Porosity - Powder or process derived?

What is porosity?

Porosity refers to the presence of small voids in a part that make it less than fully dense. These pores represent weaknesses within the material and can act as crack initiation sites. The elimination of porosity is a key focus of parameter optimisation for material build on AM systems.

Sources of porosity

When porosity is identified in a built component, it is important to determine whether this is a result of parameter choice, machine performance or metal powder, as parameter derived porosity can be more easily controlled by the user.

Metal powder derived porosity - Gas atomisation

Gas atomisation has a reputation for producing powder with inherent porosity. This is more common in powder particles greater than 45 µm in diameter. Within the size ranges applicable to laser AM the occurrence is considered negligible for most materials when powder production is optimised.

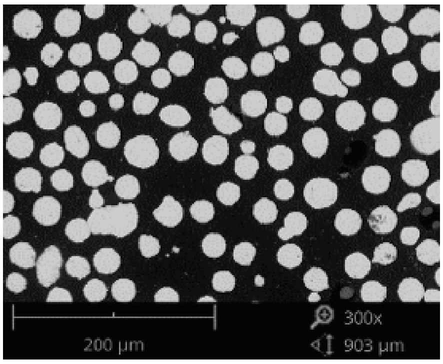

Figure 1 - SEM Micrograph of mounted and cross sectioned LPW-718 powder

Porosity from powder is considered low in severity. It typically presents in solid parts as micro-porosity, is randomly distributed, and is always spherical and smaller than the feedstock particles, which identifies it as the entrapment of gas within the melted material as it solidifies. Figure 1 shows the cross-section of gas atomised LPW-718 powder, sized for laser powder bed fusion. It is noted that no internal pores are present in the sample.

Parameter derived porosity

There are typically three different causes of parameter derived porosity. 'Lack of fusion' is caused by insufficient energy absorption or delivery, and presents as irregular shaped pores, typically aligned with layers and often containing unfused particles – Figure 2.

'Gas entrapment' is often the main cause of part porosity, and results from insufficient hatching/laser track overlap. Spherical in morphology, gas entrapment porosity is generally >20 µm which is larger than typical powder derived porosity– Figure 3.

'Vapourisation' is caused by excessive energy absorption or delivery. Large (>50 µm), irregular pores result from vapourisation and the subsequent expulsion of material from the melt pool – Figure 4.

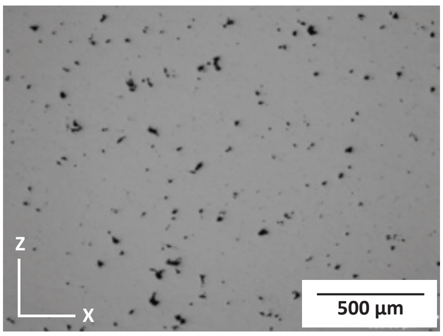

Figure 2 - Optical micrograph demonstrating lack of fusion porosity

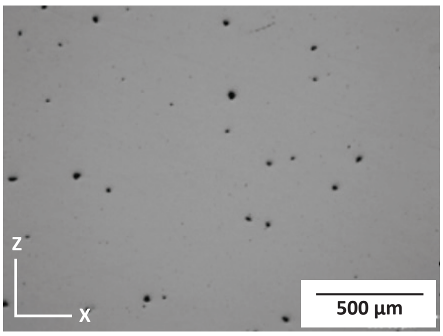

Figure 3 - Optical micrograph demonstrating gas entrapment by insufficient overlap

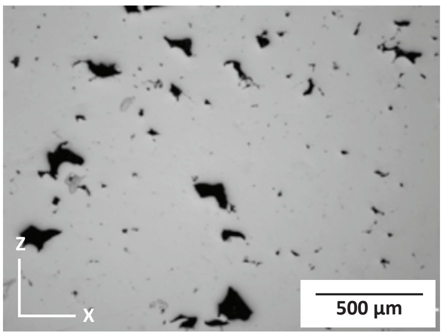

Figure 4 - Optical micrograph demonstrating vapourisation porosity

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CASE STUDY
POROSITY - POWDER OR PROCESS DERIVED?

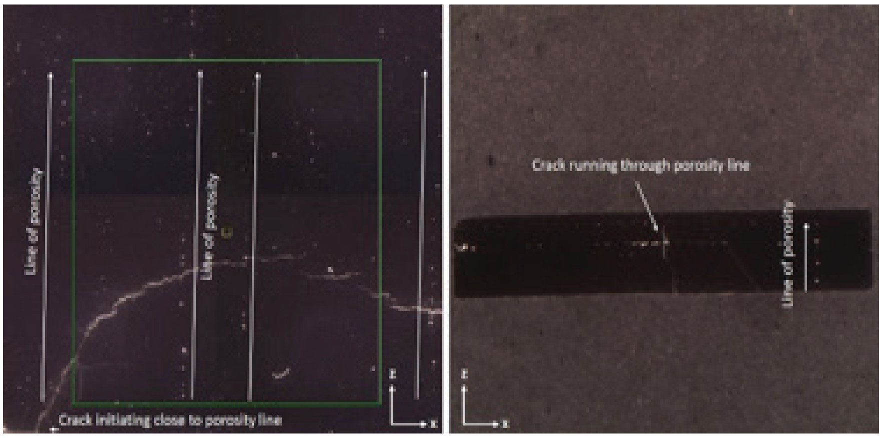

Figure 5 - Optical micrographs showing vertical lines of porosity which align closely to crack initiation or propagation paths

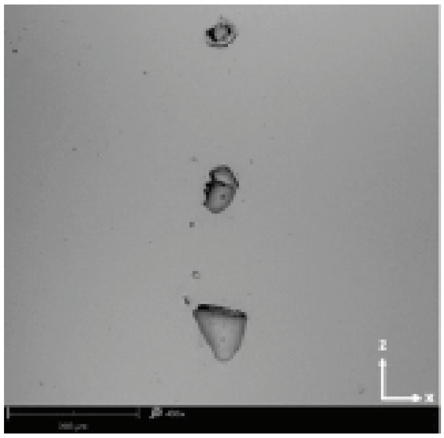

Figure 6 - High magnification SEM micrograph of porosity

Porosity – Identifying the source of cracking

Despite stress relieving heat treatment, a part fabricated with LPW-174 Stainless Steel by laser powder bed fusion had suffered severe macro-scale cracking during removal from the base plate. The concern was that the powder was the cause. Cracking had occurred during a trial of a new batch of powder.

The LPW PowderLab team examined the powder sample for contamination or deviations from the specification. No anomalies were discovered. Subsequent metallographic analysis was conducted on the solid part to find the crack initiation point and establish the root cause of the cracking. Figure 5 displays the low magnification optical micrographs of the cracked parts.

In addition to the cracks, lines of porosity were observed. Across the larger block, there were four distinct lines of porosity orientated in the build direction, whilst the smaller tensile piece had two. Figure 6 shows the pores under higher magnification. They are spheroidal and quite evenly spaced. Between 50-100 µm in diameter, they are too large to be from the powder.

The size and pattern of orientation of porosity indicated it derived from the laser scan strategy, specifically insufficient overlap of hatching. Further sectioning revealed that the porosity ran the full width of the samples. Additional analysis of the whole parts revealed a visible line on the cut surface which corresponded to the porosity and lined up with the cracks – see Figures 7 and 8.

The cracks had initiated from the porosity line, triggered when the EDM wire cut through the block. There was sufficient residual stress in the part to drive significant propagation of the crack along stress lines within it and along the line of porosity.

Combining LPW's materials knowledge and expertise with intelligent analysis, the PowderLab team excluded the metal powder as the cause of the porosity. Further discussion regarding the process revealed that the samples came from a newly installed system. The user was able to focus on optimising the process parameters for the new system, saving time, and eliminating associated problems and additional delays further into the build process.

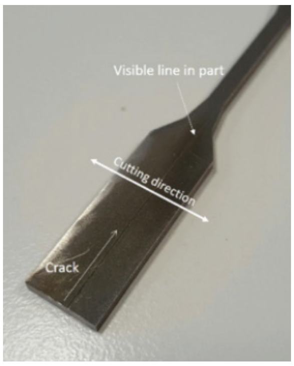

Figure 7 - Photograph of block sample showing full width of crack and EDM wire cutting direction

Figure 8 - Photograph of tensile bar with crack propagation and cutting direction direction

Figures 2, 3, 4 Harrison, Neil J (2016) Selective Laser Melting of Nickel Superalloys: solidification, microstructure and material response. PhD thesis, University of Sheffield