shape morphology with respect to the number of times they were used in a build. Finally, the samples of powder metal were analyzed for their distribution of particle size. The particle size distribution was developed from software that plots a distribution curve at various size scans. The data is displayed as the percentages of particles that fall below a certain size.

4. Results

The samples collected were tested for their flow characteristics. Some of the factors taken into consideration were the number of times the powder was reused and the morphology of the powder particles. These factors were recorded to see if they had any effect on the flow of the powders.

A main effects plot was created to quantitatively show how the usage of the powder controlled the flow rates. Figure 2 below shows the main effect plot. Briefly, it was observed that increase in usage influenced the flow ability of the powder samples.

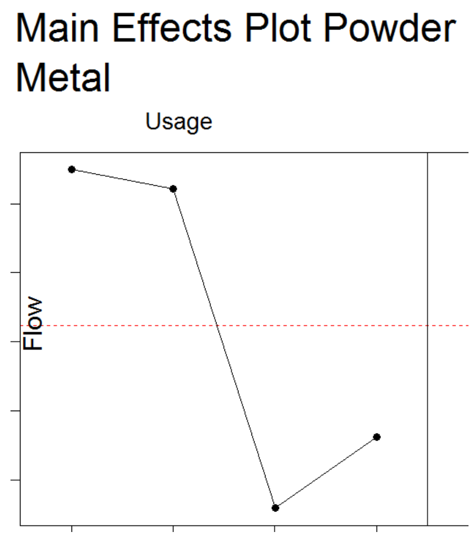

Figure 2. Main Effects Plot for Powder metal. The increase in use drastically changes the flow properties.

The change in the flow rate of the powder was also compared using a two-sample T-test shown in Figure 3. The data shows that small use powder has considerably different flow characteristics than longer use powder samples.

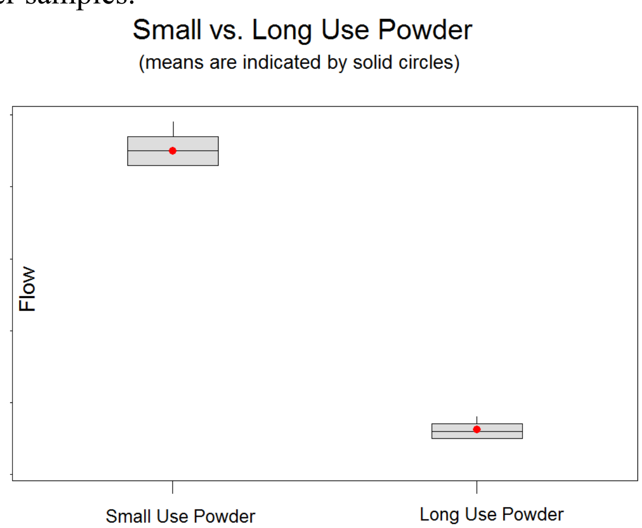

Figure 3. A 2 sample T-Test comparing small vs. long use powder and their change in flow.

Under a scanning electron microscope it was apparent that the shape of the powder changed over time. Figures 4-7 below represent magnified scanning electron images of powder samples at different reuse levels. It was apparent that the larger particles tended to agglomerate. The newer powder seemed to contain a higher concentration of finer particles while the longer term use powder seemed to have a high concentration of much larger particles.

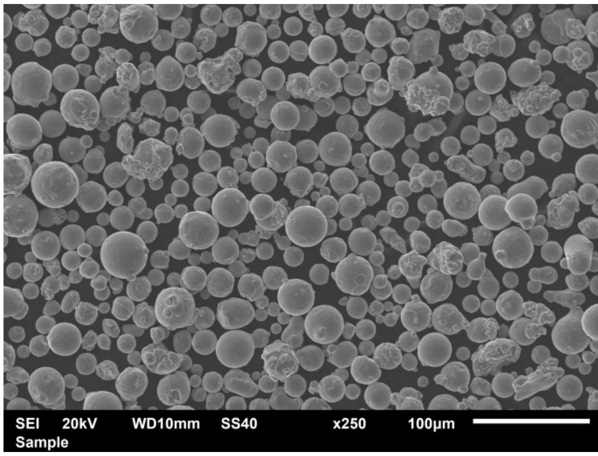

Figure 4. New Powder SEM image

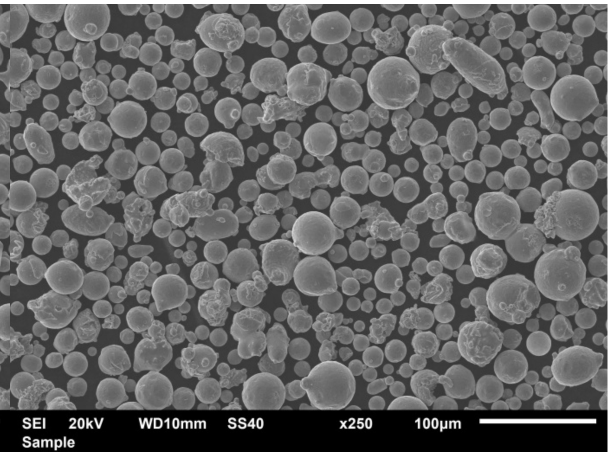

Figure 5. Short Use Powder

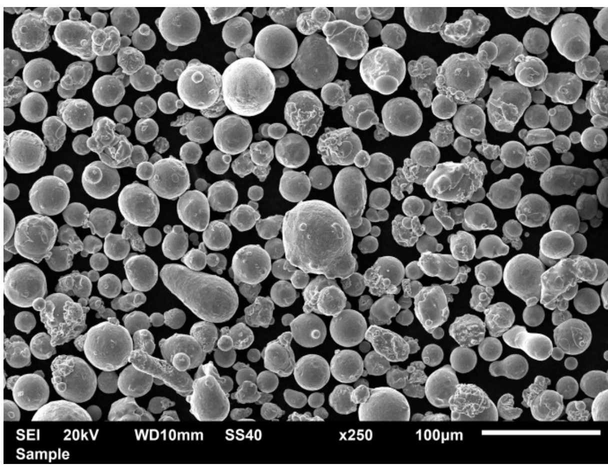

Figure 6. Medium use powder

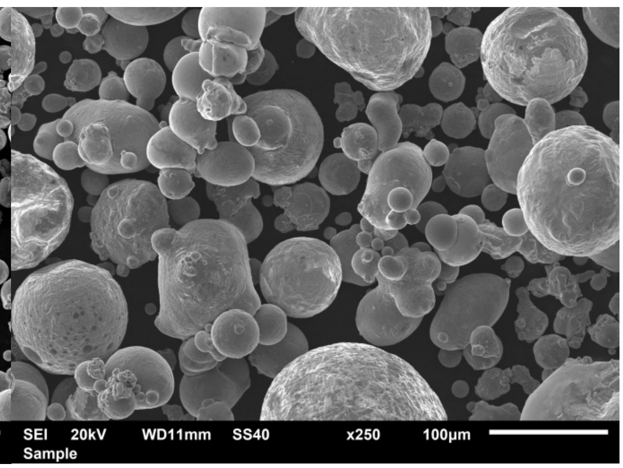

Figure 7. Long time use powder

The distribution of particle size is shown in Figure 8. The four different colors were overlapped onto a single plot to show the differences in the particle sizes between uses. There appeared to be minimal changes in the distribution of particles between different levels of use, however, the changes were noticeable. In general there was a trend that indicated a slight increase in the median particle size over the life of the recycled powder metals. This was concurrent with the fact that the flow rates changed with use, likely due to the changes in morphology and particle size. The ideal state of the powder is some that flows freely and uniformly, while also having the highest purity possible.

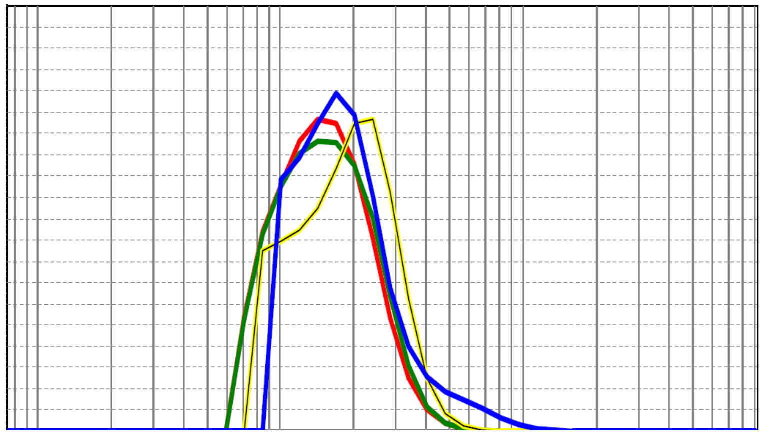

Figure 8. Distribution of particle sizes over use. The overlapping colors represent the stages of reuse for the PM samples. The distribution shifts slightly to the right with an increase in use of the powder metal samples.

5. Conclusion and Discussion

This experiment was an examination at powder metals to flow, their morphology and their change in size over time. It was apparent that in time, it is no longer useful to keep reusing powder. Although new powder is added incrementally to reused powder, there comes a time when the powder no longer has the desired properties. Interestingly, the reuse of powder actually increases the flow rates of powder metal. Some of the new powder did not flow if not dried prior to use. This would contribute to some of the powder not dispensing during a build, which could potentially ruin a part if not avoided. For this reason, proper storage and handling of powder metal is important. The SEM images revealed agglomerates forming onto larger particles regardless of the level of reuse. These agglomerates could contribute to impurities in the alloys and restrict pure metal parts from being produced.

My experimental works demonstrate that the continuation of reuse on powder has desirable flow characteristics, however runs the risk of introducing impurities. What was learned from this research is that there were noticeable changes in powder condition over its life and the changes should be monitored periodically. Industry can save money by finding the correct time, or make predictions on when to replace the powder. Flow tests and particle examination should be done on a regular basis to manage the performance of the powder, and when the powder no longer has desirable properties, it should be discarded.

6. References

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7. Acknowledgements

I would like to thank the entire GE Power MPE team in mentoring me during my internship. I would also like to thank UTSR for giving me the opportunity to work in such an exciting field and hope to continue to be able to work in the additive manufacturing industry. Finally, a special thank- you to D. Schick, S. Barnell, D. Bucci, B. Tollison and S. Kottilingam for all the help throughout the summer.