UDC 004.932

ANALYSIS OF DIMPLE SHAPE ON FRACTOGRAPHIC HEAT-RESISTANT STEEL IMAGES

I. B. Ivasenko, O. R. Berehulyak, R. A. Vorobel

Karpenko Physico-Mechanical Institute of the NAS of Ukraine, Lviv

E-mail: ivasenko@ipm.lviv.ua

The problem of image analysis of the fracture surfaces, which are formed by scanning electron microscope, is considered. This image is characterized by nonuniform illumination of the surface. That's why it needs preprocessing. To do this, a retinex transformation is applied. For further localization and analysis of the dimples on the digital image of the fracture special technology was developed. It includes Otsu segmentation of equalized image, image skeletonization, removal of small objects, calculation of size and orientation distributions of recognized dimples. Due to this, the contours of the dimples are more fully distinguished as characteristic elements of the viscous relief of the destruction of heat-resistant steels and their quantitative estimates are obtained.

Keywords: *degradation of steels, quantitative fractographic features, image segmentation, retinex, dimples.*

АНАЛІЗ ФОРМИ ЯМОК НА ФРАКТОГРАФІЧНИХ ЗОБРАЖЕННЯХ ТЕПЛОТРИВКИХ СТАЛЕЙ

І. Б. Івасенко, О. Р. Берегуляк, Р. А. Воробель

Фізико-механічний інститут ім. Г. В. Карпенка НАН України, Львів

Розглянуто задачу виділення та аналізу ямок на цифровому фрактографічному зображенні зламу для розпізнавання характерних елементів в'язкого рельєфу руйнування теплотривких сталей. Для цього застосовано ретинекс перетворення, яке вирівнює освітлення поверхні зламу. Це дало змогу повніше виділити контури ямок та обчислити їх статистичні ознаки.

Ключові слова: *деградація сталей, кількісні фрактографічні ознаки, сегментація зображень, ретинекс, ямки.*

Fractographic research is traditionally used to study the mechanisms of destruction of steels under controlled laboratory conditions and for examination of damage of the real construction elements. Often such studies are qualitative although most researchers share the point of view that the quantitative characteristics of the fracture elements are related to the energy intensity of destruction. In this case, the means for obtaining digital fractographic images is a scanning electron microscopy (SEM). On such obtained digital images the information load are the shape and size of the material fracture surfaces.

In order to more precisely define the edges of the dimples in the image of the relief structure of the fracture surface the preprocessing of digital images is used. Filtering is applied for the preprocessing of fractographic images [1]. It eliminates unsharpness and is based on the Laplace operator as a means of high-frequency component acquisition. The unsharpness as the value of the edge is calculated from the difference between the pixel gray level value in the center of local neighborhood $L(i, j)$ and low-frequency smoothed component $\overline{L}(i, j)$, where $i, j \in W$, $i = \overline{1, N}$, $j = \overline{1, M}$. This edge crispening is required for enhancements of voids from the background. In [2] the scheme was proposed to determine the closed contours of the regions denoting the surface or void. Proposed methodology uses image enhancement and relies on the systematic combination of basic image processing techniques to accomplish the task in an automated manner. In [3] pre-processing of images removes large-scale fluctuations of mean brightness and contrast. A normalization was derived as suitable method by generalization of one-dimensional stochastic processes. The brightness is transformed by a moving algorithm with mean value 128 and standard deviation 50. The above-mentioned works confirm the necessity of pre-processing of images for their further normalization.

Extreme value analysis of both the maximum dimple sizes and lateral growth factors of maximum dimples was performed correlated to the fracture behavior of spheroidal graphite cast iron in [4]. Dimple size was measured manually. A dimple image quantitative analysis method was proposed in [5]. It measured and analyzed the dimples by means of edge detection based on combination of *B*-spline wavelet transform and mathematics morphology, water-growing segmentation and measurement method. In order to extract the bottom of each dimple Otsu binarization was applied in [6]. Gaussian filter and Laplace operator for detection of dimples edges was proposed in [7].

After analysis of papers in this area, we propose a method for dimples segmentation and analysis with the following steps:

1. Image brightness equalization using retinex model [8].
2. Otsu segmentation of equalized image.
3. Image skeletonization.
4. Removal of small objects.
5. Calculation of size and orientation distribution.

Classic single scale retinex (SSR) method [8] is based on the implementation of algorithmic computation of reflectance for element $L(i, j)$ in image L by the expression

$$R(i,j) = \ln\left[L(i,j)\right] - \ln\left[L(i,j) * F(i,j)\right] = \ln\frac{L(i,j)}{L(i,j) * F(i,j)}, \tag{1}$$

where $L(i,j)$ is a gray level value of the halftone image with coordinates (i, j), $i \in \overline{1,N}$, $j \in \overline{1,M}$; $N \times M$ is the size of the image L; $F(i,j)$ is impulse response of low pass smoothing Gaussian filter; $*$ is means convolution of the impulse response $F(i,j)$ with image L, which results in smoothed image

$$\overline{L}(i,j) = L(i,j) * F(i,j), \tag{2}$$

where $F(i,j) = Ke^{-(i^2+j^2)/\sigma^2}$; σ is standard deviation; K is weight coefficient, which is selected so that

$$K \cdot \sum_i \sum_j F(i,j) = 1. \tag{3}$$

The SSR method allowed us to align object in the scene and to use basic threshold segmentation methods for dimples extraction (see Fig. 1–2).

For the segmentation of spines the Otsu method is used [9]. We calculate the threshold level T^* by maximizing the between-class variance

$$T^* = \arg \max_{1 \le T < L} \left\{\sigma_b^2(T)\right\},$$

where $\sigma_b^2(T) = P_0(T)(\mu_0(T) - \mu)^2 + P_1(T)(\mu_1(T) - \mu)^2$, $P_0(T), P_1(T)$ are cumulative probabilities; $\mu_0(T), \mu_1(T)$ are mean values; $\sigma_0^2(T), \sigma_1^2(T)$ – variances of two classes. Results of Otsu segmentation are presented in Fig. 2 (*c–d*). One can see that without preliminary SSR processing many dimple edges are missed and some dimples are binarized as edges.

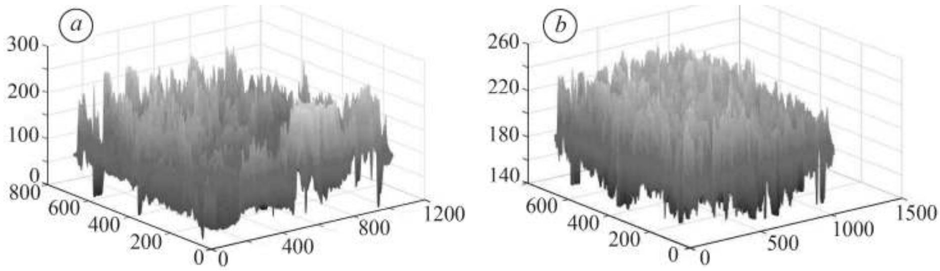

Fig 1. 3*D* representation of input image of fractured surface received by electronic microscope (*a*) and the result of its processing by SSR method (*b*).

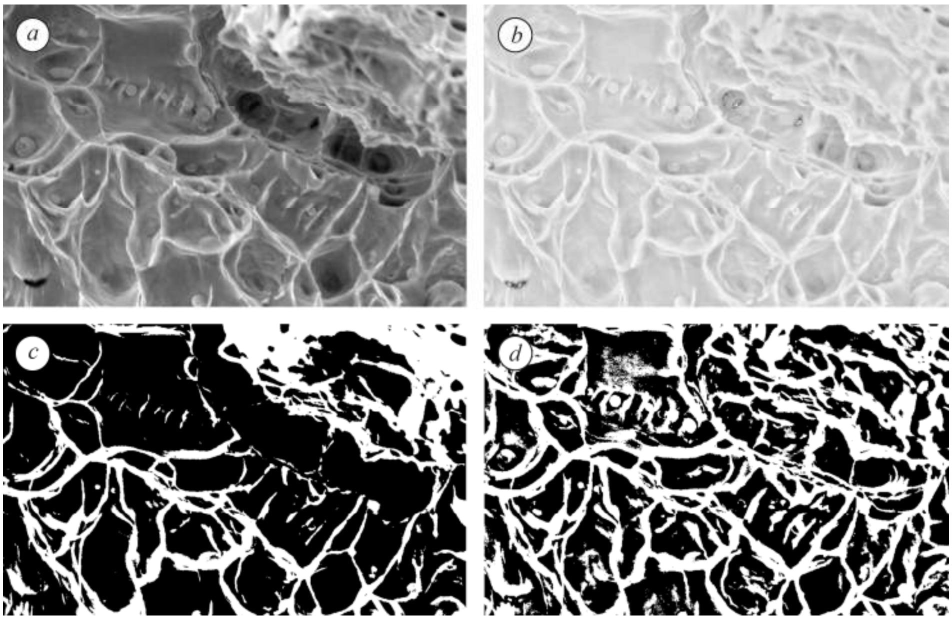

Fig. 2. Input image (*a*), processed by SSR method (*b*) and corresponding Otsu segmentation (*c*–*d*).

The next step is image skeletonization [10]. The largest detected skeleton is selected and small objects are removed using operations of mathematical morphology. The shape of every dimple is analyzed and corrected separately using closing operation with small structuring element (see Fig. 3). Histograms of dimple orientation angle from –90 to 90° and averaged diameter are presented in Fig. 4.

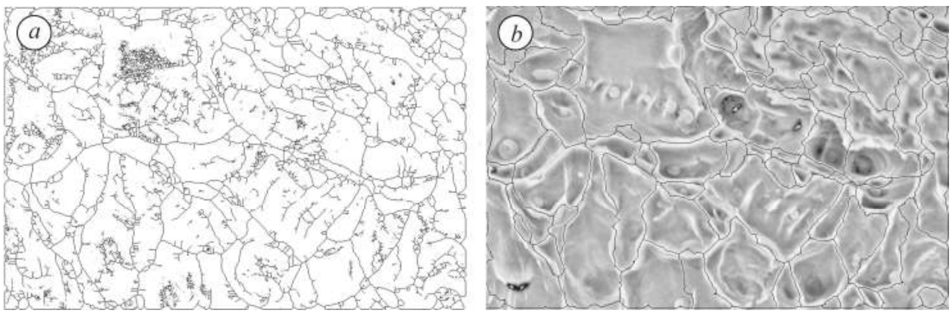

Fig. 3. Skeletonization of binarized image (*a*) and result of dimples extraction (*b*).

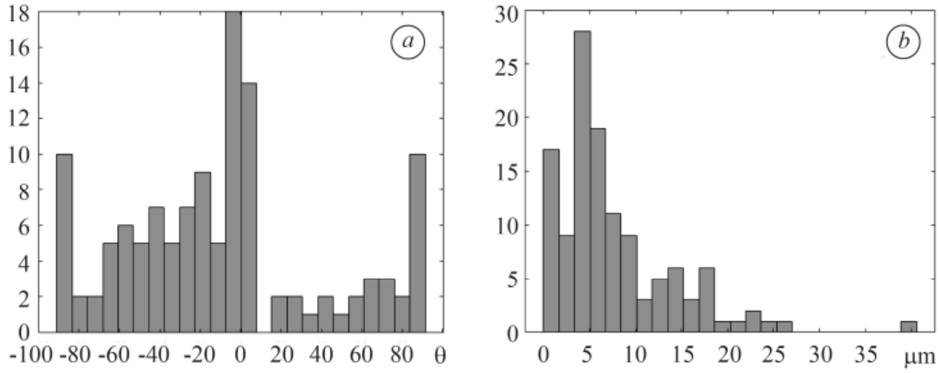

Fig. 4. Histograms of dimple orientation angle from –90 to 90° (*a*) and averaged diameter (*b*).

The proposed technology of image processing makes the analysis of dimples more precise. This is achieved by the rejection of excessively small dimples and unclosed contours. The proposed technology of dimples analysis on fractographic images of fractures makes it possible to more accurately evaluate the mechanical properties of the materials under study due to obtaining a more reliable distribution of such parameters as the orientation and diameter of the dimples.

The authors express gratitude to the prof. O. Z. Student for guidance throughout the research.

1. *Automatic* characterization of fracture surfaces of AISI 304LN stainless steel using image texture analysis / S. Dutta, A. Das, K. Barat, H. Roy // Measurement. – 2012. – **Vol. 45**. – P. 1140–1150.
2. *Extraction* of Region Contour in SEM Fractographs / S. Banerjee, K. Basu, P. C. Chakraborti, S. K. Saha // Second Int. Conf. on Emerging Appl. of Information Techn. – India: Kolkata, 19–20 Feb. 2011. – 5 p.
3. *Lauschmann H., Nedbal I.* Auto-shape analysis of image textures in fractography // Image Analyses and Stereology. – 2002. – **Vol. 21**. – P. 139–144.
4. *Ohashi M*. Extreme value analysis of ductile fracture surface by dimpled rupture associated with fracture behavior of tensile specimens // J Mater. Sci. – 2007. – **42**. – P. 9877–9887. DOI 10.1007/s10853-007-1685-8.
5. *Komai K., Minoshima K., and Ishii S.* Recognition of Different Fracture Surface Morphologies using Computer Image Processing Technique // JSME Int. Journ. Ser. **A**, Mechanics and Material Eng.,1993. – **36**(2). – P. 220–227.
6. *Research* on quantitative analysis method of steel dimples based on wavelet transform / X. Li, F. Ding, W. Zhu, X. Feng // Int. Conf. on Mechanic Automation and Control Eng. – Wuhan, 2010. – P. 365–368. DOI: 10.1109/MACE.2010.5535614.
7. *Konovalenko I., Maruschak P., Prentkovskis O.* Automated Method for Fractographic Analysis of Shape and Size of Dimples on Fracture Surface of High-Strength Titanium Alloys // Metals. 2018. – **Vol. 8**, No 3. – P. 161–173. Doi 10.3390/met8030161.
8. *Land E*. The retinex // American Scientist. 1964. – **Vol. 52**, No 2. – P. 247–264.
9. *Otsu N*. A Threshold Selection Method from Gray-Level Histograms // IEEE Transactions on Systems, Man, and Cybernetics. – 1979. – **Vol. 9**, No 1. – P. 62–66.
10. *Maragos P., Schafer R*. Morphological skeleton representation and coding of binary images // IEEE Trans. on Acoustics, Speech and Signal Proc. – 1986. – **Vol. 34**, No 5. – P. 1228–1244.

Received 20.09.2018