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ScienceDirect
Trans. Nonferrous Met. Soc. China 23(2013) 2265−2269

Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

# A new method for separating complex touching equiaxed and lamellar alpha phases in microstructure of titanium alloy

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Received 21 June 2012; accepted 15 October 2012

**Abstract:** A new method for separating complex touching equiaxed and lamellar alpha phases in the optical micrograph of titanium alloy was proposed for quantitative characterization. This new method involves three steps. First, concave points of the microstructural feature are identified with a threshold of the concaveness of the corner points which are extracted from the binarized image. Secondly, concave points pairs are selected from the concave points group established by means of marker circle or distance. Third, whether a candidate separation line which connects two concave points within a pair can be accepted or not is determined by the proposed four rules. The obtained results show that this method is effective on separating complex touching microstructural features.

**Key words:** titanium alloy; microstructural feature; separation method

## 1 Introduction

Titanium alloys have been widely used in the aerospace field due to their high specific strength, good corrosion resistance and excellent high temperature performance [1,2]. These excellent comprehensive properties depend on optimal combination of equiaxed and lamellar alpha phases. In general, equiaxed phase shows superior ductility and thermal stability, while lamellar phase shows excellent high temperature creep properties, high impact toughness and fracture toughness [3]. Moreover, the combination of these phases significantly affects the mechanical properties of titanium alloys [4]. Hence, quantitative characterization of equiaxed and lamellar alpha phases is significantly important for the optimized mechanical properties of titanium alloys.

However, previous characterization method on the touching equiaxed or lamellar alpha needs to manually identify and separate the different morphologies [5,6]. Apparently, this method is time-consuming and laborious. Therefore, a numerical efficient approach is urgently needed to separate the touching microstructural features automatically. In the field of image processing, the threshold of gray value was usually used as an effective parameter for separating the primary and secondary alpha textures in a duplex microstructure [7−9]. However, different gray values between equiaxed and thick lamellar alpha may not be remarkable.

Therefore, in the present work, a new method based on digital image analysis was proposed to separate touching equiaxed alpha and thick lamellar alpha in a tri-modal microstructure [10] of titanium alloys.

## 2 Concave point extraction

An apparent feature of touching microstructure is that there is at least one significant concavity along its boundary. The location of concavity can be indicated by its concave point. Thus, whether the microstructural features touching or not can be determined by checking the concave point. The concave point extraction algorithm includes two steps, corner point extraction and concave point identification.

Corner points of a microstructural feature in a binary image can be detected by Harris algorithm which is a well established technique with accurate corner

**Foundation item:** Projects (50935007, 51175428) supported by the National Natural Science Foundation of China; Project (2010CB731701) supported by the National Basic Research Program of China; Project (B08040) supported by the Program of Introducing Talents of Discipline to Universities, China

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DOI: 10.1016/S1003-6326(13)62727-2

detection performance [11]. Given an image $f$, the auto-correlation matrix $\boldsymbol{M}$ at position $P$ in the image is

$$\boldsymbol{M}=\boldsymbol{\sigma}_{\mathrm{D}}^{2}\boldsymbol{g}(\boldsymbol{\sigma}_{\mathrm{I}})\otimes \begin{bmatrix} f_x^2(P,\boldsymbol{\sigma}_{\mathrm{D}}) & f_x(P,\sigma_{\mathrm{D}})f_y(P,\boldsymbol{\sigma}_{\mathrm{D}}) \\ f_x(P,\boldsymbol{\sigma}_{\mathrm{D}})f_y(P,\boldsymbol{\sigma}_{\mathrm{D}}) & f_y^2(P,\boldsymbol{\sigma}_{\mathrm{D}}) \end{bmatrix} \tag{1}$$

where $\sigma_{\mathrm{I}}$ is the integration scale; $\sigma_{\mathrm{D}}$ is the differentiation scale; $g(\sigma_{\mathrm{I}})$ is a Gaussian function with deviation $\sigma_{\mathrm{I}}$; $\otimes$ is the convolution operator; $f_x$ and $f_y$ are the first image derivatives in the horizontal and vertical direction, respectively.

The commonly used Harris corner response function is given by

$$R=\det(\boldsymbol{M})-\kappa\cdot\mathrm{trace}^2(\boldsymbol{M}) \tag{2}$$

where det($\boldsymbol{M}$) and trace($\boldsymbol{M}$) denote the determinant and the trace of the second matrix $\boldsymbol{M}$ which is defined in Eq. (1); $\kappa$ is a constant coefficient lying in the interval [0.04,0.15]. High value of the Harris corner response function indicates the location of a corner point.

The Harris algorithm is applied to detecting corner points of a binarized object, as shown in Fig. 1(a). The points indicated by $P1-P17$ are the corner points detected by Harris algorithm.

The concavity of each corner point is defined by its concaveness, $C$, which is expressed as [12]

$$C=\frac{L_{\mathrm{i}}}{L} \tag{3}$$

where $L$ is the perimeter of the circle (see Fig. 1(a) at point $P1$) centered at the corner point and $L_{\mathrm{i}}$ is the arc length of the circle inside the object (see Fig. 1(a) at point $P1$).

Figure 1(b) shows the concaveness of $P1-P17$. Only the corner points with large concaveness are used to form separation line. Here, a threshold of concaveness 0.5 is used. Thus, the corner points with concaveness lager than 0.5 are extracted, which are considered concave points. The orientation of a concave point is the orientation joining the concave point and the middle point of the arc outside the object (see Fig. 1(a), point $B$ near point $P1$ is the middle point of the arc outside the object), which is used for separating the microstructural feature with only one concave point.

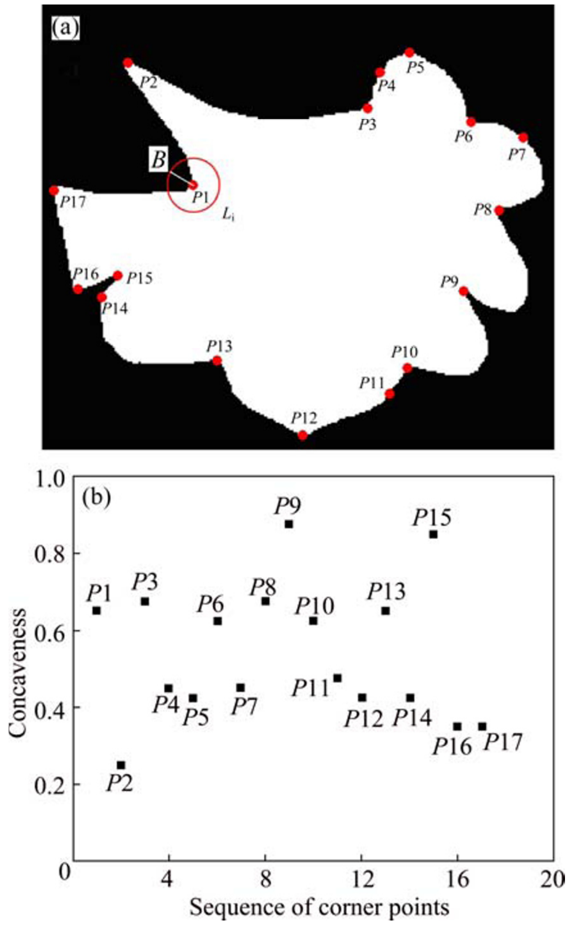


**Fig. 1** Schematic representation of concave point extraction: (a) Corner points detected by Harris algorithm; (b) Concaveness of corner points

## 3 Concave point pairing

The extracted concave points are paired in order to form separation lines. There are many concave points pairing rules, such as nearest neighbor [13] and opposite orientation [12,14]. A new method is proposed to classify the concave points into pairs based on the concave points groups that are classified by the marker circles or distance. The algorithm for concave point pairing includes two steps, classifying concave points into groups and classifying each group into pairs.

An assemble of two concave points as the candidate for forming separation line is considered a pair. However, it is time-consuming to check every candidate separation line formed by connecting any two concave points. In order to accomplish computational efficiency, the marker circle used to indicate the group of concave points is proposed.

In order to form the marker circle, the center needs to be determined at first, so the skeleton of an object is used. The skeleton of an object is the locus of the centers of the maximal disk that can be inscribed within the object [15]. The thin line in Fig. 2(b) extracted from the gray image (Fig. 2(a)) is the skeleton of the binarized microstructural feature. It can be observed that the skeleton has nearly equal distance to the boundary of the microstructural feature along the normal direction of the skeleton, and the possible separation line must cross the