Rare Metal Materials and Engineering
Volume 45, Issue 3, March 2016
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: Rare Metal Materials and Engineering, 2016, 45(3): 0548-0554.

ARTICLE

Grain Size Automatic Determination for 7050 Al Alloy Based on a Fuzzy Logic Method

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Abstract: Grain size is one of the crucial parameters in the microstructure analysis of high strength aluminum alloy. This information is commonly derived based on manual processes. However, these manual processes may take long time and error are prone to occur. Nowadays，the rapid development of the digital image processing and the pattern recognition technologies provides a new methodology for the quantitative metallographic analysis. Artificial intelligence utilized in realizing automatic metallographic analysis can overcome the drawbacks of the manual processes. In the present paper we presented a new method of digital image processing for determining the grain sizes of the metallographic images. To derive the grain sizes of the digital metallographic images, the digital image processing was applied to extract grain boundary by proposing a new edge detection algorithm based on fuzzy logic. Extensive metallographic images with different qualities were tested to validate this method. Practical application cases were presented here. The grain size was calculated in accordance with American Society for Testing Material (ASTM) standards.

Key words: microstructure analysis; grain size; fuzzy logic; edge detection; aluminum alloy

Grain size determination plays an important role in the metallic material research, and it can get the information related to the materials' properties, such as yield strength, tensile strength and elongation, which have significant influences on properties of materials [1]. Traditional methods of the grain size determination are fundamentally dependent on the manual processes leading to time-consuming and error are prone to occur. With the development of the computing and image processing technologies, the digital image processing and pattern recognition techniques have recently become primary tools for the automatically quantitative metallographic analysis and the grain size determination[2-5]. Commercial metallographic analyzers are usually equipped with the specialized image processing appliances, such as the Image-Pro Plus (IPP), Image Tool and Image J, and are widely used in the metallographic microstructure analysis. Although these appliances reduce manual workloads and improve the efficiency of analysis to some extent, the instructions of the appliances are still complex, e.g., many parameters have to be manually set up and operating steps require user's intervention. Additionally, the appliances have many specific requirements for the complicated preparation of the metallographic images of the specimens. It is difficult to identify grain boundaries in the images with low contrast and bad defined boundaries.

Many new image processing algorithms have been introduced and achieved great improvements in grain size determination[6], but there are still some shortcomings which need to be resolved. Because the characteristics of different alloy's metallographic images differ from each other, the commonest problem is that the universality of existing methods is very low. Jiang et al. used the multi-scale geodesic dilation algorithm to restore and reconstruct the grain boundaries based on the improved definition of dilation [7]. Deng et al. proposed a new algorithm based on the Canny algorithm and a gray scale

Received date: March 14, 2015
Foundation item: National Key Technology R&D Program Projects (2009BAG12A07); National Natural Science Foundation of China (51101016)
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contour line to get enclosing edge of metallographic structure [8]. The automation level of these methods is still considered low. Some procedures still need to be performed manually. C. Park and Yu Ding et al. used a convexity analysis to split composite boundaries into individual components and recover the missing components of the boundary using FPCA (functional principal component analysis)-based missing value estimation [9]. The involved algorithms in above works are still time-consuming. Dengiz et al. used the neural network and the fuzzy logic algorithms to detect the grain boundary of steel alloys[10]. Łukasz Rauch et al. has used the Feed-Back Pulse Coupled Neural Network optimized by the bio-inspired optimization algorithms to segment the material microstructure images [11]. Although they can accurately extract and position the edge, the obtained boundaries are not continuous and smooth.

In the present work, based on some metallographic images of a 7050 aluminum alloy, one of the high-strength aluminum alloys, as the research object, a methodology focused on automatic grain size determination was introduced. High-strength aluminum alloy is the key material of the high-speed rail, which attracts much attentions of researchers. According to the features of the metallographic images and the requirements of grain boundary extraction, we proposed a new edge detection method based on fuzzy logic. After pre-processed, the grain boundaries were extracted. Combined with the mathematical morphology method and other post-processing, the reconstruction of the discontinuous grain boundaries was investigated on the reliability of automatic extraction of the grain boundary.

1 Experiment

Metallographic specimen preparation process mainly consists of four stages: sampling, grinding, polishing and etching with a suitable etchant to reveal the microstructure. In the first stage, the 7050 aluminum alloy metallographic specimen was taken from the die forging axle box of a high speed train. Grinding and polishing were used to ensure the surface uniformity of the specimen. We used sand paper to grind the surface and a polishing machine to polish the specimen. The specimen had to be etched to view the microstructure. NaOH solution with a concentration of 5% is the common etchant for aluminum alloy. After the aluminum alloy was etched for 1~2 min and cleaned by the dilute nitric acid and alcohol, the grain boundary could be visually examined. At the end, the metallographic images could be acquired under a metallographic microscope.

The image processing, reconstruction, visualization and automatic grain size determination were performed on a computer with a 2 GHz Intel Core 2 dual-core processor, 2 GB of RAM and NVidia GT240 discrete graphics cards. All the procedures and algorithms were realized by VC programming (Visual Studio 2010, Microsoft). The image processing was also carried out by Image-Pro Plus 6.0 (Media Cybernetics Inc.) for the comparison of the proposed method.

2 Results and Discussion

After the digital images have been captured, they must be processed to meet the requirements of automatic determination of the grain size. However, there exist too many factors influencing the quality of the images, such as illumination conditions and surface irregularities. Fig.1a shows an original aluminum alloy metallographic image. Fig.1b corresponds to part of the square in Fig.1a. The figure indicates that the metallographic image have low contrast, severe noise, and bad defined boundaries. Traditional image processing methods, for instance, the global threshold method (two-peak method, iterative method and Otsu method) and the differential edge detection operators (Sobel, Prewitt, Laplacian of Gaussian and Canny), cannot obtain ideal results. Fig.1c displays the threshold result of the Fig.1b obtained through Otsu method and indicates that the method is not capable of separating grain boundaries and background.

In order for yielding desirable results, other efficient image processing techniques must be introduced. The proposed algorithm developed is based on the fuzzy logic. After the digital images' noises are eliminated from the pre-processing stage, a fuzzy model based on the fuzzy logic is constructed to calculate the membership of a pixel to edge point, and produces a reconstructed image. Then the image is deconstructed by the decision function. Finally, the morphology and other methods are invoked in the further processing. The described process flow is summarized in the Fig.2.

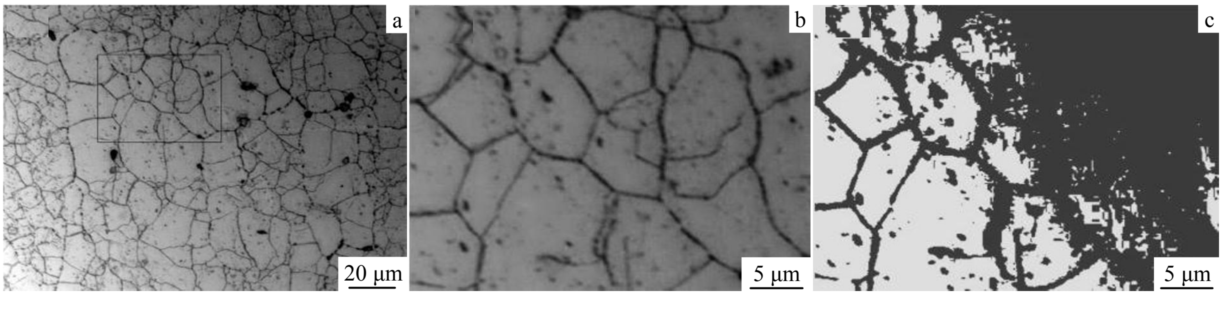

Fig.1 Metallographic images of 7050 Al alloy: (a) original image, (b) zoom view of block in Fig.1a, and (c) segmented by Otsu method