Microscopy and imaging are vital tools for quality control of materials without which our confidence in the safety of airplanes, cars, bridges, buildings, ships, etc. would be greatly reduced. Almost all materials have a microstructure (a fingerprint in the micro world), and the condition of this microstructure can often tell why a bolt failed, a building collapsed, or a material behaved in an unpredictable way. In general, microscopy and imaging strive to link the macroscopic properties of a material to its underlying microstructural features in an effort to predict a materials performance.

Over the past twenty years, digital imaging has shaped a paradigm shift from manually looking through the microscope’s eyepieces to working with a mounted camera and imaging software. By seamlessly integrating the microscope, camera, database, and analytical tools, an image of a microstructure may almost instantly be captured, analyzed, and archived to be recalled at any time. Images can be rotated, enhanced, digitally zoomed, or manipulated in countless ways to aid in their analysis. The digital image is a column and rows matrix of numerical values (pixels) ideally suited to mathematical manipulation. Each pixel contains information detailing the x and y position of the pixel, and a numerical value defining its color or grayscale level. These numbers are exploited when digitally enhancing images (filtering) and when isolating regions of interest in the image based on the color or grayscale values (thresholding). This technology has propelled the industry from relying largely on qualitative observations through the eyepiece toward depending primarily on quantitative analysis using software. Confidence in the accuracy of analytical measurements is typically ensured by calibrating the imaging system using length standards that are traceable to an authoritative body such as National Institute of Standards and Technology (NIST).

Organizations such as International Organization for Standardization (ISO), ASTM International (ASTM), Japanese Industrial Standards (JIS), German Institute for Standards (DIN), and national standards bodies ensure that imaging systems are traceable to authoritative standards.

Fig. 1 — Comparing an image of a sectioned PCB on the left with reference images on the right (a); multiple individual images stitched to form a composite image of a surface fracture with a length measurement (b); and focused image of foam comprising multiple images acquired at different heights above the surface (c). The focused areas from each individual image are retained in the final composite image.
Standardization (DIN), American Society of Mechanical Engineers (ASME), Society of Automotive Engineers (SAE), and Institute of Printed Circuits (IPC) have published various industry best-practice standards and methods for analyzing materials at the microstructural level. In general, it involves preparing the materials surface to reveal features of interest and then measuring those features following appropriate and relevant procedures. Various examples of applying digital imaging to solve real-world measurement applications are detailed below.

Digital imaging is versatile

The ability to acquire an image and compare it to a reference image is of immense importance to a materials microscopist performing simple quality control pass/fail analysis. Digital imaging ensures ease-of-use by allowing the acquired image to be manipulated (rotated, digitally zoomed, etc.) to closely match the reference image being used for comparison. The use of comparison tools to examine copper in a sectioned printed circuit board (PCB) is shown in Fig. 1a.

In addition to working with a single field-of-view, digital imaging offers enhanced image capture possibilities. For example, if one wishes to inspect a large feature at high magnification, separate images may be stitched together to create a composite view of the entire feature, where the composite image remains suitable for quantitative measurements. Use of a stitched image for inspecting a surface fracture is shown in Fig. 1b. For surfaces that are not smooth, it is often impossible to view an image that is sharply focused at all locations across the field-of-view. Digital imaging can easily surmount this problem by acquiring multiple images at different heights above the surface and creating a composite image that retains the “focused areas” from each individual image. This type of functionality is shown in Fig. 1c.

Quality control tools

Typical quality control measurement applications include, but are not limited to, dimensional measurements, area percent phase analysis, grain size, and particle shape and size analysis. Digital imaging systems offer a variety of manually interactive dimensional measurements such as length, parallel distance, curve length, object area, angle, and point count grids. Point-and-click tools like these are an efficient means for measuring a few parameters on an image. Figure 2a shows a parallel line measurement to estimate the average thickness of a protective coating.

When the application entails a significant amount of image acquisition or analysis, automated methods offered by digital imaging are invaluable. For example, the coating thickness measurement discussed above can be significantly enhanced by automatically dropping a grid of measurement lines on the coating enabling a statistical analysis of the coating thickness for quality purposes (Fig. 2b).

Volume fraction measurement by systematic point count, as detailed in ASTM E562: Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count or ASTM E1245: Standard Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis, is an ideal candidate for highlighting the benefits of digital imaging and automated analysis. A traditional manual point count would be achieved by overlaying a grid on the image and counting the intersections between the grid and phases of interest. Increasing the points in the grid increases the measurement accuracy, but manually counting very large grids is impractical. With a digital image, each pixel is a point on the grid enabling a dramatic increase in grid points whereby the software and computer effortlessly
does the counting. Pixels with color values falling between certain thresholds are assigned to different material phases thereby enabling, for example, the calculation of the relative volume fractions of phases in a multiphase system. In practice, it is common to assign the different phases under investigation to colored bitplanes as shown for the multiphase material in Fig. 3. Expanding this to compile statistical data over multiple fields of view is straightforward with digital imaging.

Once individual objects such as particles or pores are isolated, they may be measured individually. Generally, objects that are interconnected and those which are not fully contained within the field of view have to be removed from consideration. This is easily achieved with a digital imaging system. When a large number of objects are present, individual object measurements would be extremely impractical using traditional microscopy methods. These ideas are explored for measuring pores in a porous coating (Fig. 4).

Grain size measurements for quality control are widespread throughout materials industries and are particularly

Fig. 4 — Cross sectional view through a thermal spray coating showing pores (black areas in the image) in the coating (a); individual pores with areas less than 600 μm² are assigned to a green bitplane, while all larger pores are assigned to a blue bitplane (b). Detailed quality control of porosity in coatings, such as analysis of oversize pores, is possible using these types of measurement techniques.
suited to digital imaging. Standards such as ASTM E112: Standard Test Methods for Determining Average Grain Size, written for manual measurements of average grain size may be easily adapted to benefit from digital imaging methods. Additionally, ASTM has produced guidelines for automation of grain size measurements in ASTM E1382: Test Methods for Determining the Average Grain Size Using Semi-Automatic and Automatic Image Analysis. Digital imaging is particularly powerful for effortlessly determining the ALA grain sizes (ASTM E930: Methods of Estimating the Largest Grain Observed in a Metallographic Section) and efficiently handling image data for evaluating grain sizes in duplex distributions (ASTM E1181: Methods of Characterizing Duplex Grain Sizes). Figure 5 shows examples of using digital imaging to perform grain size measurements.

Understanding the size and shape distribution of individual objects in a host matrix is important for many guest-host materials, such as inclusions or reinforcements in composites, inclusions in steel, graphite nodules in ductile iron, etc. While techniques in ASTM A247: Standard Test Method for Evaluating the Microstructure of Graphite in Iron Castings describe a manual comparison method for classifying graphite nodules in iron castings, widespread use of digital imaging to measure graphite nodules is currently driving the necessity for a standard test method for automated analysis. Size distribution analysis of objects is straightforward with digital imaging, where the objects can be isolated, individually measured, and statistically analyzed. Of equal importance is an understanding of the shape distribution of objects, because this can influence tensile strength, machinability, and other mechanical properties of materials. Object shape factors are often based on relationships between the object’s perimeter, diameter, and area. An example of size and shape distribution measurements of graphite nodules in ductile iron is shown in Fig. 6.

**Conclusion**

As new testing standards for materials are developed to take full advantage of digital imaging capabilities, part of the process will entail determining the optimal approach for consistent testing, measurements, and results that minimize inevitable sensitivities to the resolution of the imaging system. The ability to almost instantaneously process large images, access multiple fields of view, automate analysis, and scrutinize large numbers of objects individually presents a significant opportunity to take microstructural analysis far beyond the limits of traditional microscopy. The enhanced information that digital imaging can derive from a material’s microstructure should help deliver new, powerful quality tools to help predict anomalous macroscopic behavior of materials based on the condition of the underlying microstructures.

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