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TECH NOTES

Quantitative Image Analysis, Part II Applications

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Introduction

"Quantitative Image Analysis, Part I: Principles", the history of imaging systems was reviewed along with an in depth look at the principles governing imaging systems. That summary of stereology, gray levels, binarization, pixel representation, filters and primary measurements laid the foundation for our current topic, Image Analysis applications.

Throughout the past 20 years of Buehler's involvement in image analysis, a number of applications stand out and may be of interest to most image analysis users. A review of the measurements used for the majority of applications is found below.

Grain Size - Image analysis systems provide a rapid and accurate means for automating grain size determination normally conducted manually according to ASTM E 112. Even if etching is unable to produce complete grain boundaries, or if there are twins that could skew the data, binary image modifications can be employed to make corrections. If a specification cites grain size limitations, the outlier grains may be transferred to a different bitplane color to provide visual as well as numerical feedback.

Phase Percentage - This is a simple measurement for imaging systems because it is only a ratio of the detected pixels of interest to the total number of pixels comprising the image. Knowing the area percent of various phases or constituents in a microstructure is important because it influences the properties. The tensile strength of grey iron, for example, is directly related to the percentage of pearlite in its microstructure. Likewise, the relative percentage of porosity in a powder metallurgy material will determine its suitability for a given application.

Using image analysis software, multiple phases can be detected in a single image, measured and presented graphically. For example, when evaluating the inclusion content of steels, it would be useful to examine the overall inclusion content as well as isolating particular inclusion types, such as oxides and sulfides.

Linear Measurements - Simple point-to-point manual measurements are widely used for making occasional measurements; however, in cases where a high quantity of measurements and more statistics are required, automated image analysis should be considered. A coating or layer can be detected based on the pixel color values and then, after binary isolation of the coating, grid lines are superimposed. Using Boolean logic to evaluate the common pixels between the layer and grid lines, the result is the automated generation of multiple measurement lines, representing the variation in the thickness.

Feature Shape and Size - Individual features within the image can be measured providing the total number present, number per unit area, maximum size, average size and the size distribution in the form of a histogram. In addition, most imaging systems offer several approaches to classifying the shape of features by comparing the perimeter and area. This can be critical for some materials such as cast iron. Ductile iron was developed such that the graphite would occur in the form of spherical nodules with the result of dramatically improved mechanical properties. However, variations in chemistry and other factors can cause the nodules to be irregular, leading to some degradation of the properties. The ability to monitor the graphite shape or determine "nodularity" is another capability of image analysis.

These measurements and techniques can be utilized for almost any application ranging from grain size in steel to entrapped air in concrete and even growth rings in dinosaur bones. Automated imaging applications are based on a fundamental series of steps shown in Table 1. Depending on your goals, some or all of these steps may be utilized. For this Tech-Note, three materials were chosen to illustrate just a few examples of imaging capabilities.

Table 2. Primary Imaging Steps

Acquisition	Capture, load, or import an image
Clarification	Develop the necessary contrast and clarity for detecting the features of interest
Thresholding	Detect the features of intereset
Binary Operations	Clean-up any detection discrepancies, categorize features, and overly measurement grids
Measurements	Conduct field or feature specific measurements in a single field of view or over multiple fields
Data Analysis	Evaluate statistics and relevance of the measurements
Archive	Store images, annotations, and associated measurements in a database
Distribution	Printing or electronic distribution of images and results

Weld Characterization

Welding is an integral part of the manufacturing process for automobiles, earthmoving and construction equipment, submarines, art and sculptures and many more items that touch our daily lives.

For example, race cars require hundreds of welds. Most welds join intersecting tubes that make up the frame and the all-important roll cage. NASCAR requires the frame and roll cage components to be fabricated from lowcarbon steel. This allows the car to absorb the forces of a crash in a bend-before-break mode. Although the driver cannot be protected from every incident, most drivers walk away unhurt. This is attributed to the chassis design and weld quality.[1]

By conducting a metallographic examination it is possible to verify the presence of voids and cracks indicated by nondestructive test methods as well as measure the extent of those flaws. In addition, the depth of the weld penetration for different processing parameters can be measured, enabling process improvements. More often than not, this type of measurement, when conducted using an imaging system, is operator interactive. Interactive measurements require the operator to use a mouse to select the start and end points for each measurement. The most common of these are point-topoint, parallel, radius or diameter, curvilinear, and angle. An operator will typically make several measurements over the area of interest. This method is appropriate for a limited number of measurements or where an average value is of interest.

The size of a weld may be determined by making several different interactive measurements. The weld geometries listed in Table 2 are typically annotated or measured. Figure 1 demonstrates a leg, plate thickness and penetration measurement using the parallel and point-to-point tools for a low-carbon steel lap weld. Oftentimes, it is the relative size of the weld that is important; a general rule for fillet welds is that the ratio of the leg size to plate thickness should be between 3:4 and 1:1.2 The direct transfer of the weld measurements to a spreadsheet for further calculations and quality control documentation is a benefit of using an imaging system.

Table 2. Nomenclature for Weld Microsections[2]

Feature	Definition
Root	Points at which the back of the weld intersects the base metal surface
Toe	Junction between the weld face and the base metal
Leg	Shortest distance from the root to toe in a fillet weld
Penetration	Depth a weld extends into the root of a joint

The appropriate methods for weld characterization depend on the weld's function and the properties required for the application. In some instances, the main criteria is dimensional as shown in Figure 1. In other cases, it is more important to characterize metallurgical factors such as weld composition and microstructure. Properties such as strength, ductility, toughness or corrosion resistance are linked to these criteria.

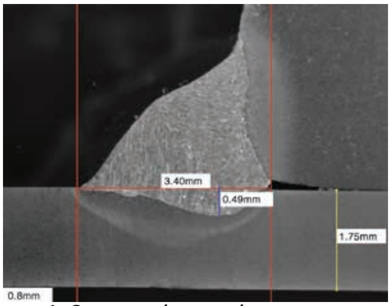


Figure 1. Operator interactive measurements of the weld leg (red), penetration (blue) and plate thickness (yellow) using the parallel and point-to-point tools for a low-carbon steel lap weld.

Most microstructural observations for welds focus on the fusion zone and heat-affected zone (HAZ). The heat introduced by the welding process creates a temperature gradient which in a wrought steel component can generate a variation in grain size. Figure 2 displays a cross section of a low-carbon steel weld where the base metal is on the far left and the weld material is on the right. Not only is the individual grain size and morphology of interest, but also the relative position of those features. The graph demonstrates the refinement of the grain size in the HAZ.

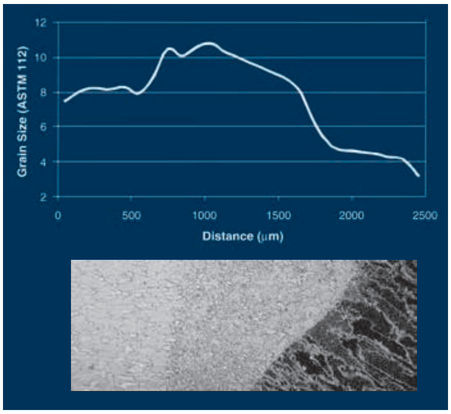


Figure 2. A cross section of a low carbon steel weld where the base metal is on the far left and the weld material is on the right. The grain size in the HAZ has been refined during the welding process.

For this example, the area of individual grains was measured in order to calculate the grain size according to ASTM E 112. The methodology included the following steps:
• Detection of the grain boundaries
• Binary commands to ensure that all the grain boundaries and only the grain boundaries were detected
• Inverting the detection such that the grains were detected instead of the boundaries
• Thickening the grains so each boundary was only one pixel wide
• Measuring the feature grain size (the area to grain size value calculation is automatic within the software)
• For graphing purposes, the average grain size was calculated in a spreadsheet with 100μm size intervals

When measuring grain size using this approach it is important to select the correct etching technique to reveal the grain boundaries as clearly as possible. While most software programs have the capability to estimate the location of missing grain boundaries, proper preparation techniques will improve the repeatability of the results. In addition, it is important when determining feature measurements to have a minimum of 100 pixels representing each feature. While the image shown was captured using the 5X objective on the microscope, the images for analysis were captured using the 20X objective. The only exception being for the grains within the weld itself where the lower magnification image was analyzed.

If the main interest is in determining the average grain size for each field and not the range of grain sizes present, you could use the chord length of the grains as determined by evaluating each grain boundary intersected by a row or column of pixels. Or, you can collect less data and replicate manual techniques by imposing a 3-circle or other grid over the image.

Coins – Plating Thickness

There are quality specifications for all the coins that are produced. The specifications for Canadian coins provide the steel blank weight, diameter and other parameters. Preannealed steel blanks go through an electroplating process to produce multilayer plated blanks. The current and the time for the electroplating of the steel blanks are calculated based on the desired thickness of each layer.

The thickness of the nickel and copper layers, as shown in Figure 3, is critical for both the manufacturing process and the final product. If the thickness is not sufficient when the coin is struck, it damages the base material. Likewise, the outer layer provides the necessary corrosion resistance for the coin to remain in circulation. And finally, the most significant criteria, the magnetic signature of each denomination depends on the thickness of each layer. This is critical for the coins to be accepted by vending machines, parking meters and toll booths.

An automated imaging approach was used to evaluate the thickness of the coin plating layers as shown in Figure 3. To capture the image of the coin microsection, a color camera was selected so that it was not necessary to etch the specimen to accentuate the copper layer. However, 2% nital was used to create a distinct line between the Ni layer and the steel blank. The detection process was straightforward, selecting the layers based on the HLS (hue, luminance and saturation) values of the pixels. Basic binary operations, such as trap, which distinguishes detected areas based on the number of pixels in contact, were employed to clean up the image. Once the layers, and only the layers, had been properly detected, a vertical grid was placed over the image. Using the Boolean command, AND, it was possible to isolate the chords that contain both the layers and the grid lines.

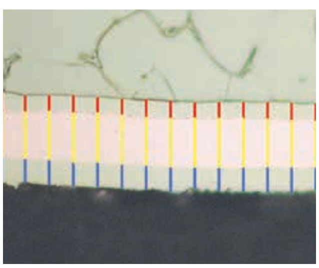


Figure 3. The thicknesses of the coin plating layers were evaluated by measuring the corresponding chords: Ni-red, Cuyellow and Ni-blue.

Table 3 contains the results from measuring the grid lines superimposed on the coatings. The number of grid lines needed would depend on the extent of the variation present. For a fairly flat coating, very few lines would be necessary to evaluate the surface. In addition, this technique can be used for quality control by visually flagging any dimension out of tolerance. For example, if a minimum thickness of 4.5 micrometers were required for the outer Ni layer, it is possible to change the color of any grid line less than that value to another color such as green. An additional measurement can then be added to the routine, counting each time that a green grid line appears in the image.

Evaluating Composites

There are many materials that contain a secondary phase or constituent. It may be as a result of the solidification process, such as graphite in cast iron, or it may be deliberately introduced, such as silicon carbide particles in an aluminum matrix composite. In either case, the mechanical properties are highly dependent on the volume fraction, shape, size and distribution of that second phase.

In evaluating a two-dimensional metallographic cross section, the volume fraction is approximated by measuring the area percentage. Traditionally, comparison to standard chart images, or manual point counting would be performed to estimate the volume fraction. Using automated image analysis to evaluate the area percentage is actually automating the point count process. The number of the detected pixels of interest is compared to the total number of pixels comprising the image.

For example, in Figure 4 the silicon carbide particles in the Almatrix have been detected and highlighted with the red bitplane. The result is an average of 18.5% SiC over the ten randomly selected fields.

The distribution of a second phase is often qualitatively described as one of the following: interdendritic, clustered, ordered, or random. In order to quantify the distribution, grids (radial or linear) can be applied to determine the nearest neighbor or mean free path distance. When using automated grid overlays the intersection points will be random and an individual feature may be intersected multiple times depending on its size and orientation.

An alternative technique to quantify distribution is to use a tessellation. Using this technique the particles are allowed to "grow" until they are one pixel point short of connecting. The mean diameter of the resulting cells is measured to determine the average center-to-center distance of the particles. Figure 5 displays the outline of the resulting cells in blue. The histogram in Figure 6 contains the results for this composite after evaluating 10 randomly chosen fields. The histogram displays not only the measurement information, but also gives a representation of the distribution. An ordered structure will have one very distinct peak whereas a more random structure will create a flatter histogram. Likewise, for a clustered distribution, the histogram will be bimodal.

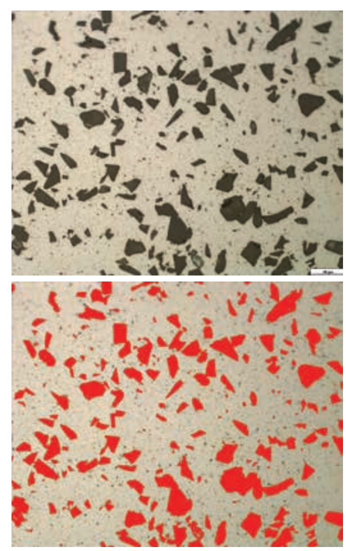


Figure 4. The silicon carbide particles in the Al-matrix (top) have been detected and highlighted with the red bitplane (bottom).

Selecting an Imaging Analysis System

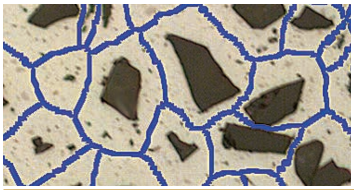
Imaging systems have become an integral part of materials testing laboratories. Images are used to evaluate research, verify quality and serve as evidence in a failure analysis. Digital images offer many advantages over traditional prints in terms of the immediacy enabling the operator to quickly detect and correct any errors in focus, illumination or magnification selection as well as an overall cost reduction. The initial cost of film is eliminated and the images can be distributed electronically to as many customers as needed. In addition, associated data can be stored with the images in a database allowing for easy retrieval of information through later searches.

Table 3. Coin Measurements

Layer	Average Thickness	Minimum	Maximum	Standard Deviation
Ni-red	3.24µm	2.97µm	3.60µm	0.19
Cu-yellow	9.68µm	8.84µm	10.18µm	0.41
Ni-blue	4.86µm	4.15µm	5.48µm	0.37

Most imaging systems have three primary components: a microscope, camera and computer. The microscope and camera are the principal contributors to the final resolution of the images captured. Resolution is defined as the imaging system's ability to reproduce object detail by resolving closely spaced features.

The clarity and definition of a digital image depends largely on the total number of pixels used to create it. Typical pixel array densities range from 640 x 480 to 3840 x 3072. Multiplying the two numbers gives you the total number of pixels used to create the image. Because a large number of pixels leads to more image information, you might conclude that it is always desirable to capture images with the largest pixel array possible. That is not necessarily always true. The problem with large array images is that the initial rate of capture and subsequent viewing of the images will be slower based on the file size. As a result, these images are not recommended for posting on web sites or for email use. It is important to take into account what you intend to do with your images when selecting the appropriate camera.



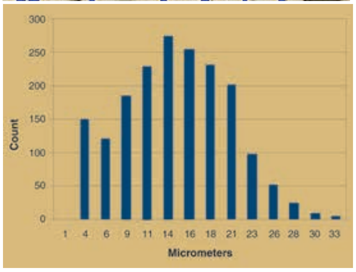


Figure 5. (top) A close-up of the blue cell outlines which resulted from expanding the SiC particles. Figure 6. (bottom) Histogram displaying the distribution of the center-to-center distances of the SiC particles.

The application will often dictate some of the criteria. For example, if the image will be distributed by email, it will be important for the file size to be relatively small. At the same time, if the end user intends to display the image as an 8 x 10 inch (203mm x 254mm) print, it will be important to have sufficient pixels otherwise the image will appear as discrete squares rather than as a continuous image. All of the images in this article were captured with a PixeLink camera with a 1280 x 1024 pixel array.

Because of the many choices of camera types, an imaging system must be flexible. Analog CCD cameras, black and white or color, are most frequently used since they offer live refresh rates combined with reasonable resolution and file size. Component video and composite video signals and a number of color video standards such as NTSC, PAL and SECAM are generally supported. Images acquired in the materials laboratory are optimized in real time by adjusting brightness, contrast, and color saturation. The analog output camera signal is then digitized utilizing an analog input frame grabber board.

Alternatively, digital cameras may be integrated with a SCSI, USB or FireWire (IEEE1394) connection. Since the late 1990's digital video cameras have become increasingly popular for scientific imaging applications. This is largely accounted for by two factors: 1) higher pixel densities in the acquired images potentially providing for higher spatial resolution and 2) the cost range of digital cameras is now similar to the combined cost of an analog camera and specialized capture board. Capturing an image with a digital camera is often a two-stage process, first a preview image is viewed for focusing and selecting the field of interest and then a snapshot of the image is taken. The preview image window displays the image at a lower pixel density and at a higher refresh rate. The refresh rate will determine the amount of lag time between the operator adjusting the microscope and the new image being displayed. In order to be comparable to an analog camera, this rate should approach 25 frames per second.

In order to compare several cameras, a theoretical system resolution was calculated. This calculation takes into account the camera and the microscope. The capabilities of a microscope are often approximated using the following equation:

$$\text{Limit of Resolution} = \frac{1}{\text{Resolving Power}} = \frac{\lambda}{2 \times \text{N.A.}}$$

Where:
N.A. : numerical aperture for the objective
λ : wavelength of light used (0.55µm for green light)

Figure 7 displays how these values compare for the different cameras, assuming the same microscope is used for all of the systems. In addition, the resolution for that microscope was calculated based on the numerical aperture values of the objectives. Note that at higher magnifications the limiting factor is the microscope and not the camera. Also, you can see that camera selection is more critical when you are working at lower magnifications.

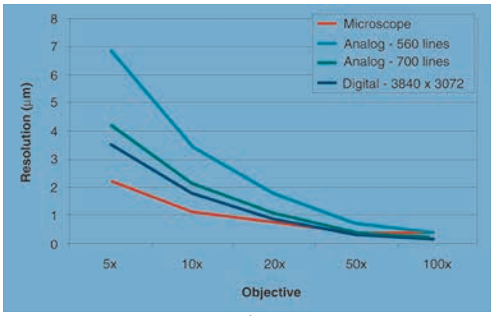


Figure 7. A comparison of theoretical resolutions is shown for three cameras and a microscope.

The only other issue that you may have to consider is the compatibility of the camera you have selected with either the hardware and/or software you intend to use. For this reason, it is ideal to have a system that is integrated by the provider.

When selecting imaging software, it is important to consider your goals. Oftentimes, images are just another step in the documentation process. For example, in a failure investigation it is useful to capture the image of a complete component before the sectioning process. Or, an image of the microstructure might be attached to a report as an indication of a pass/fail condition.

When you are collecting a large number of images, it is important to have a structure in place to track and store the images. A database that is able to track not only the images, but also the associated parameters and measurements is ideal. For longterm use, it is essential to be able to back up and archive images to a network drive or removable media. If you have multiple workstations or several departments that need access to the images it is helpful to have distributed imaging on the network using viewing software.

Tech-Tips

Additional functionality of an imaging system might include a scale marker overlay and point-to-point or other operator interactive measurements. Fully automated image analysis includes detection of the features of interest based on grey level or color differences as well as morphological characteristics such as size and shape as shown in the examples in this article.

Aligned with these imaging goals, Buehler offers a series of upgradeable OMNIMET® imaging products. The OMNIMET IMAGE CAPTURE & REPORT System focuses on the basics of image capture and generating simple image reports. The OMNIMET ARCHIVE imaging product has additional capturing features that enable image comparison and multi-layer focusing as well as a powerful database for tracking projects and measurements. The OMNIMET EXPRESS and OMNIMET ENTERPRISE products include automated quantitative measurements in addition to the operator interactive measurements and databasing found in the other products. OMNIMET EXPRESS has specific application modules while the OMNIMET ENTERPRISE product provides a comprehensive toolkit that enables the user to tackle any application. The OMNIMET LAN browser is viewing and reporting software for local area network (LAN) deployment in a multiple user environment where the main OMNIMET database is located on the LAN server. This provides accessibility of the images and data to all users and departments.

Question: How do I determine the magnification of an image on a monitor or projected viewing screen?

Answer: Both the chip size of the camera and the transfer lens linking the camera and the microscope directly affect the magnification observed on the monitor. Oftentimes, the area and magnification observed through the microscope eyepieces are different from that observed on the monitor.

To determine the on-screen magnification for each objective simply use a standard stage micrometer as the specimen and measure the projected size on the monitor screen with a clear plastic rule. Divide the measured length by the actual length represented by the micrometer to calculate the magnification.

Or you can calculate the magnification using the following equation:
On-screen Magnification = optical magnification x electronic magnification,

Where:
optical magnification = objective magnification x transfer lens magnification

electronic magnification = monitor diagonal / sensor diagonal.

Example: Determine the on-screen magnification when using a 10 X objective, 0.38 transfer lens, 1/ 3” sensor size with a 6mm diagonal and a 19in. monitor.

On-screen magnification = 10 x 0.38 x (19 x 25.4 / 6) = 305.5 X

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