QUANTITATIVE METALLOGRAPHY OF TITANIUM ALLOYS

Automated image analysis of titanium alloys enables the evaluation of alpha-beta microstructures for area percent primary alpha phase, grain size, and lamellar alpha plate thickness.

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The maturing of image analysis technology in the last twenty years has changed the world of quantitative metallography. Many standard measurements that were made manually can now be done with fully automated systems, reducing subjectivity and operator fatigue, thereby enhancing the quality of the statistical result outputs. Examples of widely recognized methods are ASTM 112 for Grain Size Measurements in Austenitic Steel, and ASTM E45 for Inclusion Rating in Rolled Steel. Automated image analysis is commonly used also for general applications such as Knoop and Vickers hardness testing, evaluation of nodularity in cast iron, particle size analysis, and coating thickness in quality control labs and in research.

In cases where the microstructure is such that the phases of interest cannot be detected automatically, semi-automated methods allow the operator to mark, trace, or delineate the features of interest. Multiple fields can be measured and the results compiled automatically, enabling larger areas to be covered. This reduces the time required for statistically representative results and the error associated with operator fatigue.

As a general rule, microstructures in which distinct features are represented by distinct gray levels and / or colors are easy to quantify by automated image analysis. It is important to realize that advances in image analysis depend on the quality of the image acquired. Thus, sample preparation, camera resolution, and microscope optics are crucial for taking the best advantage of artificial intelligence solutions.

This article describes how automated methods are applied to the point count method and grain size measurement. It then details how cameras and software work together to permit quantitative measurement of primary alpha and prior beta microstructures, as well as lamellar alpha plate thickness in titanium alloys.

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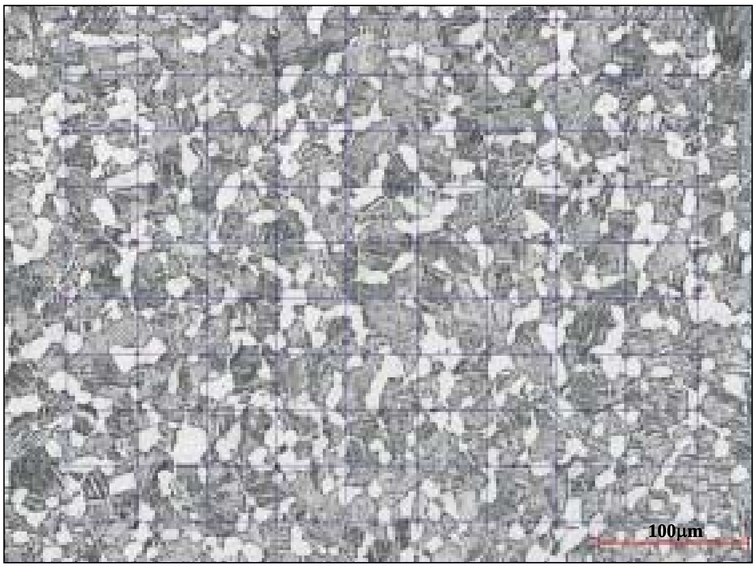

Fig. 1 — Measured area percent alpha titanium is 22%, whereas the count in Fig. 3 shows 31%, because the grid was moved 20 microns diagonally.

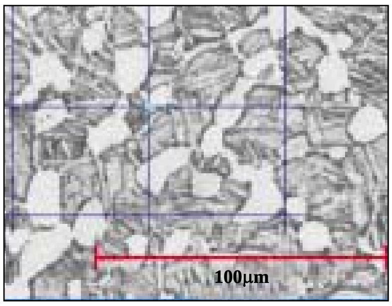

Fig. 2 — This is an enlargement of the lower right corner of Fig. 1.

Point count method

In many laboratories, titanium alloy microstructures continue to be evaluated by traditional methods, in which quality of results is subject to operator fatigue and level of experience. For example, comparison of microstructures to drawings or photomicrographs for evaluation of the volume percent of primary alpha particles can easily lead to mistakes, especially if the area percent is relatively low.

With the point count method, a grid with 100 points is overlaid on an image of the alpha-beta microstructure, at 200X magnification. A value of one is attributed to intercepts that fall completely inside the alpha phase, and a value of 0.5 is attributed to intercepts that fall on a grain boundary. The total count corresponds to the "area percent primary alpha." Unfortunately, this method can generate misleading results, particularly for the lower area percentages shown in Fig. 1 and Fig. 3. They show the same photomicrograph of an alpha-beta phase, on which the grid has been moved 20 microns diagonally. Figures 2 and 4 are the corresponding enlargements of the lower right

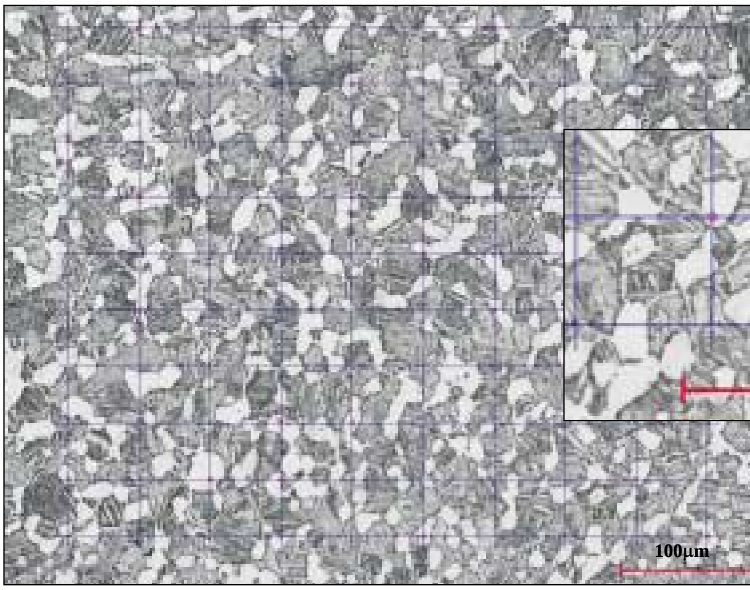

Fig. 3 — Measured area percent alpha titanium is 31% in this image because the count was taken in a slightly different area, after the grid was moved 20 microns diagonally.

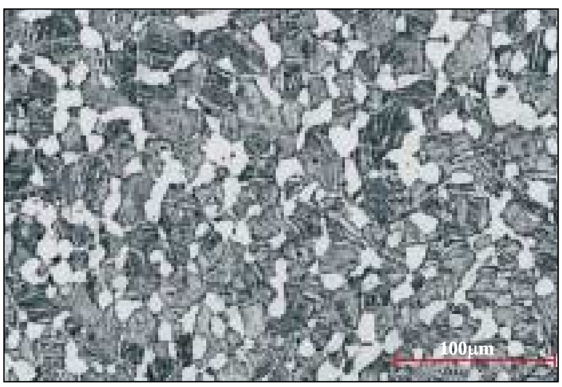

Fig. 5 — This photomicrograph shows a typical field of an alpha-beta microstructure at a magnification of 200X.

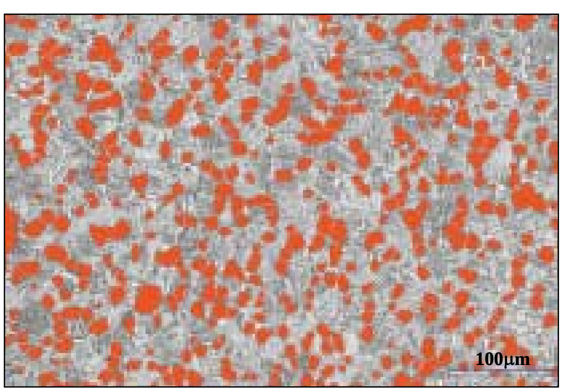

Fig. 6 — The primary alpha titanium particles are detected and shown in red at 200X magnification.

corner. The magenta points on all four micrographs show where the intercepts fall on the alpha particle (1), and the cyan points show where the intercepts fall onto a grain boundary (0.5).

The point count method generated area percent alpha results of 22.5% (Fig. 1) and 31.0 % (Fig. 3) depending on where the grid lies on the same micrograph. The difference between the two measurements is an area percent measurement of 9%, or a variation of 25%. The true value measured on nine fields on this sample by automated image analysis is 23.97% primary alpha. One reason that precise measurements are achieved with image analysis is that the number of intercepts is as high as the resolution of the camera.

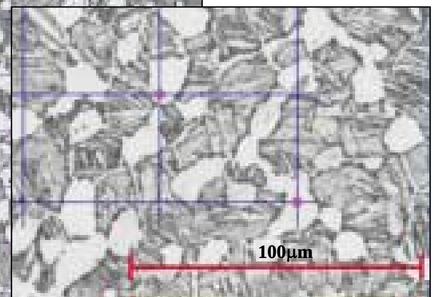

Fig. 4 — This is an enlargement of the lower right corner of Fig. 3.

Image analysis solutions

Advances in camera technology in recent years have tremendously improved image acquisition. A camera image at 500X can often show clearly what the eye could not observe at 1000X. At the same time, the camera allows a larger area to be covered, without the inconveniences associated with the very-high-magnification objective lenses.

In addition to the cameras themselves, powerful and versatile image analysis software combined with high-precision motorized stages enable a multitude of applications that were extremely challenging or impossible until now. Tools such as Multilayer Grab reconstruct an uneven image into one plane of focus, and permit observation at high magnification of texture resulting from etching. Mosaic builds an image from several fields of view, and permits reconstruction of very large grains at low magnification.

Primary alpha

Automated and semi-automated quantitative measurements of various titanium microstructures have been assessed via the Clemex Vision PE. In the alpha-beta microstructure, the following features were evaluated with fully automated image analysis: primary alpha volume percent, primary alpha particle size and shape, and lamellar alpha plate thickness and length.

In the prior beta microstructure, a semi automated image analysis method was used to evaluate grain size and extremely fine alpha plate thickness. In addition, image analysis methods are under development for the measurement of lamellar alpha colony size and percentage, and to evaluate a number of lamellar alpha plate angles per grain.

• **The area percent primary alpha** was measured on a alpha-beta sample. Figure 5 illustrates a typical field of such a microstructure. Figure 6 shows the alpha particles detected in the red bitplane. The motorized stage was used to cover an area of 2 x 2 mm with a 3 x 3 mm field stage pattern at 200X magnification. The time required for the analysis was 18 seconds. The area percent primary alpha measured on each field varies from 20.62% to 26.44%, and averages 23.97%.

It is interesting to note that the real primary alpha area percent value lies between the two primary alpha area percent values resulting from the point count method, as described in the previous section and illustrated on Fig. 1 to 4. Several measurements were made on various samples and, as expected, the higher the area percent alpha phase, the closer were the true area percent and grid-intercept area percent.

• **The size and shape of alpha particles** were also measured on the same run. Circular diameter was measured for particle size, and aspect ratio was measured for shape. Many parameters can be measured to represent the size and shape information; the user can select as many as needed, without significantly increasing the time of analysis, as each measurement takes 0.002 seconds.

Figure 7 shows the linear histograms of the results for measurement of circular diameter and aspect ratio. A total area of 2 mm square was covered and 4205 primary alpha particles were measured.

Practically unlimited measurements can be carried out on the detected features; a large selection is readily available. For example, the system allows the user to define shape factors. Volume measurement can be defined as cylindrical or ellipsoidal rather than spherical. Also, once parameters are defined, they can be selected to define the *x* or *y* axis. The result outputs offer great flexibility, which benefits both researchers and quality control laboratories when specific parameters are inherent to the process.

Lamellar alpha plate thickness

In the past, the measurement of such fine lamellar structures by image analysis was beyond the limit of resolution of the cameras. We can now accurately assess features as small as 0.1 micron with a high-resolution digital camera. When the sample surface is highly textured as a result of etching, which happens frequently in titanium, focusing is difficult at the magnification required to distinguish the lamellar alpha plates.

In this case, 500X magnification was used, and in order to bring the image into one focal plane, the Multilayer Grab function was applied on each field. This function records images at different focus levels and reconstructs an image that appears completely in focus.

Figure 8 shows the image of a typical field of fine lamellar alpha at 500X magnification, after the Multilayer Grab was executed.

Figure 9 shows the lamellar alpha plates after detection in the yellow bitplane.

To find statistically significant results, many fields were analyzed, because only a limited number of plates could be detected on each field. The analysis of 1.87 mm^2 area was completed in less than four minutes, and over 1000 plates were measured. The time required is relatively long for automated image analysis due to the Multilayer Grab function.

Titanium colony structure

The most challenging application in the evaluation of titanium microstructures is the analysis of lamellar alpha colonies. It is extremely difficult to separate very thin plates by image analysis. Furthermore, if the plates are composed of various gray levels that are difficult to differentiate from the grain boundaries, it is very complicated to achieve any automated measurements.

Preliminary work was carried out on such microstructures to first identify the oriented features, which account for most the colonies.

Figure 10 shows an original image of lamellar alpha colonies, and Fig. 11 shows the result of the application of an algorithm in which each object is assigned a color according to its orienta-

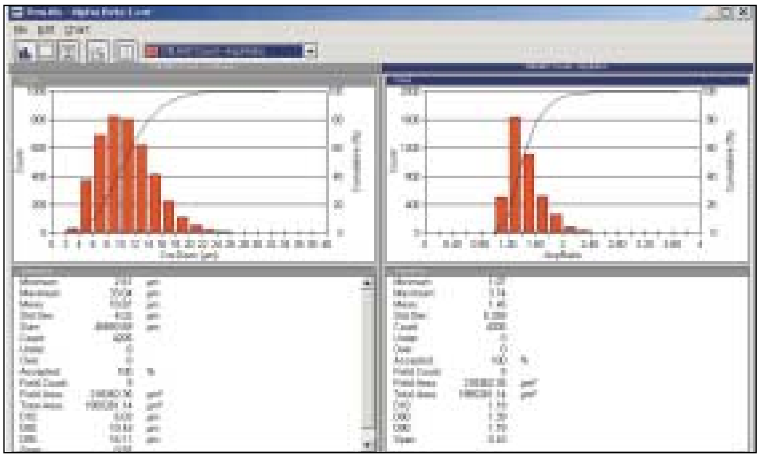

Fig. 7 — Linear histograms of the results for measurement of circular diameter and aspect ratio. A total area of 2 mm square was covered, and 4205 primary alpha particles were measured.

Fig. 8 — Fine lamellar alpha titanium microstructure is shown at 500X magnification after the Multilayer Grab was executed.

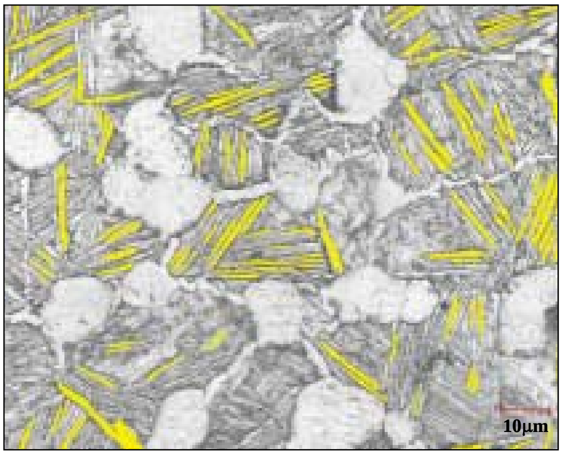

Fig. 9 — Lamellar alpha plate microstructure was detected and is shown in yellow.

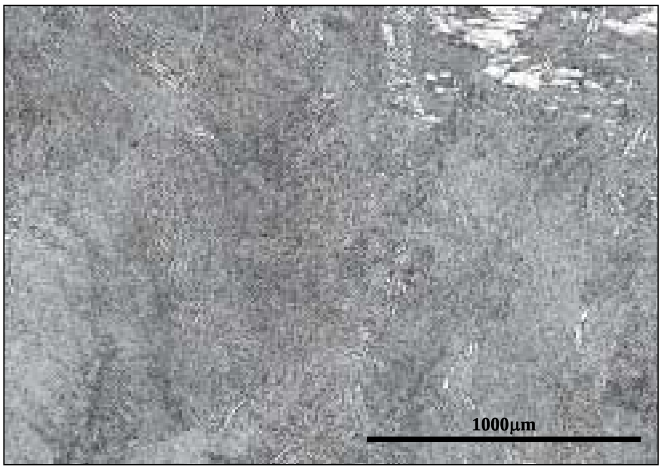

Fig. 10 — Lamellar alpha titanium colonies shown after using the Mosaic tool at 200X. Mosaic builds an image from several fields of view, and permits reconstruction of very large grains at low magnification.

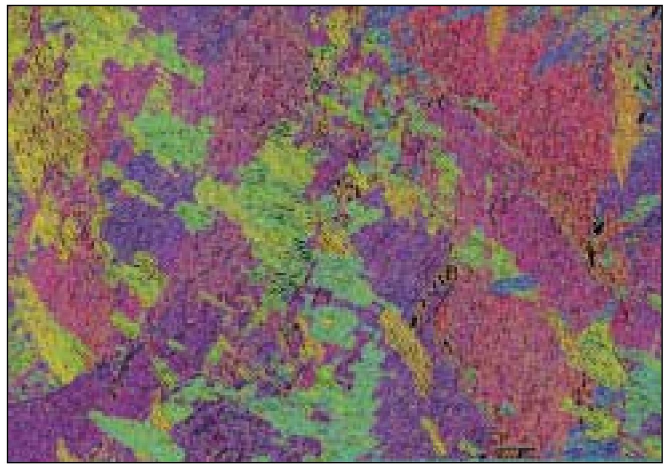

Fig. 11 — This image shows the same alpha titanium colonies as those shown in Fig. 10, and is the result of the application of an algorithm in which each object is assigned a color depending on its orientation.

tion. Further developments in the software would be required to complete the analysis.

To this day, no production automated image analysis applications have been developed for the standardization of titanium alloy metallographic evaluation because of the complexity of the microstructures.

However, with advances in camera technology, improved microscope optics, and continuing evolution of artificial intelligence, innovative automated image analysis solutions are becoming possible for a wider range of challenging applications. ■

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