Image Analysis for Materials Testing

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The ability of automated digital image analysis to improve the quality of many laboratory procedures and tests is leading to increased applications in materials testing and characterization. The automated analysis of geometrical and structural properties of materials has proven practical implications in terms of mechanical properties of materials.

Quantitative metallography allows engineers and researchers to determine and control the conditions necessary to achieve, in a reproducible way, a material microstructure that has required macroscopic properties [1,2]. This tool can be used both in the development of new advanced materials and as a control method in the production process. To be able to control the microstructure and, therefore, the required/target properties of a material, it is necessary to study and understand in a three-dimensional (3-D) context how the microstructure (constituent shape, orientation, size and ordering, for example) affects properties (hardness, wear resistance, elasticity, etc.).

It is possible to deduce from a polished and etched surface of a sample the relationship between certain parameters and the three-dimensional properties of the material being analyzed. Some of the most basic and important three-dimensional material properties can be determined by just observing the sample surface, a very useful science called stereology.

Phase content

Phase content, the relationship between the volume of the phase of interest and the total material volume, is one of the oldest and (next to particle sizing) most often applied procedures of quantitative microstructure analysis. The following simple equation, which is the cornerstone of stereology, has been proven theoretically [3]:

$$V_V = A_A \qquad \text{Eq 1}$$

where V_V is the volume fraction and A_A is the area fraction. In simple terms, the equation says that one can determine the three-dimensional phase content by measuring the surface percentage of the said phase on some two-dimensional cut through the sample (Fig. 1).

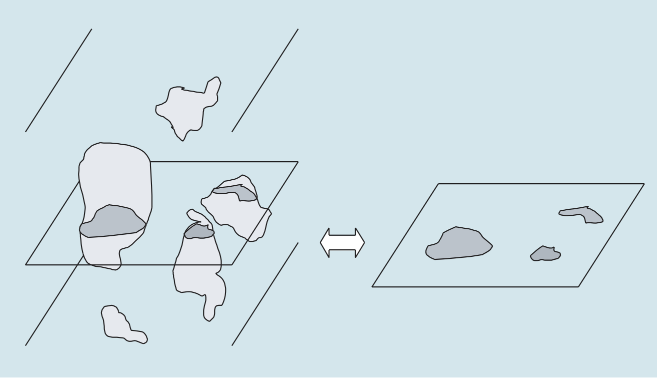


Fig 1 *Surface percentage (right) is equal to the volume percent*

The equality of Eq 1 must be understood in a statistical sense. That is, the surface analyzed should be representative of the sample in much the same way as the volume percent measured on the sample under a microscope is assumed to be representative for the real-life material. The measurement of A_A is an unbiased statistical estimate for the real value of V_V. This also means the more surface evaluated, the more accurate (i.e., closer to reality) the measured value, which is very important in case of low phase content, for instance. Therefore, automatic image analysis becomes very important

Note that Eq 1 is valid only if the phase is randomly distributed. In the case of oriented structures, the area percent observed under the microscope will depend on the orientation of the cut made through the sample.

Specific surface and surface density

Specific surface is the surface-to-volume ratio, where surface could be real surface (the surface of the pores, for example) or the surface of the interphase contact (grain boundaries, for example). This very important three-dimensional property is easily determined from two-dimensional sample sections in the equation:

$$S_V = \frac{\pi . L_A}{4} \qquad \text{Eq 2}$$

where S_V is surface-to-volume ratio and L_A is the length-per-surface ratio of the phase in question, for instance, the ratio of the sum of pore perimeters to the sum of pore areas. The result is completely independent of the particle form and is valid both for isolated particles and for continuous interfaces.

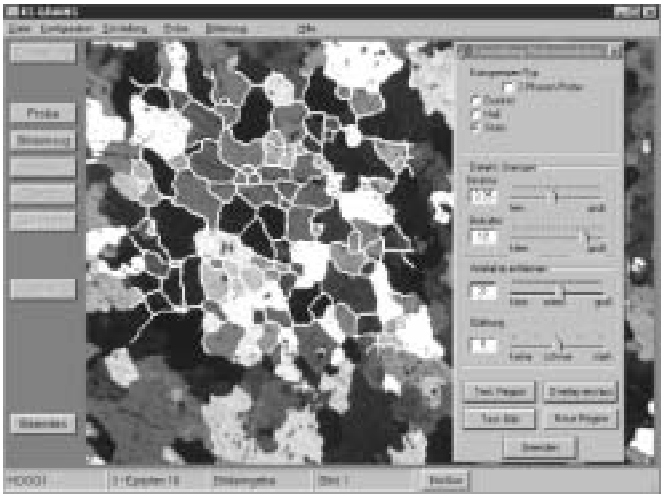


Fig 2 *Aluminum sample under polarized light*

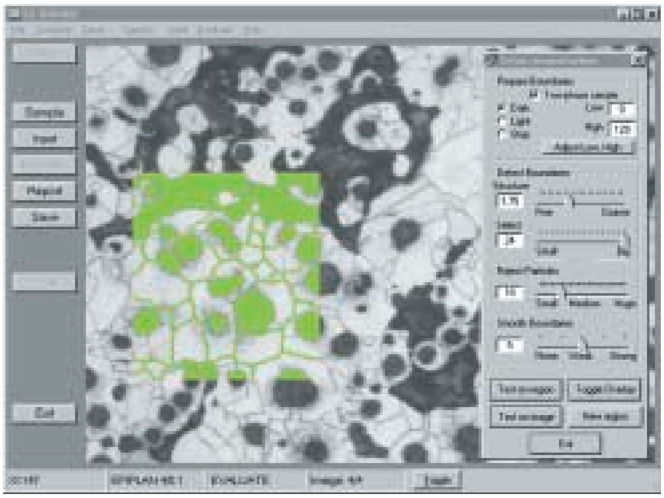


Fig 3 *Particle size analysis (spheroidal graphite) in cast iron.*

Size and size distribution

It is impossible (theoretically and practically) to determine the three-dimensional particle size distribution from a two-dimensional section through the sample. As a result, it also is impossible to measure the so-called numerical density; that is, the number of particles per unit volume of the sample. There is one glorious exception to this rule: for spherical particles, both the three-dimensional size distribution and the numerical density can be determined from two-dimensional sections.

The grain size, which routinely is used to quantify metallographic samples, is based on two-dimensional analysis of the sample. As a result, the three-dimensional properties may differ from what the results reveal, especially in the case of anisotropic (variation of mechanical properties in relation to the direction in which they are measured) samples, if the sampling procedures required by the standard are not followed.

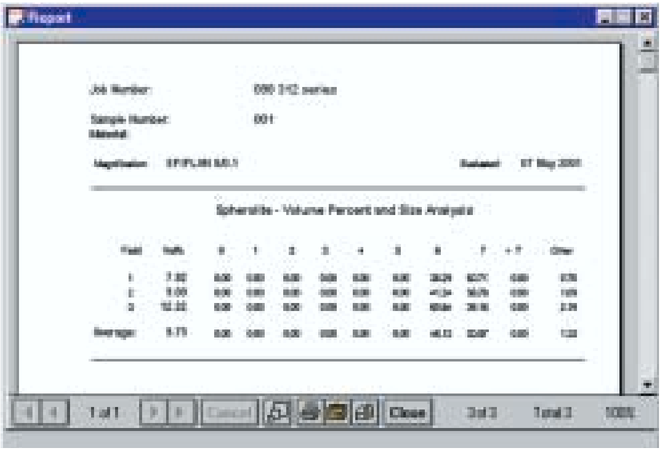
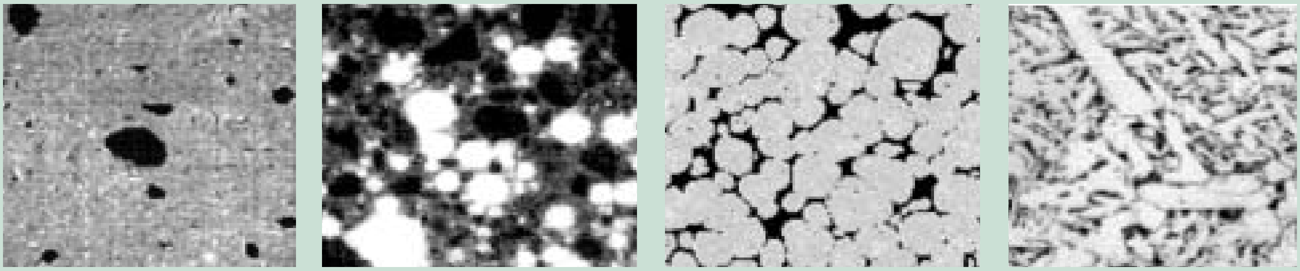


Fig 4 *Report for the analysis of the microstructure in Fig. 3 includes phase content and particle size distribution for each analyzed image and the sample average*



Undissolved Carbon black:
Carbon black is an important additive in the production of car tires. Size/size distribution of undissolved carbon black are important production parameters.

Concrete air pores:
Pores have a decisive influence on frost resistance of the material, as well as other mechanical properties.

Sintered ceramics:
In this case, the size and shape of pores, and their time dependence during the process of sintering is of interest.

Pearlite content:
The carbon content of steel can be determined by measuring pearlite content.

Fig 5 *Typical examples of particle size analysis in materials science*

Typical applications

Two possible applications using automatic image analysis are particle size and grain size measurement. These applications from Carl Zeiss Vision are KS GRAINS (for automatic grains size analysis of metallic samples) and KS PHASE (for routine size analysis).

The grain size analysis program allows, in a simple, straightforward fashion, automatically measuring grain sizes in metal samples including ferrous and nonferrous metals. Figure 2 shows the etched surface of an aluminum alloy sample under polarized light. The results of the analysis in this case include the average grain size (DIN or ASTM), the average stretching factor and grain size distribution.

KS PHASE is simple to use; the operator does not require any experience with computers or image analysis. The program is executed by simply pressing the Do All button (Fig. 3), and the images of the sample are taken one by one, then analyzed and eventually presented in a report (Fig. 4). Figure 5 shows a range of possible particle-size analysis applications in material science. **IH**

References

1. H.J. Bargel and G. Schulze (Hesg.), Werkstoffkunde 6., 2nd ed., VDI Verlag, Düsseldorf ,1994
2. M. Merkel and K.H. Thomas; Taschenbuch der Werkstoffe, Fachbuchverlag Leipzig GmbH, 1994
3. Quantitative Methods in Morphology/Quantitative Methoden in der Morphologie, ed. Ewald R. Weibel and Hans Elias, Springer Verlag, 1967
4. Carl Zeiss Vision, KS Materials, Kundenbuch, Hallbergmoos, 1999

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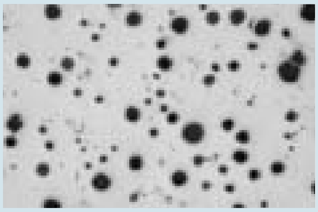
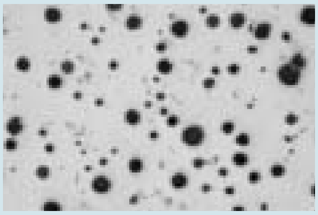
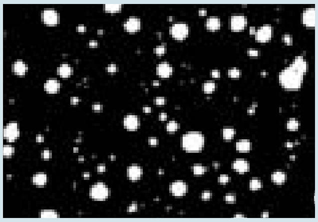
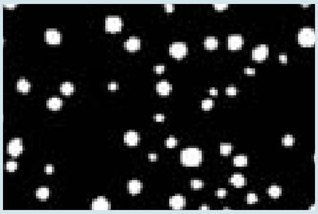
IMAGE ANALYSIS STEPS

The purpose of image analysis is to extract quantitative information from images produced using various kinds of image sources. In the digital world, an image is represented by a rectangular matrix of image points, or pixels, whose values reflect the gray values (or color values, if the image is a color image) at the corresponding positions. The subsequent processing of these pixel values allows extracting the quantitative information desired.

The natural sequence of steps is illustrated using a simple example [4] of determining the volume content and size distribution of dark particles (i.e., of spheroidal graphite in cast iron).

STEP	RESULT OF THE OPERATION
Image input: The image, as seen by a camera attached to the microscope, is converted into a digital image. Because pixel values can vary from black, to shades of gray, to white, this type of image is called "gray" image, in contrast to a so-called "binary" image, where only black and white values are present.	
Gray-image processing: The quality of the image can be improved by manipulating its gray values; for instance, to enhance the interesting parts of the image. In this example, the image contrast is improved to be able to differentiate better between the bright iron phase and dark graphite particles.	
Segmentation: To be able to obtain quantitative data, it is necessary to indicate what is of interest. Changing the gray image to a binary image does this; the particles to be evaluated are now white, and the uninteresting background black.	
Binary image processing: As in the case of gray image processing, it is possible to similarly process the binary image to enhance the useful information or to eliminate uninteresting parts. In this example, particles that either were too small or not round were eliminated.	
Image evaluation and post-processing: At this step, the information in the image is converted into numerical form (usually into a data file), which contains the requested data. The results either can refer to the image itself (for instance, volume percent) or to individual particles or objects in it (for example, spheroid sizes). These data also can be post-processed to obtain a particle size histogram, for instance.