



Bridge You and Nano

Exponential Business and Technologies Company

Mapping Mechanical Properties of Additive-Manufactured Products using XPM

Additive Manufacturing (AM) allows for rapid and customized production in various industries, such as aerospace, automotive, medical, energy, and consumer products. The AM market is expanding rapidly, with the technology being easy to utilize with efficient optimization and customization. While additive manufacturing is often utilized for prototyping, a large portion of AM products are end-use and put on the market after production. There is a large appeal for using AM to tailor products for different customers, allowing industries such as medical devices, footwear, and fashion to have perfectly fitting products for people at reasonable costs. Aerospace, automotive, and energy industries can manufacture components that require high dimensional accuracy, quick turnaround time and unique properties unachievable through other manufacturing techniques.

To assess the quality and the processing conditions of AM products, knowledge of spatially resolved mechanical properties can be very important and informative. Accelerated Property Mapping (XPM) is a new nanoindentation method to measure the mechanical properties on a nano- and micro-scale. Accelerated property mapping utilizes a diamond tip to perform nanoindentation testing at speeds of up to 3 indents per second. Each indent generates a force-displacement curve, and with a known area function of the indenter tip, it can be used to determine reduced elastic modulus and nanohardness based on the Oliver and Pharr method. Arrays of these indents are used to generate maps of mechanical properties of large areas, called XPM maps.

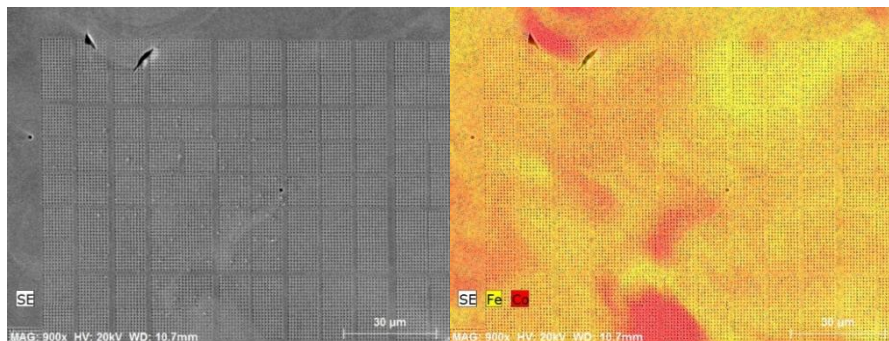


Figure 1. SEM (left) and EDS (right) images of an AM metal pen cross section at 900 X with XPM nanoindentation grid overlays.

For this analysis, 10,800 indents, with 1 μm spacing between each, were performed on an AM metal pen cross-section to generate XPM maps. Figure 1 shows a Scanning Electron Microscopy (SEM) and an Energy Dispersive X-Ray Spectroscopy (EDS) image with nanoindentation grid overlays of the metal pen cross-section used for XPM testing. The left image in Figure 1 displays the morphology and the right image displays the elemental distributions for iron in yellow and cobalt in red. Other alloying elements that are present in the pen cross-section, like nickel, chromium, and silicon are not shown here for visual clarity. There are noticeably distinct regions



with different morphologies and compositions in the pen cross-section. To assess how the morphology and composition influence mechanical properties, XPM analysis was employed.

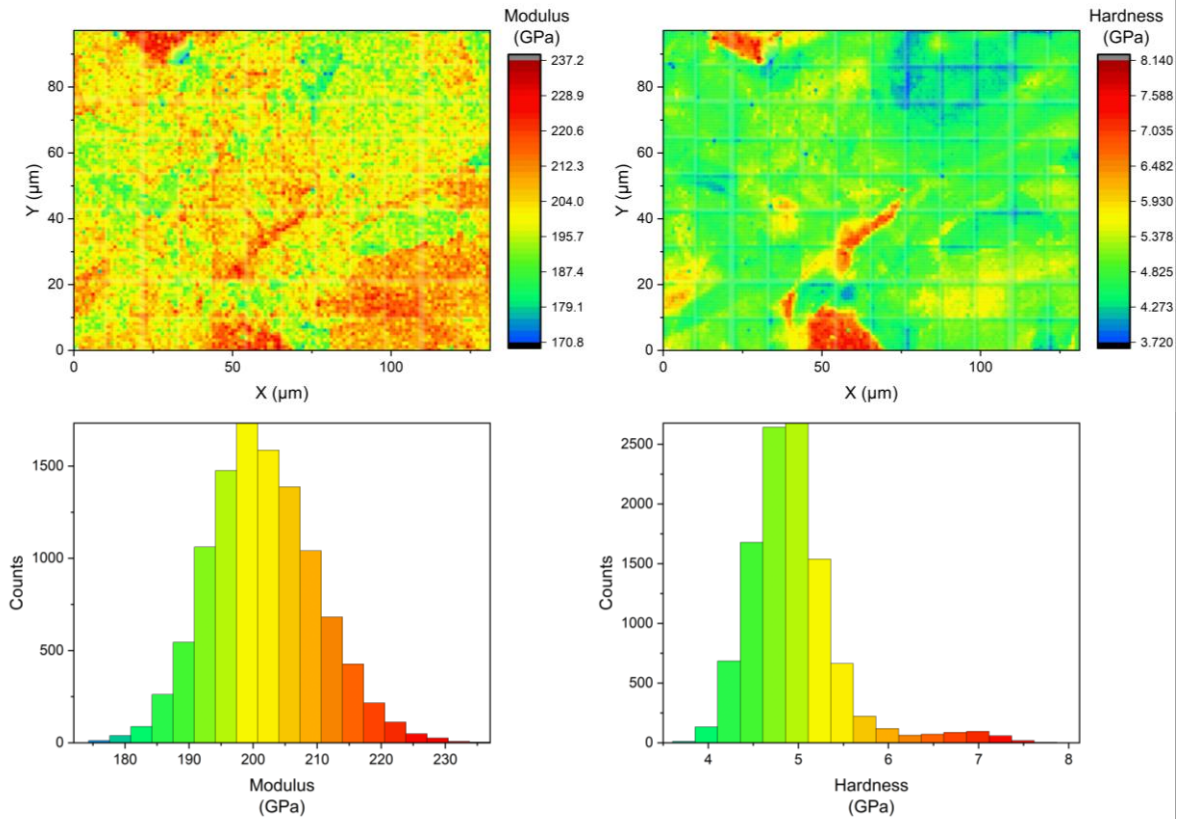


Figure 2. XPM maps (top) and histograms (bottom) of the reduced elastic modulus (left) and nanohardness (right) of an AM metal pen cross-section.

Figure 2 presents the XPM data for the reduced elastic modulus and nanohardness measured on the metal pen cross-section with the color maps showing regions where the reduced elastic modulus and nanohardness values are noticeably different. These maps correlate well with the morphology and elemental data shown in Figure 1. The Co-rich regions on the EDS map all have hardness values between 6.0 and 7.5 GPa, while Fe-rich regions have lower hardness values from 4.0 to 5.5 GPa. The differences in reduced elastic modulus are less noticeable between the two different kinds of element-rich regions, but the regions with higher modulus values still match Co-rich regions.

As illustrated above, accelerated property mapping (XPM) is a valuable tool for characterizing AM products. XPM performs nanoindentation tests at extraordinarily fast speeds and at high spatial resolutions to reveal mechanical property distributions at a nano-, micro-scale. It can be utilized to assess defects, impurities, inclusions, different phases, or compositional variability in additive manufactured products.