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Phase Determination in Low Carbon Steel Metallographic Image Using Wavelet Transform

RAJESH KUMAR, and D.P. JENA
Precision Metrology Laboratory, Department of Mechanical Engineering
Sant Longowal Institute of Engineering and Technology, Longowal, INDIA
Tel.: +91-1672-305300; fax: +91-1672-280057, email: rajesh_krs@rediffmail.com

A filtering technique for processing the noisy metallographic images of low carbon steel acquired by CCD camera has been presented in this paper. To enhance the image which makes extraction of the phase information easier, histogram equalization followed by wavelet filtering and thresholding has been implemented. Percentage volume of ferrite in the structure was determined by analyzing the processed image. Results are in good agreement with that obtained from spectro-photo meter. Average variation in result obtained from processed metallographic image and spectro-photo meter is less than 1%.

Key Words: Ferrite, Histogram, Image processing, Metallography, Wavelet transform

INTRODUCTION

Mechanical properties of a material are dependent on the nature of the phases, distribution of the phases, and size of grains present in it. Metallography deals with the study of the structure of metals that provides information regarding the compositions and properties of the metal. Quantitative metallography can be used both in the development of new advanced materials and as a control method in the production process. The interpretation of the micro structural features such as grain size, inclusions, impurities, porosity, segregation or surface effects require an understanding of the processes by which various structures are formed[1,2]. Majta and Zurek have studied modelling aspects of microstructure development under intercritical forming conditions in microalloyed and low carbon steel[3].The grains of a metal objects are very small and cannot be seen with the naked eye. To observe the structural features of the small grains, an optical microscope or an electron microscope at magnification 100-200 or even greater is usually required. Grain sizes of metals have been measured by Latala and Wojonar by using manual and image analysis methods[4]. Many investigators have measured the fine scale ferrite grain size and pre eutectoid ferrite volume fraction in low carbon steel. They have also determined the particle parameter in intermetallic matrix composite by processing the metallograph in the commercial softwares like ' Image Tool'. The enhancement and analysis of some of the information such as fraction of phase etc. specific to the metallographic images however cannot be effectively done using the commercially available softwares and manual stereological methods. A suitable flexible image processing technique is needed for the analysis of different constituents in metal. Different techniques have already been proposed to acquire and enhance images of metrological importance[5,6]. It has been established that the wavelet based techniques are very effective in noise reduction along with contrast enhancement while maintaining the sharp features in the image[7]. Appropriate pre and post processing in conjunction with wavelet filtering can tune the metallographic image for analysis of phases in it.

In this paper, an algorithm has been proposed for processing and analyzing metallographic images of low carbon steel. To enhance the contrast of metallographic image, histogram equalization followed by wavelet filtering has been implemented. Further, thresholding has been implemented to make analysis from the filtered image. Percentage volume of ferrite is determined from the processed metallographic image.

EXPERIMENTS AND RESULTS

The experiments were conducted on plain carbon steel standard sample. Average percentage of carbon and manganese in steel sample were 0.25 % and 0.43% respectively. To determine percentage of ferrite, a 2D image of the sample was used. Surface of the sample was prepared by polishing using emery paper of 60, 200, 600, 1200 grid in sequence. After polishing using emery paper the specimen was further polished with velvet cloth for 30 minutes. The polishing resulted in a mirror like surface which was etched properly with Nital (98% methyl alcohol + 2% Nitric acid). The sample so obtained was cleaned with water and dried. The image of the sample was acquired using metallographic microscope attached with CCD camera. A typical raw image on gray scale is shown in Fig. 1(a). The sample was having two-phase structure which is also observed in the image. The Ferrite in the sample appears bright and Pearlite in the sample appears dark. Grains of ferrite phase are polygonal and equiaxed. Pearlite however is unresolved. Contrast and signal-to-noise ratio in the raw image are poor. Histogram of the raw image is shown in Fig. 1(b) which shows that intensities of the pixels are in the range of 30-195 (on the gray scale range of 0 to 255) which leads to poor contrast in the image.

A three stage filtering scheme has been investigated to process and analyse the metallograph. In the first stage histogram equalization is implemented. The histogram equalization rescales the range of an image's pixel intensity values to produce an enhanced image whose pixel intensity values are more uniformly distributed. The enhanced image tends to higher contrast. Wavelet transform is implemented on the histogram equalized image in the second stage of processing. Conventional methods based on Fourier transform, such as low pass filtering or spectral subtraction image-restoration, have proven to be quite efficient to reduce noise from the image. Fourier methods however do not preserve details of the image. This is basically due to the reason that the Fourier transform expands the original function in terms of orthonormal basis functions of sine and cosine waves of infinite duration[7]. Thus errors are introduced when filtered metallographic image is used to determine the grain boundaries. Wavelets are computationally efficient and provide significant noise reduction alongwith contrast enhancement while maintaining the sharp features in the image. The 'symlets' are compactly supported wavelets with least asymmetry and higher number of vanishing moments for a given support width. Associated scaling filters are near linear phase filters, which make easier to deal with the boundaries of the image[7]. Implementation of symmetrical wavelet on the metallographic image makes the grain boundary sharp and distinct. In the third stage thresholding is implemented. It allows segmentation of pixels in image into multilevel classes. Wavelet filtered image is the source image for thresholding. Low carbon steel has two phase structure (ferrite and pearlite). We have used two level thresholding which divide the intensity value set into two non overlapping ranges, each of which can be associated with a unique value in the resulting image. It is helpful in automatic evaluation of percentage volume of ferrite in the image.

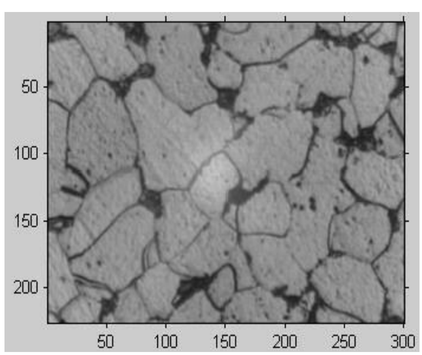

Fig. 1(a): Raw image of the sample

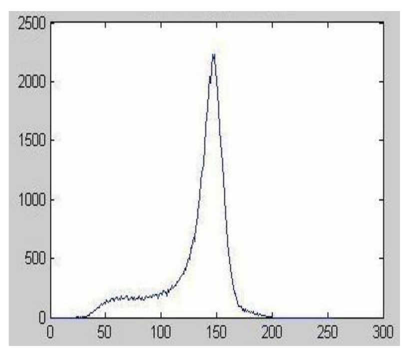

Fig. 1(b): Histogram of raw image

Following the above filtering scheme, we have applied histogram equalization on the raw image shown in Fig. 1(a) and implemented symlet wavelet. Threshold value was selected carefully for calculating the accurate percentage of ferrite in the sample. Considering the condition that the pearlite zone should appear dark, sampling of intensity of pixels in the pearlite zone were made. Maximum intensity of pixel in the sampled zone was 59 on the gray scale 0-255 which was taken as a threshold value. Care has to be taken in selecting the threshold in a way so that any part of the grain boundaries does not vanish. All the pixels in the image having intensity less than or equal to 59 have been replaced by the intensity value 0. Pixels having intensity values 60 or above have been replaced by intensity 255. If we consider the whole image it appears that this threshold value is very close to the sum of the minimum intensity and the standard deviation of the intensity in the image. The threshold image is shown in Fig. 2(a). Histogram of Fig. 2(a) is shown in Fig. 2(b) which clearly shows that now there are only two intensity values 0 and 255 i.e. dark and white respectively. Percentage of white pixels in the image i.e. ferrite was obtained as 70.40%. One more area of the specimen was focused for acquiring image and processed in the similar fashion with the same threshold value. The ferrite in this zone comes to be 71.56%. It was due to the reason that the grain boundary and grain size was not exactly same in both the vicinities. The algorithm for processing and analyzing the image was developed in Matlab environment.

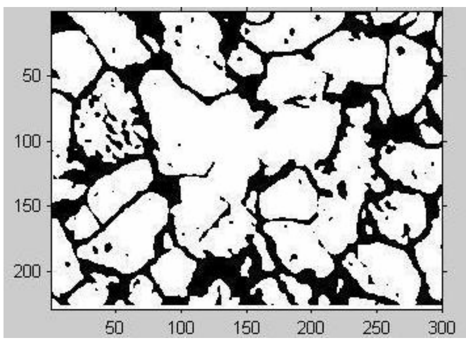

Fig. 2(a): Processed image for analysis after implementing histogram equalization, wavelet filtering and thresholding

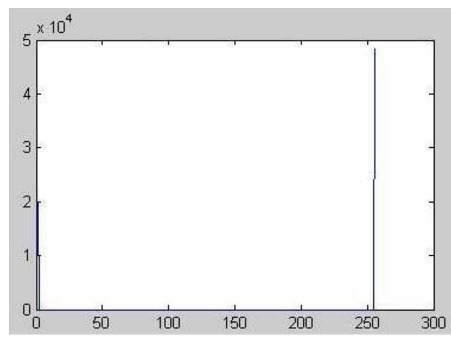

Fig.2(b):Histogram of image shown in Fig 2(a)

For verification of the results, carbon percentage by weight in the sample was determined by spectro-photo meter. Average carbon in the test sample was obtained as 0.2537% by weight. From iron carbon equilibrium diagram of plain carbon steel, at room temperature, the maximum ferrite (100%) is present at 0.025% of carbon and maximum pearlite (100%) is present at 0.8% of carbon by weight. Using lever rule (shown in Fig. 3) the ferrite comes to be 70.49% in the plan carbon steel having 0.2537% carbon (as obtained from spectro-photo meter).

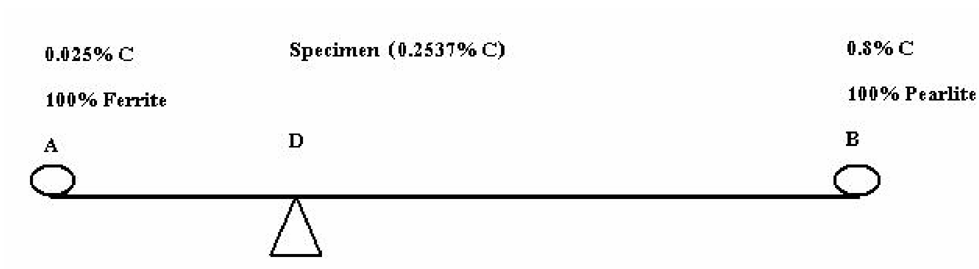

Fig. 3: Evaluation of percentage ferrite using lever rule

The results obtained from processed metallographic image and spectro-photo meter are in good agreement. Average variation in result from processed metallographic image and spectro-photo meter is approximately 1%. Variation in result may be due to excessive lighting in certain zone of the image while its acquisition and the assumption that the 2D image (i.e. cross section of the volume) is representative of the 3D sample.

CONCLUSION

The image processing technique based on histogram equalization followed by wavelet transform and thresholding is very effective in enhancing contrast of the recorded metallographic image and analysis from it. Wavelet transform is very much effective in making the grain boundaries sharp in the metallographic image. For the threshold value in the range of 0-59 and 60-255 as 0 and 255 respectively, the fraction of bright area in the image is 70.40%. It implies that the volume of ferrite in the specified zone of the sample is 70.40% at the above mentioned threshold. Selection of proper threshold plays an important role in extracting the required information from the image quantitatively. Average variation in result from processed metallographic image and spectro-photo meter is less than 1%. The algorithm developed makes the phase determination system simple and cost effective. Early investigations establish that analysis of constituents in different zones of welding is also possible by the algorithm presented in the paper.

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