

A method of quantitative characterization for the component of C/C composites based on the PLM video

Y X Li^{1,3}, L H Qi¹, Y S Song¹ and H J Li²

¹School of Mechatronic Engineering, Northwestern Polytechnical University, Xi'an, Shaanxi, China

²Carbon/Carbon Composites Research Center, Northwestern Polytechnical University, Xi'an, Shaanxi, China

E-mail: crystal1507@163.com

Abstract. PLM video is used for studying the microstructure of C/C composites, because it contains the structure and motion information at the same time. It means that PLM video could provide more comprehensive microstructure features of C/C composites, and then the microstructure could be quantitatively characterized by image processing. However, several unavoidable displacements still exist in the PLM video, which could occur during the process of image acquisition. Therefore, an image registration method was put forward to correct the displacements by the phase correlation, and further to achieve the quantitative characterization of component combined with image fusion and threshold segmentation based on the PLM video of C/C composites. Specifically, PLM video was decomposed to a frame sequence firstly. Then a series of processes was carried out on this basis, including selecting the frame as equal interval, segmenting the static and dynamic regions and correcting the relative displacements between the adjacent frames. Meanwhile, the result of image registration was verified through image fusion, and it indicates that the proposed method could eliminate the displacements effectively. Finally, some operations of image processing were used to segment the components and calculate their fractions, thus the quantitative calculation was achieved successfully.

1. Introduction

Carbon/carbon (C/C) composites, as a kind of new high-performance materials, have been widely used in aerospace and military fields [1-3]. They have excellent mechanical and thermodynamic properties, especially under high-temperature environment [4-7]. However, complex technology parameters and high cost have made them hardly be used in the civilian fields. Therefore, it is necessary to conduct studies on the relationship between the technology, microstructure and properties for process optimization and performance design. In particular, the most important issue is how to characterize the microstructure of C/C composites quantitatively [8-11].

Qualitative description of microscopic images could not illustrate one problem or phenomenon completely in common research. So image processing is used, as a powerful tool, for characterizing the microstructure quantitatively through image feature describing and analyzing, by more and more researchers. In C/C composites, carbon fibers (CF) are reinforced by the carbon matrix [12]. It means that the fiber and matrix phases are all formed by carbon elements. So it is difficult to distinguish the fiber and matrix on the images of Metallurgical microscopy or Computed tomography(CT). Polarized



light microscope (PLM) image is the most intuitive and convenient tool, which could observe the fiber, matrix and pores easily by eyes, during the microstructural research.

An image segmentation method developed by Miaoling Li was used for segmenting the PLM image based on a sequence of PLM images in different angle. However, the condition for image acquisition was very strict [13]. In fact, the extinction crosses of C/C composites have obvious moving feature by rotating the analyser of microscope. PLM video could store the structure and movement information of C/C composites at the same time, so it is important to analyze and characterize the microstructure quantitatively. Unluckily, some unavoidable displacements between the adjacent frames of video still exist, during the analyzer rotating. That would lead to some serious errors and even a wrong result in the subsequent image processing. Therefore, to eliminate the displacement between the adjacent frames, a displacement correction method based on the phase correlation algorithm was put forward in this paper. And then the component fraction was calculated successfully by image fusion, threshold segmentation and morphological processing, etc.

2. Materials and method

2.1. Materials

C/C composite samples were prepared by isothermal chemical vapor infiltration (ICVI). The temperature was 1150°C and the total pressure was 2.5kPa. The prepared sample was mounted with resin and grounded coarsely by water proof abrasive papers firstly, and then polished by diamond paste for 30 minutes and the water for 45 minutes successively.

During the image acquisition process, the magnification times of the objective was kept at 50× for the Leica DMLP. To acquire the moving process of extinction cross, the PLM video was collected when the analyzer was slowly rotated from 0° to 360° and stored as a format of AVI, the resolution was 1280×960 and the frame rate was 5fps.

2.2. Phase correlation algorithm

Since the primary displacement is caused by the translational motion for the PLM video of C/C composites, a phase correlation algorithm, which is mainly used to calculate the displacement between the adjacent frames, was introduced to solve the image registration problem in this paper.

Suppose that $f_1(x, y)$ and $f_2(x, y)$ are two image matrices with the same size, and a translational motion relationship is between them. The mathematical expression is shown as follow:

$$f_2(x, y) = f_1(x - x_0, y - y_0) \quad (1)$$

The expression (1) can be transformed to (2) by fourier transformation. Where $f_1(x, y)$ and $f_2(x, y)$ are forms of and after the successive fourier transformation.

$$F_2(u, v) = F_1(u, v) e^{-j(ux_0 + vy_0)} \quad (2)$$

The cross power spectrum of them is shown in (3), where $F_2^*(u, v)$ is the complex conjugate of $F_2(u, v)$.

$$\frac{F_1(u, v) F_2^*(u, v)}{|F_1(u, v) F_2^*(u, v)|} = e^{-j(ux_0 + vy_0)} \quad (3)$$

A two dimensional pulse function $W(x - x_0, y - y_0)$ can be obtained by inverse fourier transformation from $e^{-j(ux_0 + vy_0)}$. The translational parameters of x_0 and y_0 can be determined by the peak position of pulse function $W(x - x_0, y - y_0)$, which is the key of phase correlation algorithm[14].

3. Results and discussion

3.1. Pre-processing of PLM video image

PLM video is decomposed into frames to extract the information of the PLM image by the home-made soft and stored as the format of JPG firstly. Considering the mode of manual sampling cannot keep the analyzer rotation with a constant speed and the data of frames are too massive, the frames are need to be selected at regular intervals, and as in this paper the interval is 10° . The average gray value of each frame is calculated, and then the front and end static parts are removed according to their different gray values. In particular, the difference of gray value is close to 0 for the static parts, and the remainder parts usually have a certain value. The moving part of average gray value is fitted by cosine curve, because in fact, the variation of average gray value is consistent with the cosine curve. To further reduce the error during the process of fitting, the data of gray value is fitted piecewise in this paper.

Although the removing speed of image acquisition is not consistent, the extreme points still correspond to the angles of 90° , 180° and 270° . We could divide the intervals to $(0\sim90^\circ)$, $(90\sim180^\circ)$, $(180\sim270^\circ)$ and $(270\sim360^\circ)$ based on the positions of extreme points and fit the average gray values by the cosine function successively. Figure 1 shows the relationship during the process of sampling. The x-data (frame number) of fitting curve is further divided by the 10° sampling intervals, as the data of the fitting curve represents the situation that the angle of analyzer is uniform motion. The corresponding y-data (average gray value) could be obtained by the fitting curve, which is just the theoretical average gray value uniform motion. So the actual frame number could be selected from the regional average gray value data by the corresponding y-data.

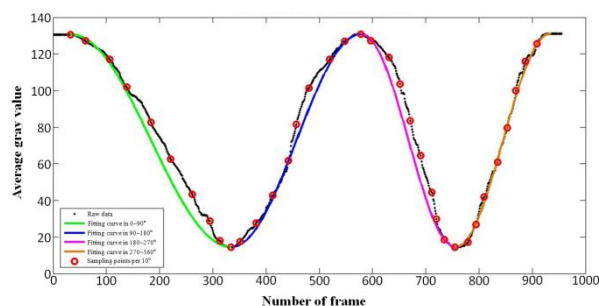


Figure 1. The average gray value of PLM video

3.2. Segmentation of the static and dynamic regions

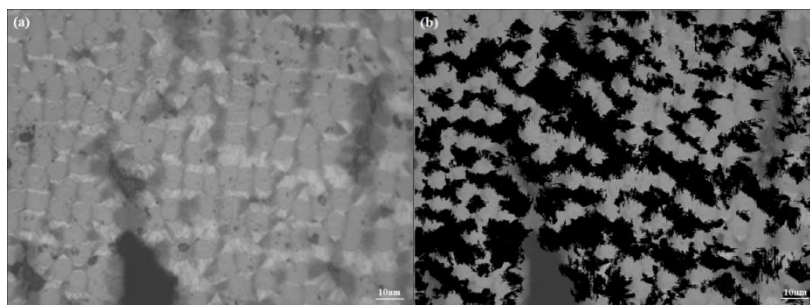


Figure 2. Segmentation of the static and moving regions: (a) raw image. (b) segmented image.

Considering the movement of extinction crosses would change the content of image, they have a larger area on the image, a processing of image segmentation is needed for reducing error between the dynamic and static regions, in which the dynamic region is belong to part of pyrocarbon, and the static

region contains CF and pore. The methods of threshold segment and morphological processing are used to segment them, and a new frame sequence that only contains the information of static region is introduced to the next step processing, as the figure 2(b) shown.

3.3. Correction of the relative displacement by phase correlation method

For each new frame, the projections of gray value along the directions of X and Y are calculated respectively, and the cross-correlated analysis is carried out. Figure3 shows the result of cross-correlated function, which indicates the matching degree of two data sequence on the different relative positions. The data of cross-correlated function on the X direction illustrate correlation between the two groups of gray value projective data when the one group data shift a certain value relative to the other group, in which the point of maximum correlation is just the position of maximum matching degree for the two frames on the X direction. The relative displacement could be easily obtained by calculating the distance between the matching position and the origin, as the figure 3(a) shown. Meanwhile, the relative displacement on the Y direction could be obtained by the same method, as the figure 3(b) shown.

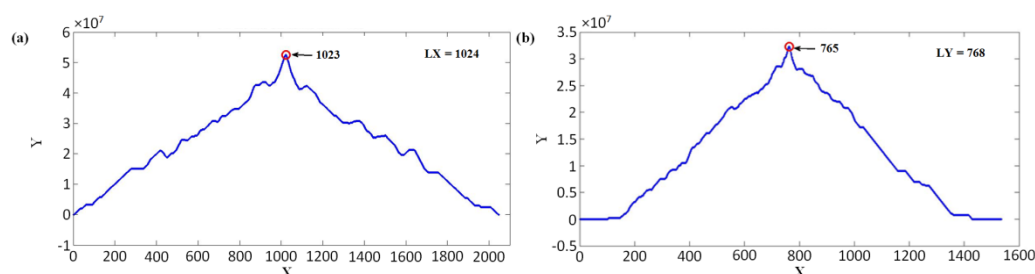


Figure 3. Calculation of the matching positions on the X and Y directions: (a) matching position on the X direction. (b) matching position on the Y direction.

Table1. The relative displacement of frame sequence

Number	1	2	3	4	5	6	7	8	9
<i>sx</i>	-1	1	-2	3	-2	-2	-2	1	-2
<i>sy</i>	-3	1	2	0	2	1	7	0	-1
Number	10	11	12	13	14	15	16	17	
<i>sx</i>	-3	1	-3	-1	-3	3	-1	-4	
<i>sy</i>	5	0	1	0	0	-3	1	0	

Table.1 shows the results of the relative displacement for all of the adjacent frames in the interval(0~180°), in which the *sx* and *sy* refer to the displacements on the X and Y directions successively. Thus, through correcting the frame sequence according to the data in Table.1, the registration of the frame sequence could be achieved by the phase correlation method. In addition, a processing of image fusion is carried out for verifying the results of registration, because the relative displacement between the adjacent frames is tiny and difficult to distinguish by eyes. The figure4 shows the comparative results of image fusion, in which the fusion image of registered frames is more clear than the unregistered frames. It means that the relative displacements between the adjacent frames exist really for the unregistered frame sequence, and they have been eliminated well by the phase correlation method.

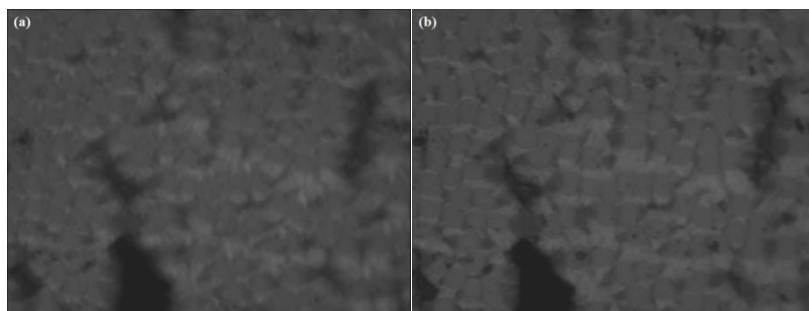


Figure 4. The contrast of the registered and unregistered PLM video: (a) fusion result of the unregistered PLM video. (b) fusion result of the registered PLM video.

3.4. Calculation of the component fraction

The regions of CF, pore and matrix show different gray value in the fusion image because of the different microstructure, especially for the matrix with different texture. So each component could be segmented by the methods of threshold segmentation and morphological processing according to their different gray value. As the figure 5 shown, the regions of CF and pore are segmented from the PLM image, and fractions of pore, CF and pyrocarbon are in order of 5.36%, 48.60% and 46.04%. Thus, the quantitative characterization of component fraction is achieved by a series of image processing methods based on PLM video.

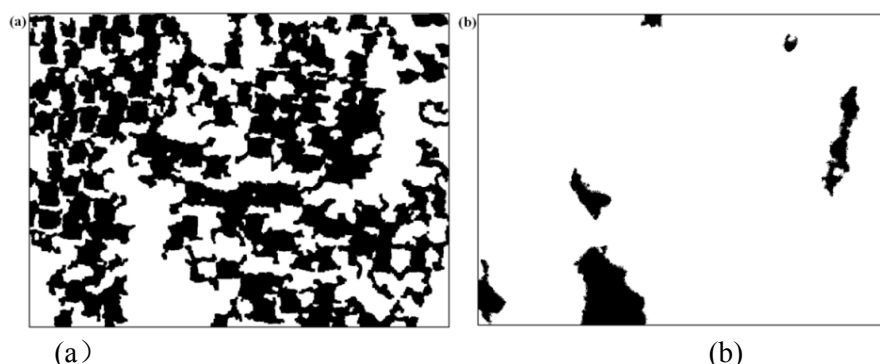


Figure 5. Segmentation of components: (a) CF region of C/C composites. (b) pore region of C/C composites.

4. Conclusion

A quantitative characterization method for the component of C/C composites based on PLM video was researched by a series of imaging processing methods and the phase correlation method in this paper, the main results are as follows:

- The phase correlation method was introduced to calculate the relative displacement between the two adjacent frames, and the frame sequence was registered on this basis.
- The component fraction was characterized quantitatively by a series of imaging processing methods.

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