Bridge You and Nano

Exponential Business and Technologies Company

Porosity Measurement of Additive Manufactured Products using SEM

Additive manufacturing (AM) is a process by which parts and products are made layer-by-layer. There are a variety of types of AM, such as extrusion, powder bed fusion, material jetting, binder jetting, VAT photopolymerization, sheet lamination, and directed energy deposition that can be used for polymers, metals, ceramics, and composites. Additive manufacturing is a rapidly growing field that impacts numerous commercial areas, such as aerospace, automotive, medical, energy, and other industries. One of the common challenges in the AM process is unintended porosity within the printed piece. This porosity may come from poor layer adhesion, filament quality, powder packing, or unoptimized fabrication parameters. When the total porosity of a part increases, its mechanical properties such as stiffness, tensile, compressive, and fracture strength tend to decrease. As known from fracture mechanics, the stress that causes fracture in a brittle material, σ, is closely linked to the maximum flaw/pore size, a, by

$$\sigma \propto \frac{1}{\sqrt{a}}$$

Porosity and pore distribution impact product density, thermal conductivity, electrical conductivity, permeability, and many more other properties that may be relevant and important for a given application.

One technique to measure the porosity of a part is to image its cross-section using scanning electron microscopy (SEM). A scanning electron microscope functions by having a focused, high energy electron beam raster scan a sample surface area to gain topographical and compositional information. The SEM at Ebatco's NAT Lab is equipped with a large specimen chamber that allows for analysis of a wide variety of samples with sizes and shapes up to 70 mm in height and 178 mm in diameter. Our SEM is utilized for high resolution imaging at magnifications of 30x – 300,000x and can be operated in low vacuum mode to examine non-conductive samples without needing an electrically conductive coating for the sample surface.

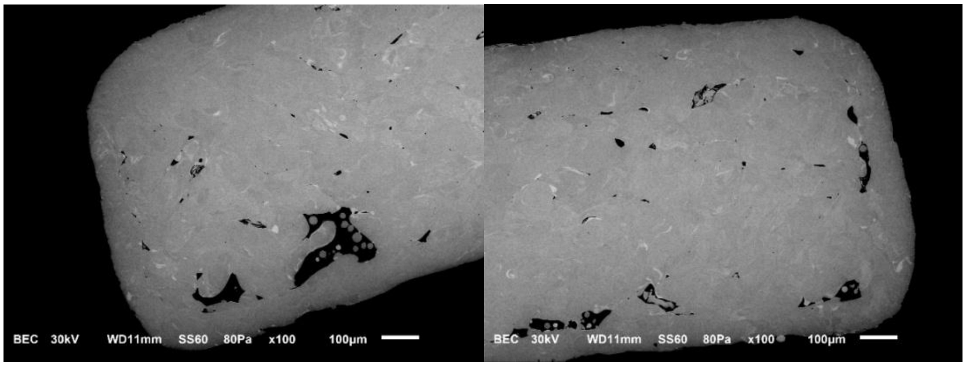

Figure 1. Low vacuum SEM images of two sides of a metal AM product cross section at 100x.

Two regions of a cross section from an AM product made with laser powder bed fusion are shown in Figure 1. The high resolution and brightness contrast make it possible to clearly identify the pores in the sample as the darker regions. The readily visible large pores may be caused by a low powder packing density or improper fusion during the manufacturing process. Inside the larger porous regions, spherical metal particles can be seen, which may be due to incomplete fusion. In the images, smaller features like cracks and small pores are also visible. With these high-quality SEM images, an image processing software, ImageJ, was used to quickly identify the pores within the cross-section and to determine key aspects of the sample porosity.

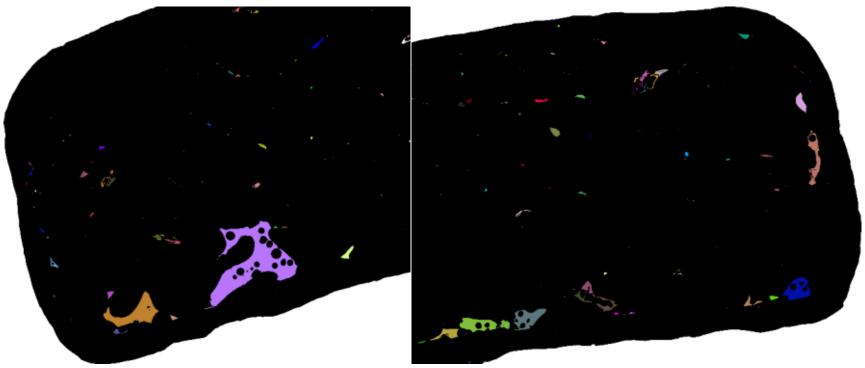

Figure 2. ImageJ analysis of porosity on two sides of a metal AM product.

Table 1 Quantitative Porosity Characteristics of Two Sides of a Metal AM Product

Total Porosity (%)	**Average Max Feret Diameter (µm)**	**Average Min Feret Diameter (µm)**	**Average Pore Area (μm^2)**	**Largest Pore Area (μm^2)**
2.66	13.25	5.98	171.21	17,155.14

Figure 2 shows the ImageJ processed SEM images with colored overlays on porous regions and a black background for the non-porous fused metal. ImageJ was also used to analyze the images and to determine the porosity characteristics. As displayed in Table 1, the total porosity determined from all pores found on the two sides is 2.66%. In addition, every pore is individually analyzed and statistics for the porosity of the AM product are determined. From Table 1, the average maximum pore Feret diameter is 13.25 µm, the average minimum pore Feret diameter is 5.98 µm, and the average pore area is 171.21 μm^2. Further, the largest pore, as shown in light purple overlay of Figure 2, has an area of 17,155.14 μm^2.

As mentioned previously, microstructural flaws such as cracks, pores, voids and other defects within a part can have significant influences on the fracture and failure of the part. The microstructural flaws can act as stress risers and might induce failure during its service. SEM analysis of a part cross-section can be used to identify the size, location, and shape of individual pores at micro and nano scales in additive manufactured parts. With the assistance of an image analysis tool, pore size distribution and porosity can also be obtained easily. A better understanding of porosity in additive manufactured parts will help to achieve desirable mechanical strength and other material properties for additive manufactured products.