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METALLOGRAPHIC STUDIES

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The article discusses the directions of implementation of metallographic research. Analysis of grain counting methods and the use of these methods in metallographic analysis. The principles of implementing a web application are given.

Metallographic studies are used in many areas of industry: metallurgy; automotive industry; nuclear industry; energy; aerospace industry; research and survey work in various research and scientific centers, universities, laboratories [1]. In this case, the initial data is used as a microchip having a specially prepared surface (the structure is revealed by etching, cutting) for microanalysis, which is currently represented as a digital image. The analysis of metal images requires a large amount of time, so special algorithms for processing digital images and software tools are developed and used [2-4]. Such systems require a fairly good quality of preparation of the surface of the micro-section, since the presence of noise components leads to a decrease in the reliability of the analysis [5]. However, even the use of modern automatic machines does not allow to fully obtain the surface of the micro-section with the complete absence of interfering factors [6]. Thus, the development of algorithmic and software for the analysis of images of the metal microstructure based on modern methods of digital image processing is relevant.

The metallographic analysis uses GOST 5639-82 "Steels and alloys. Methods for detecting and determining the grain size", which contains methods: determining the grain size by comparison with reference scales; counting the number of grains; counting grain border crossings; measuring chord lengths. The method for determining the grain size by comparison with reference scales is based on a visual comparison of the target image and a set of standards, which are given in GOST 5639-82. The method of counting the grains per unit of the surface of the section consists in counting all visually distinguishable grains on the section, while the automatic processing algorithm must take into account the need to separate the grains according to the criterion of crossing the image boundaries: internal and boundary, i.e. crossing the image boundaries. The method of calculating the intersections of the boundaries of equiaxed grains by straight segments with the determination of the average conditional diameter involves measuring by constructing two perpendicular lines at the characteristic place of the image of the cut and dividing them into segments bounded by the contours of the detected grains. Next, you need to calculate the arithmetic mean of the lengths of the obtained segments, followed by comparison with the table parameter of the average conditional diameter. The method of calculating the intersections of the boundaries of non-equiaxed grains by straight line segments with the determination of the number of grains in 1 mm³ differs from the method intended for equiaxed grains by the need to use an additional image obtained across the main axis of symmetry. The analysis is performed by calculating the number of grains crossed by a line in terms of its length equal to 1 mm, which allows you to calculate their number per unit volume and compare the result with a parameter that matches the average number of grains per 1 mm³ and a certain grain score in GOST 5639-82.

In [4], a segmentation algorithm is described based on the selection of a grain contour based on the brightness difference of adjacent pixels and traversing the found border in a circle. As a preprocessing, the input image is convoluted with a kernel that allows you to select the contours of objects, in this case-the Laplace operator (Sobel or Canny operators can also be used), the resulting image is binarized. The author notes that there may be situations when the grain boundary is not closed due to the defects of the section, and the resulting gaps will be quite large. This can cause a single grain to be defined as multiple objects. In [5], an approach for preprocessing is presented using the Otsu binarization method, using the closing and opening operations to filter the binary image and further highlight the contours on it. The paper [7] presents a general scheme for processing the image of a microstructure using the "beetle" algorithm for selecting contours in the image. The methods from [5,7] will not allow for high-quality contour selection on real images, which will lead to a deterioration of the analysis.

The initial data can be used: one image of the slot along the main axis of symmetry; two images, including an additional image to the previous one, obtained across the main axis of symmetry; a set (package) of images for simultaneous processing. To improve the accuracy of determining quantitative indicators and to improve the quality of the input image, taking into account the preservation of the correct grain boundaries for further automatic processing, preliminary image preparation is required, which includes the following operations: image sharpening; brightness correction; contrast enhancement; noise filtering.

To implement the method of determining the grain size by comparison with reference scales, a universal digital standard has been developed that supports scaling, taking into account the restriction that the image resolution and the grain number are known in advance.

The task of automatic quantitative analysis requires the segmentation of the grains in the image of the section and is reduced to the selection of closed areas corresponding to the grain boundaries. One of the most common

defects is non-uniform brightness and contrast. Therefore, it is necessary to improve the original images. In existing systems for determining the grain score, the histogram alignment method is used. If the brightness distribution of the input image is not uniform, for example, one half of it is darker, this method does not work well enough, since one part of the processed image will also be darker. Therefore, it is proposed to use the adaptive histogram equalization algorithm with contrast restriction (CLAHE) to improve preprocessing [8]. With this approach, the image is processed not in its entirety, but in fragments, which, after correction, are combined using bilinear interpolation to suppress sharp transition boundaries between fragments. When using the CLAHE algorithm, there is almost no light unevenness in the output image, in contrast to the image obtained on the basis of histogram alignment. To remove Gaussian and pulse noise, two-dimensional filtering is used in the spatial domain with the corresponding types of filters and apertures of different sizes, since different types and levels of noise can be present in the images.

After pre-processing, a grain segmentation step is performed, which will allow you to apply various analysis methods in the final stages. For this purpose, it is proposed to apply adaptive binarization, remote transformation, and the watershed method to the image, as well as mathematical morphology methods for binary images.

To implement the method of counting grains, an algorithm is proposed that requires the following basic steps: segmentation of grains based on contour analysis on a binary image, each of which is described by coordinates and area; selection of grains and, calculation of the value of the total number of grains in the image; reduction to the number of grains per unit area and comparison of the result with the parameter from GOST 5639-82, which corresponds to the range of values of the average number of grains per 1mm² and a certain grain score; calculation of the numbers of grains most often found in the image.

Methods for measuring chord lengths and counting grain boundary intersections require the construction of reference lines, from which segments are distinguished in the areas where they intersect with the grains. For the method of measuring chord lengths and counting the intersections of the boundaries of equiaxed grains, the average length of segments is calculated, for non-equiaxed grains, the number of segments is calculated. The obtained values are compared with the table parameters.

Based on the considered algorithmic support, the application is presented in the form of a website. The application has several roles: administrator, registered user, and guest. Depending on the role, different application functions are provided. The guest has limited functionality, which is controlled by the administrator. A registered user can use the full list of functions. The administrator moderates users and controls access to functions for the "Guest" and "Registered User" roles» The site has registration and authorization forms. These forms use an E-mail and password or OAuth 2.0 to log in. The OAuth 2.0 authorization protocol allows users to exchange certain data with the application, while keeping their usernames, passwords, and other information secure.

After the user is logged in, the main page of the site will be displayed. This page is divided into the following sections: image, menu, toolset, dimension. On this page, you can upload an image that will be displayed in the output window with the processing of the uploaded image applied. Tools for processing the input image, tools for binarizing the data under study and working with the resulting image, and counting methods will also be available. In turn, the counting methods include the following analysis methods: the method of determining the grain size by comparison with reference scales (GOST 5639-82, p.3.3); The method of counting grains (GOST 5639-82, p.3.4); The method of counting the intersections of the boundaries of equiaxed grains (GOST 5639-82, p.3.5.3); The method of counting the intersections of the boundaries of non-equiaxed grains (GOST 5639-82, p.3.5.4); The method of measuring chords (GOST 5639-82, p. 3.6).

The method for determining the grain size by comparison with reference scales includes the following sections: image, working with a file, the list "Grain number, G", the list "Color scheme", the list "Window width and height". When you change the list "Grain number, G", the scale of the image under study automatically changes to the corresponding grain number. When you change the "Color Scheme" list, the color scheme of the reference image changes accordingly. When you change the "Window Width and height" list, the scale of the display window of the reference and the image under study automatically changes to the appropriate resolution.

The method of counting grains includes the following sections: source and final image, working with the file, "Counting grains", "Tabular data". The section "Counting grains" shows the number of detected grains in the current area and in terms of an area of 1 mm², also displays the first three numbers of grains that occupy the largest area in the image. The Tabular Data section shows the G number corresponding to the number of detected grains, the tabular value of the average diameter of the calculated grain number, and the value of the average area of the calculated grain number. Figure 1 shows the form of the grain counting method

The method for calculating the intersections of the boundaries of equiaxed grains includes the following sections: source and final image, working with the file, "Range of values". The "Range of values" section shows the number of measurements taken, the minimum and maximum grain size present in the image, calculated from the length of the segments, as well as their average value, and outputs the first three grain numbers, which are represented by the maximum number of segments. Figure 1 shows the form of the method for calculating the intersections of the boundaries of equiaxed grains.

Fig. 1. – Form of the method for calculating the intersections of equiaxed grain boundaries

The method for calculating the intersections of the boundaries of non-equiaxed grains includes the following sections: source and result images, working with the file, "Counting grains". The "Counting grains" section shows the number of measurements taken, the number of crossed grains in terms of 1 mm on each axis, and the resulting number of grains per 1 mm³, and shows the number G corresponding to the number of detected grains.

The method for calculating the chord measurement includes the following sections: the source and final image, working with the file, and the "Range of values". The "Range of values" section shows the minimum and maximum grain size present in the image, calculated from the length of the segments, as well as their average value, and outputs the first three grain numbers, which are represented by the maximum number of segments.

As a result, an application for image processing with different counting methods is presented.

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