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QUANTITATIVE METALLOGRAPHY BASED ON COMPUTER ANALYSIS OF PHOTOGRAPHS ALLOY

Abstract. Using computer analysis of data obtained by photography by quantitative metallography eutectics and composite materials, such as volumetric content of the phase components, the value of the phase, the distance between such particles and others.

Keywords: quantitative analysis, microstructure, computer analysis of photographs, phase volume content.

Introduction. Eutectic crystallization plays an important role in the industrial hardening alloys. Double eutectic in a large number of classical studies. But for multicomponent systems is very rare even morphological description eutectic structures. In multicomponent alloys eutectic areas may have an area too small for micromechanical studies, but they contribute to the mechanical properties and performance of all alloy. Thus, a promising research direction is to study multiphase natural and artificial composites.

Quantitative metallography widely used to characterize the microstructure of the alloy, namely phase volume content, grain size, specific surface grain boundaries, the distance between similar particles or phases so on. These characteristics need to know to build diagrams, in studies of phase transitions, recrystallization processes, diffusion, for evaluation of physical, mechanical and operational characteristics of alloys [1].

When metallographic analysis alloys investigated structure can be compared with the reference schematic representation structures ASTM (semi-quantitative method) or quantitatively determine the characteristics of the alloy [2]. In the first case, the real structure attribute to mark a grain *N*, a matching circuit. The drawback of these studies is the subjective determination of *N*, because errors assessment and obtained enough information. In the second case, the measured properties of the alloy manual or automated means, for example, using structural analyzer «Epiquant». However, quantitative analysis of the structure of the alloy phase which have similar chemical resistance, can also lead to inaccurate results.

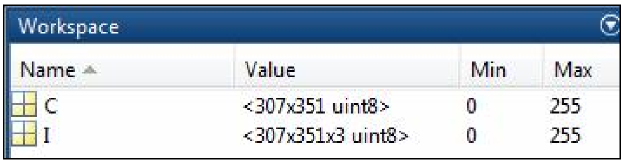
Recently developed commercial software analyzer «Epiquant», which leads to structural analysis phase sample to estimate the grain, calculate the volume and mass distribution of phases and semiquantitative determine the average reflectance of light phases [3]. But maximization, which supports analyzer «Epiquant» – x1000, which in many cases is not enough to work with eutectic microstructure. The purpose of this work is to develop methods of computer analysis of photographs for quantification alloy microstructure characteristics of multicomponent alloys.

The main part. Phase composition of the alloy can be identified using microanalysis (or structure) and metallographic analysis. In both cases it is possible to take a photo with increasing alloy sections, which allows you to clearly distinguish the individual phases. Computer analysis of the photos is pixel by pixel reading and analyzing the information received.

In the MATLAB environment to download images using function *imread*, which pass as parameters the name of the image file and its format, for example:

```
C=imread('D:/image004.jpg');
```

We get an array that corresponds to the dimension of the image with values in format uint8 (Fig. 1).



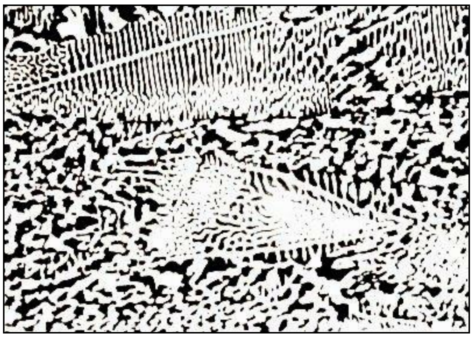
Workspace

Name	Value	Min	Max
C	<307x351 uint8>	0	255
I	<307x351x3 uint8>	0	255

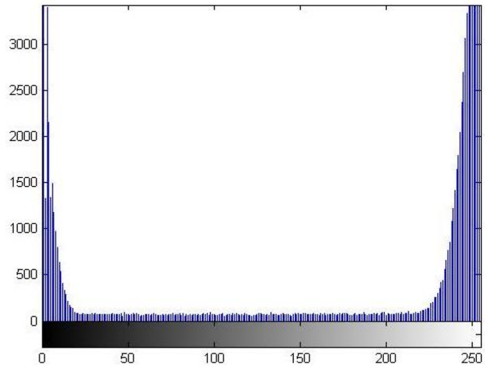
Figure 1 – The result of the function *imread*

If the original image has a color depth of no more than 256, the matrix C is two-dimensional and each of its values would represent an appropriate level of brightness point. If the point of the original image is represented, for example, 24 bits, the matrix and have a maximum dimension 1024x1024x3, where the third dimension will match the original color composite image [4]. Then two-dimensional array for each color can be done by separating layers of data, for example, `red=c(:,:,1);` After obtaining three dimensional matrix, they can be combined in a two-dimensional matrix of brightness and so on. Data from the two-dimensional matrix can be visualized as a histogram, which is in the package MATLAB built using *imhist*. The value limits of individual phases used for calculation of volume content and other quantitative characteristics of the alloy.

The method of computer analysis of photographs tested on alloys, which are characterized experimentally by quantitative-rystyky. For example, in Fig. 2, a eutectic alloy are photo Fe-3,8%B, which form a phase Fe and Fe_2B. Due to less chemical resistance than phase Fe_2B, Fe phase in the photo has a dark color [5]. Histogram color that is based on this photo, is shown in Fig. 2,*b*.



a



b

Figure 2 – Alloy Fe-B: photography x500 (*a*); color histogram (*b*)

Volume content of each phase (V_p) are as the ratio of pixels specified range of color to the total number of pixels. For the linear analysis phase is the average size

$$l_c = \frac{\sum_i l_{\alpha_i}}{n_i \cdot M}, \qquad (1)$$

where l_{α_i} – the size of the *i* particles of phase α, belongs to an arbitrary cross-section; n_i – number of particles of this phase, which crosses an arbitrary secant; M – zoom (enlarge).

For the determination of the external geometric specific surface phase [6] using the formula

$$S_w = \frac{f \sum_{i=1}^{N} n_i l_c^2}{\rho \sum_{i=1}^{N} n_i l_c^3}, \qquad (2)$$

where f –phase particle form factor (f = 6 for spherical and cubic, f = 6,4 ÷ 7,7 for rounded and sharp, f = 12 for prisms, f = 18 for plates, f = 18÷30 for thin needle particles); ρ – density; d_i – average particle diameter.

For artificial composites basic structural parameters that determine the effectiveness of the filler is the mean free space between particles

$$l_p = \sqrt{\frac{2l_c^2}{V_p}(1-V_p)} \,. \tag{3}$$

Table 1 shows some results of quantitative metallography alloys obtained by computer analysis of photographs.

Table 1

The results of quantitative metallography binary alloys

	Phases	V_p, %	n^*	l_c, μm	l_c, μm exp	S_w,m^2/g
Fe-3,8%B	Fe	42±3	134	111±7	–	–
	Fe_2B	58±2	133	136±11	141±3	0,011±0,002
Fe-12%P [7]	Fe	54±2	116	55±4	–	–
	Fe_3P	46±3	118	93±7	87±3	0,020±0,004
Fe-3%C-1,8%B-1%P [8]	Fe	57±2	93	14±3	12,2±1,8	–
	Fe_3C	41±2	95	18±5	16,9±4,1	0,044±0,007

* – the number of particles crossing an arbitrary secant

In addition, computer analysis of photographs allows to get statistics. For example, in Fig. 3, and given the size distribution of particles in the eutectic phase Fe_2B alloy Fe-3,8%B [5].

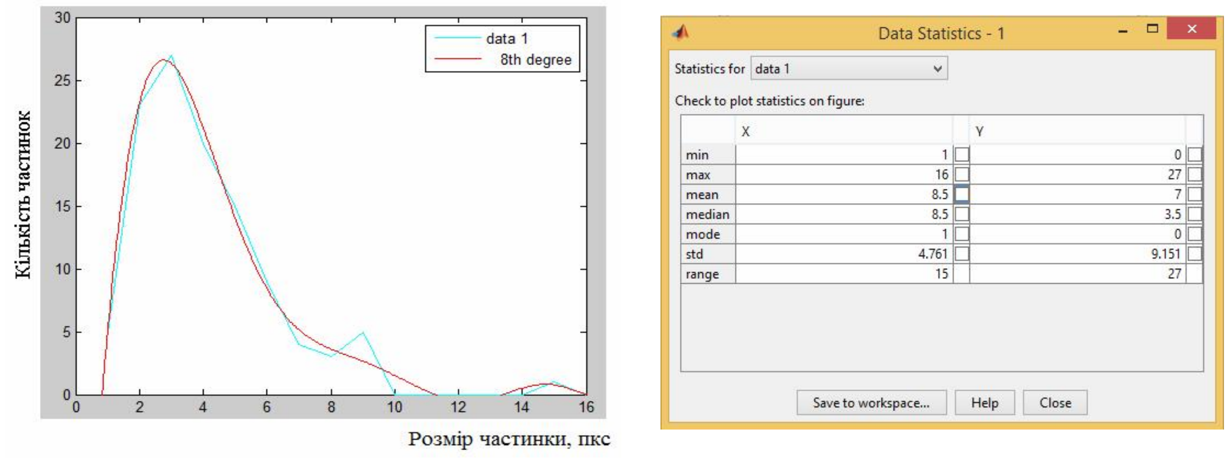
According to the statistics of this type can be defined branching eutectic (differentiation colony)

$$\delta = \frac{x_{\max y}}{\sqrt{M}} \,. \tag{5}$$

Colony differentiation associated with the speed of crystallization front (v) by the formula

$$\delta = k_t v^{-n} \,, \tag{6}$$

where k and n – constants.



a *b*

Figure 3 – Distribution of particles phase Fe_2B in the alloy Fe-3,8% B of a size (*a*); statistics (*b*)

Defining value δ, can plot the distribution of the local rate of crystallization of eutectic colonies and find instant acceleration. For example, in Fig. 4 shows how in the alloy Fe-B (Fig. 2,*a*) on an arbitrary cross-section changes v^n in according to δ.

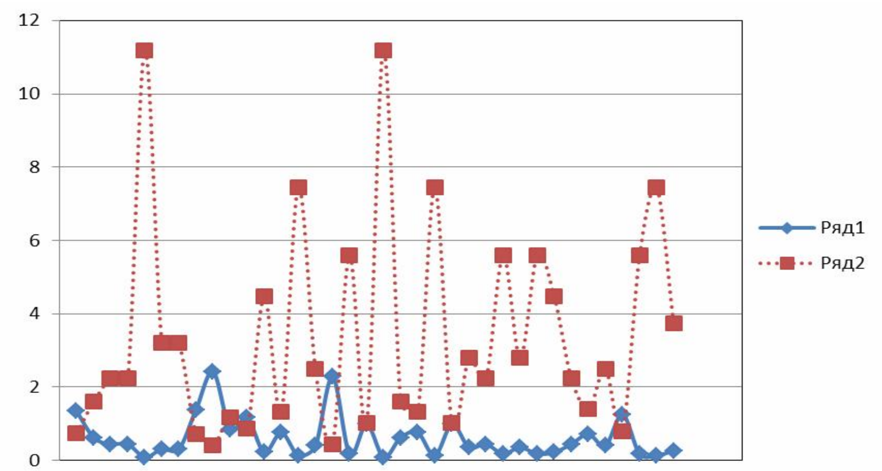
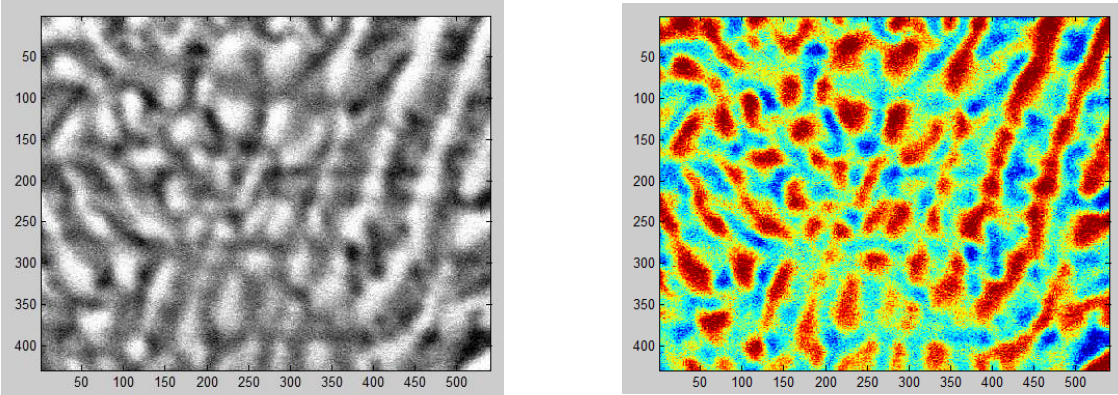


Figure 4 – Relationship between differentiation eutectic colony (line 1) and local rate of crystallization (line 2)

For binary eutectic comparison of experimental data obtained from calculation shows sufficient precision calculations.

Computer analysis allows to distinguish components of multiphase alloy and qualitatively show the distribution of impurities.

Fig. 5,*a* shows a photo of the alloy Fe-C-Mo-B, made with an electron microscope, with increasing x10000. Computer analysis of the photos to clearly distinguish the individual phases of the alloy (Fig. 5,*b*) because they have different reflectance of light. Thus, we can construct a histogram by which define the limits of the brightness of each phase (Fig. 6). Quantitative characteristics of ternary alloy is determined by formulas similar to the above.



a *b*

Figure 5 – alloy Fe-C-Mo-B: with increasing x10000 (*a*);
brightness distribution of the phases of the alloy (*b*)

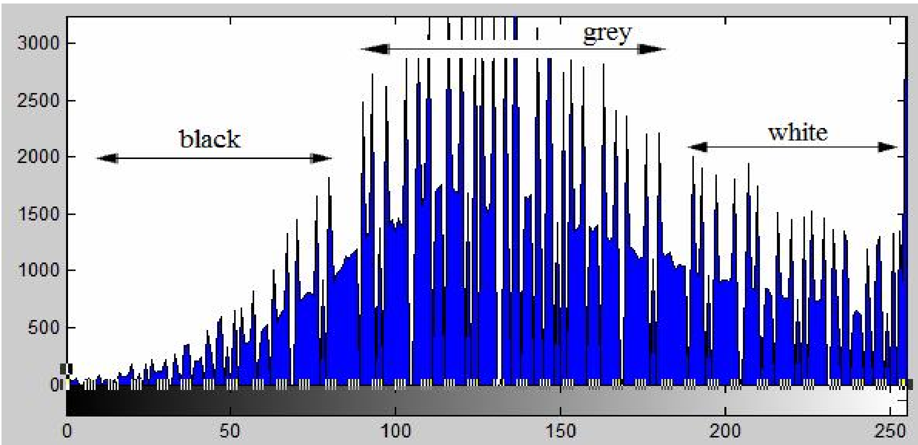


Figure 6 – The histogram is based on data obtained from Fig. 5,*b*

Conclusions. Computer analysis of the alloy photography to determine the quantitative characteristics are promising method of modern metallographic studies. Adjust contrast and image overlay corresponding color filter can improve accuracy. This can be useful when using methods of chemical or thermal etching impossible to distinguish phase alloy. In addition, this method can significantly reduce the time of the research.

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