LPW TECHNOLOGY
CASE STUDY:
THE IMPACT OF POWDER VARIABILITY ON ADDITIVE MANUFACTURING BUILD QUALITY

The impact of powder variability on Additive Manufacturing build quality

Why is a controlled AM metal powder specification necessary?

For metal powders to deliver consistent AM built parts with the required properties it is critical to define an appropriate material specification, with due regard for tolerances on manufacturing and testing variance. It is also necessary to establish limits which are tight enough to ensure any variations do not have a negative impact on process and application performance. Changes within specification values can cause variations in material processability during part manufacture, or the final mechanical properties of the part itself (see LPW case study 'Maraging Steel: The effects of alloy chemistry on processability').

Why does powder vary within specification?

A metal powder can not only move out of, but also vary within, specification in terms of its chemistry and physical properties. The concentrations of individual elements can differ between powder batches due to manufacturing variability such as vacuum quality and gas regulation, or changes in raw materials and consumables. This is of particular importance when comparing multiple powder suppliers for the same material. Deviations in size, shape, flow, density, etc., can be due to processing or environmental conditions.

The study

Building on its previous work to highlight powder specification variability, the impact of porosity, and the importance of the powder processing window LPW has conducted a study to evaluate the impact of powder variability during the Laser Powder Bed Fusion (LPBF) process. A series of density cubes were built from three different batches of AlSi10Mg using different atomising conditions. Nine cubes were built across a range of AM processing parameters, varying beam velocity and beam offsets.

Why is AM part density important?

In AM production density is a key quality metric, and a density of >99.9% is considered the benchmark for near fully dense builds. Porosity, the presence of small voids (pores) in a part represents weaknesses within the material, and these pores can act as crack initiation sites.

The elimination of porosity is a key focus of parameter optimisation for material build on AM systems (see LPW case study 'Porosity - Powder or process derived?').

Processing conditions, including laser offset, power, scan speed and spot size, among others, will all interact with the powder layer and therefore impact the quality of the end product (see LPW case study 'Testing powder for optimal processing window'). Consistent AM built parts depend on the consistency of the metal powder once the parameters have been devised to optimise its performance. LPW's experienced applications engineers can optimise metal powder for the specific AM machine and application, maximising the powder processing window to deliver consistent optimal results and increased successful AM builds.

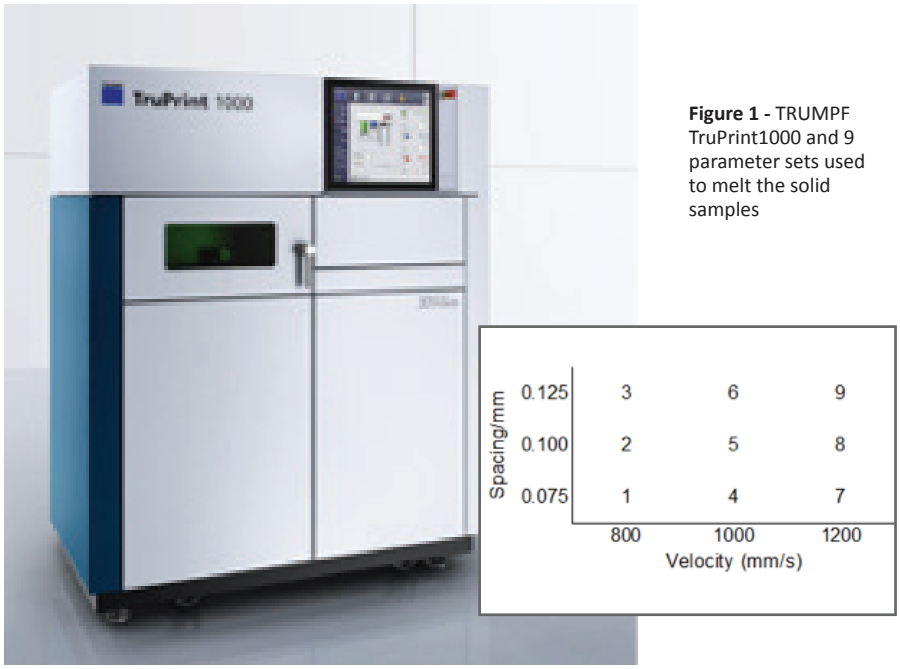

Figure 1 - TRUMPF TruPrint1000 and 9 parameter sets used to melt the solid samples

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LPW AlSi10Mg metal powder

Aluminium AlSi10Mg is popular within AM as one of a few aluminium alloys which is readily processable by LPBF, and in the 'as processed condition' it displays room temperature tensile properties rivalling that of high performance wrought aluminium alloys. It possesses a high specific strength and low density as well as very high thermal and electrical conductivity. It is easily machined and is used throughout several industries for applications which require a combination of good thermal properties and low weight.

The evaluation study

The study evaluates the impact of powder variability during the LPBF process. Three batches of aluminium alloy AlSi10Mg with nominal sizing 20-63microns were used to build 10mm density cubes on a TRUMPF TruPrint1000. Each batch was manufactured using different atomising conditions. A 3x3 array of samples were built at 9 different processing parameter settings. The beam velocity and weld track offset were varied over the 9 samples according to the diagram in Figure 1. All other parameters were kept constant (laser power: 175W, beam diameter: 50 µm, layer thickness: 30 µm).

The study examined the success of the LPBF process at achieving the highest density for the alloy, how sensitive the process is to powder characteristics, and how sensitive each powder batch is to variations in melting parameters.

Experimental results:

The three powder batches were analysed to quantify their differences in size and shape. The results display SEM imaging – Figure 2, Laser Size Diffraction – Figure 3, and quantitative shape analysis – Figure 4.

The solid samples produced (9 per batch, 27 in total) were cross-sectioned, ground and polished before image analysis was used to calculate area fraction of porosity.

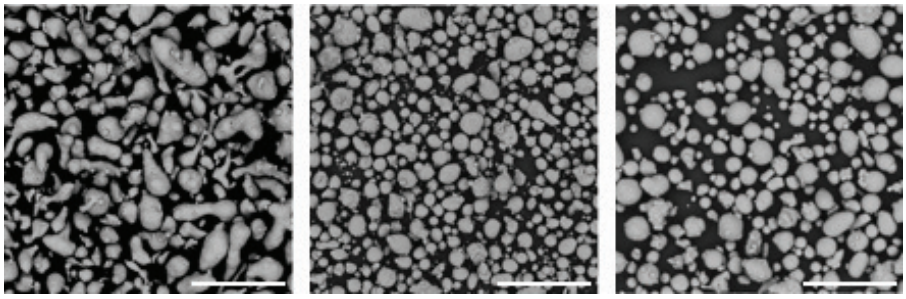

Figure 2 - SEM images of Powder 1 (left), Powder 2 (centre) and Powder 3 (right). White scale bar indicates 200microns and magnification is 300x in each case

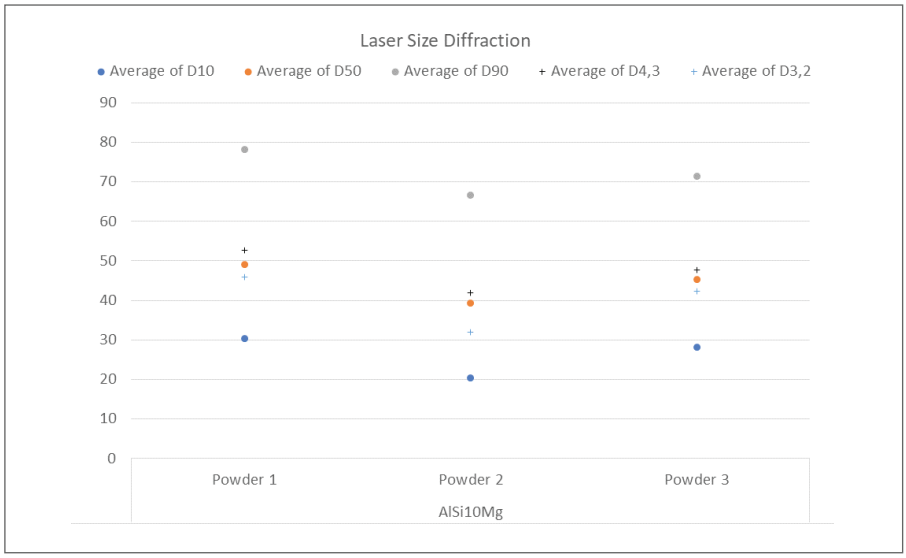

Figure 3 - Laser Size Diffraction results for the three powder batches

Powders 1 and 2 were nitrogen atomised and powder 3 argon atomised (see case study 'Nitrogen vs Argon Atomisation of 17-4 PH Stainless Steel and its Effects on AM Processing').

SEM imaging (Figure 2) reveals a significant difference in powder morphology between Powder 1 and the other two batches. This is distinctive of an aluminium alloy which is atomised in the presence of oxygen. The rapid formation of an oxide layer on the molten droplets creates a shell and locks in an elongated shape before surface tension can form a sphere.

The results of Laser Size Diffraction analysis, Figure 3, reveal that Powder 1 contains a larger proportion of coarser particles due to the elongated particles observed previously. Powders 2 and 3 are very similar with Powder 2 containing more fine particles indicated by a lower D10 value.

To better understand the link between powder morphology and build quality it is necessary to quantify the shape of a powder batch. 10,000 particles of each powder batch were imaged and the circularity, convexity and aspect ratio distributions of each were reported. Figure 4 shows the mean and D10 for the three parameters measured and clearly shows that Powder 1 has more particles with lower aspect ratio and fewer circular

(or spherical) particles compared to 2 and 3. All three have good convexity which indicates that satelliting of the powder has been avoided.

The solid samples:

Metallographic samples were prepared from the 27 density cubes built using LPBF. Figure 5 shows an example of SEM images obtained and the measured area fraction (% density) obtained. It is shown that all three batches are capable of delivering 100% density (to 1 decimal place) or at least 99.95%, however, not at the same melting parameters. Figure 6 shows the results plotted against energy density.

Powder 3 shows greatest consistency over the processing window investigated, Powder 2 performed similarly but less consistently at higher energy densities (low velocity, small offset), and Powder 1 showed acceptable results at the lowest energy densities (high velocity, large offset) suggesting it may be more stable if the processing window was transposed 'up and right' in the parameter space (i.e. relative to the heat maps in Figure 5).

Conclusions:

All three powder batches delivered good density results (>99.9%) at certain parameters despite their differences in particle size and shape. There was no common parameter set for all three powders to achieve their maximum densities, demonstrating that while all three powders conform to the standard specification for AlSi10Mg, if the metal powder used is not consistent the final built parts may not achieve their desired mechanical properties.

Future work:

Studies are ongoing to look at the influence of differing environmental conditions, the development of the oxide layer of powder, different types of porosity and the impact of surface roughness, on AM build quality.

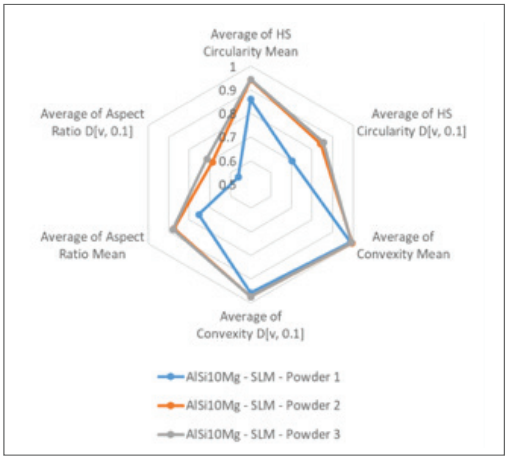

Figure 4 - Quantitative shape analysis of powder batches 1, 2 and 3

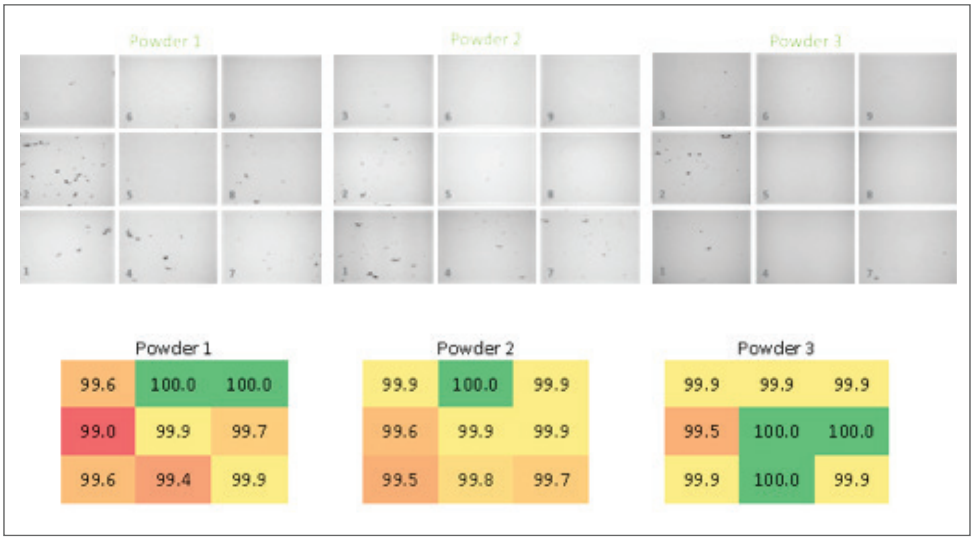

Figure 5 - SEM images of cross sections for the 9 samples of each powder batch (top) and heat maps of density % obtained after image analysis

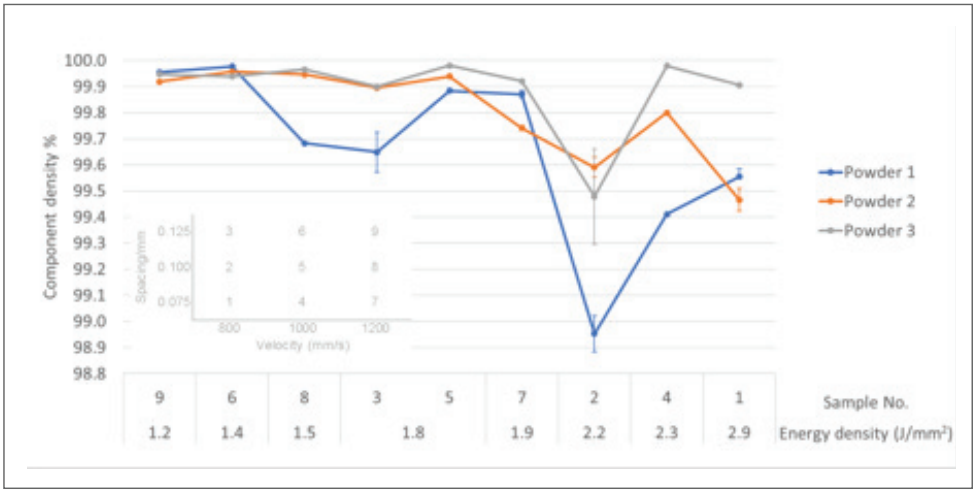

Figure 6 - Density of samples vs. energy density

$$\text{Energy Density} = \frac{\text{Power}}{\text{Beam velocity x offset}}$$