

Powder Reuse and Its Effects on Laser Based Powder Fusion Additive Manufactured Alloy 718

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ABSTRACT

Laser Based Powder Bed Fusion, a specific application of additive manufacturing, has shown promise to replace traditionally fabricated components, including castings and wrought products (and multiple-piece assemblies thereof). In this process, powder is applied, layer by layer, to a build plate, and each layer is fused by a laser to the layers below. Depending on the component, it appears that only 3-5% of the powder charged into the powder bed fusion machine is fused. Honeywell's initial part qualification efforts have prohibited the reuse of powder. Any unfused powder that exits the dispenser (i.e., surrounds the build or is captured in the overflow) is considered used. In order for the process to be broadly applicable in an economical manner, a methodology should be developed to render the balance of the powder (up to 97% of the initial charge weight) as re-usable. Though multiple manufacturers may be re-using powder, there is no industry standard methodology or practice for powder re-use. The present study (with 10 uses of the same powder lot) shows no appreciable impact on nickel-base superalloy 718 chemistry, powder size / distribution, or mechanical properties, with exception of gradual increase in oxygen content of the powder.

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INTRODUCTION

Laser Based Powder Bed Fusion (LBPBF) and other Additive Manufacturing (AM) methods have shown promise to replace traditionally fabricated (TF) components, including castings and wrought products (and multiple-piece assemblies thereof). This results in reduced time to deploy new designs, reduction of concept-to-prototype time, and reduction of machining and tooling costs. Honeywell International has recognized the potential of Additive Manufacturing and is taking measures to make the process more economical.

Laser Based Powder Bed Fusion, a specific application of additive manufacturing, is a process in which powder is applied, layer by layer, to a build plate, and each layer is fused by a laser to the layers below. Initial part manufacturing qualification efforts have prohibited the re-use of powder until the effects of re-use can be quantified. Any unfused powder that exits the dispenser (i.e., surrounds the build or is captured in the overflow) is considered used. Depending on the component, initial efforts show that 3-5% of the powder that exits the dispenser is actually fused. Therefore, a methodology must be developed to render the balance of the powder (up to 97% of the initial charge weight) as re-usable. Other studies have been completed on both similar and dissimilar materials, showing a of effects, ranging from no measurable effect to the extent of properties measured [1] to significant changes in particle size distribution and decreases in major constituents[2]. Though many manufacturers may be re-using powder, there is no industry standard methodology or practice for powder re-use. [Table 1](#) provides a list of powder characteristics that have shown potential to be influenced by powder reuse.

Table 1. Powder Characteristics that may be influence by re-use..

Characteristic	Examples
Chemical Composition	Bulk and surface-area driven constituents (oxygen, nitrogen, moisture)
Powder Size Distribution	Shift in d_{10} , d_{50} , d_{90}
Powder Morphology	Soot, spatter, and satellites
Cleanliness	Metallic (cross-contamination, equipment wear), ceramic, organic

Nickel-base superalloy 718 (UNS N07718) is the most widely used superalloy, due to its ability to be fabricated (cast, forged, machined, and joined) along with its balance of properties across a broad range of temperatures (from cryogenic conditions to upwards of 1300°F). Many manufacturers have recently focused efforts on development of additively manufactured Alloy 718 as an alternative product form to traditionally fabricated Alloy 718. This has resulted in a powder feedstock that is essentially a commodity. Despite its commodity status, typical prices for this material, suited for use in laser based machines, approach \$90 US per kilogram. Without re-use, the cost of virgin powder in the fused state can approach \$3000 per kilogram (i.e., \$90 per kilogram divided by 3% yield).

There are two types of concerns associated with re-using powder. The first is the cumulative effect of re-use, which can be defined as the changes in the chemical and physical nature of the powder due to interactions with the laser and machine environment. The second is the introduction of discrete defects due to the powder handling, interactions with contact surfaces, and exposure to the environment external of the AM machine. This study is intended to address the cumulative powder degradation concern to the extent that powder is re-used in the study. This understanding, in addition to implementation of robust powder handling equipment, handling procedures, and inspection methodologies, is critical to enabling powder re-use. The ultimate goal of this study is to determine whether re-using powder (to the extent captured in this study) degrades the powder to levels beyond the acceptance limits of Honeywell's internal specifications for AM Alloy 718 powder and parts.

APPROACH

Standard Alloy 718 build conditions validated on production parts were used to systematically build a series of test specimens with powder of increasing levels of re-use. Each build consisted of twenty test-bars, as depicted in [Figure 1](#). The test bars blanks were 1.27 cm in diameter and of decreasing lengths due to the nature of the study. The bars were built all built in the vertical orientation relative to the build plate (which maximizes build height and number of layers sampled in subsequent testing).

The study comprised the following steps:

1. Virgin (unused) powder was loaded into the machine's powder load chamber for the first run. The initial build (Build 1) maximized powder use (i.e. the height of the build consumed the entire powder charge).
2. At the end of the first build and each subsequent build, a powder sample was collected from the top of the powder that surrounding the build. This material was evaluated for particle size distribution, morphology, and chemistry.
3. The unfused powders from both the Build Chamber and Overflow Chamber were then removed from the machine and combined and then sieved through a 53 micron sieve.
4. After the sieving was completed, powder samples were collected from both the oversized and undersized fractions (i.e., > 53 micron and < 53 micron fractions). The undersized fraction (< 53 micron) was analyzed for particle size distribution, morphology, and chemistry; the oversized fraction was scrapped.
5. The undersized powder was then loaded back into the powder load chamber.
6. This process was repeated 10 times (i.e., one virgin powder build and 9 re-used powder builds). After 10 total builds, the build height was diminished to the minimum height required for a mechanical test bar.

To summarize, each build was designed to maximize powder use (i.e. the height of the build consumed the entire powder charge) and consisted of twenty (20) vertically-oriented bars ($\frac{1}{2}$ " diameter) that were used for metallography and mechanical testing. Photos of Build 1 and Build 10 are provided in [Figure 2](#).

Mechanical testing consisted of tensile and low-cycle fatigue (LCF) testing. This testing, along with robust powder handling equipment and associated procedures, is required to justify the re-use of Alloy 718 for production of AM parts.

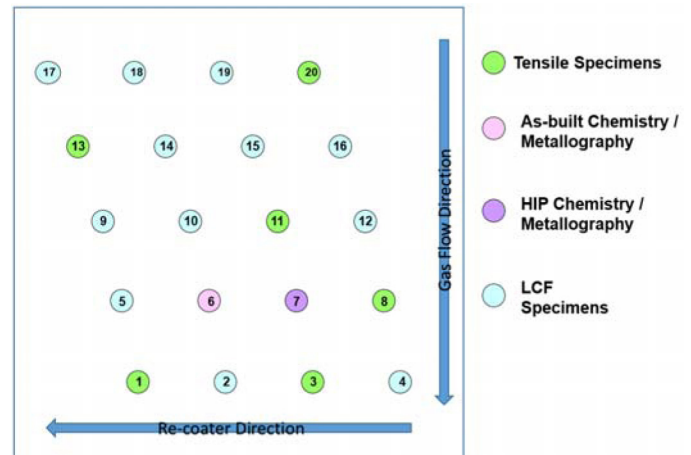


Figure 1. Test bar identification and relative location with each build cycle.

After building the test bars, they were thermally processed in accordance with ASTM F3055 Class D [3] (i.e., stress relieved, hot isostatically pressed, solution treated, and aged). Stress relief was performed prior to removal of the bars from the build plate.

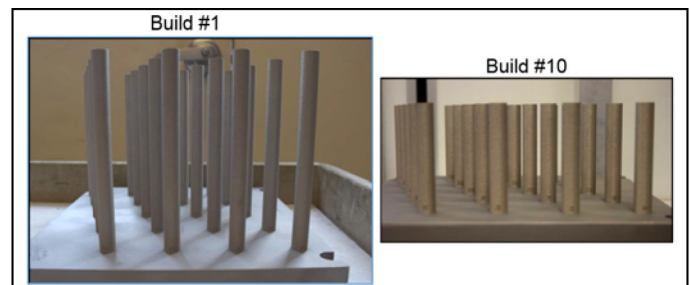


Figure 2. Builds 1 and 10, showing relative height, based on available powder.

RESULTS AND DISCUSSION

Powder Particle Size and Morphology

Samples of the as-received powder, referred to as "virgin", and the sieved powder resulting after each build were analyzed in accordance with ASTM B822-10 [4] using a Microtrac particle size analyzer. Results are shown in [Figure 3](#). It can be seen that the powder after processing and screening through a 53 micron sieve exhibits a consistent particle size at d90 (i.e., the particle size at which 90% of the particles, by weight, are smaller), d50 (i.e., the median particle size), and d10 (i.e., the particle size at which 10% of the particles, by weight, are smaller).

The virgin powder and the sieved powder resulting after each build were subjected to a more qualitative analysis by placing samples in a Scanning Electron Microscope and capturing digital images for comparison. Representative images are provided in [Figure 4](#). There is no apparent change in particle morphology.