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The Characterization of the Structure of Composites via Digital Image Analysis Method

Zoltan Gácsi (University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary) femtangz@uni-miskolc.hu;
Tamás Bubonyi; (University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary) fembubo@uni-miskolc.hu;

Dániel Pethő ;(University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary) femdani@uni-miskolc.hu
Péter Barkóczy (University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary) fembarki@uni-miskolc.hu

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Abstract

Evaluation of the microstructure of composite materials is an important task. Several methods are developed to describe the basic properties of the arrangement of the particles. Two main properties are their ordering and clustering. The possible methods to test these properties are the covariance functions and radial distribution functions. Artificial images were developed with different level of arrangement and the effectiveness of these method are tested.

Introduction

Particle reinforced composites have several types and applications. The microstructure of these composites is basically the same: particles in a matrix [1]. It is known that the properties of the composites depend on the spatial distribution / arrangement of the particles [1,2]. Therefore, the evaluation of the spatial distribution of the reinforcements is highly important when testing composite materials [3]. Literature suggests several mathematical methods, using these opens up possibilities to describe the spatial distribution [3]. However, a common property of these methods is that it is not able to describe the composite material in general [3]. One is suitable for describing the ordering, and another for detecting the clustering of the reinforcements.

In this study a comparison is shown between two different kinds of evaluation methods. Artificial microstructures are generated to test these methods, where the properties of the microstructures are described by numbers instead of measurements by the human vision. The correlation of the results with these descriptors is observed and evaluated in this paper. Based on this research, real composite structures could be evaluated and compared clearly, which helps in engineering and optimizing the production technology of composite materials.

Mechanical properties are strongly related to the microstructure of metals and composite materials. On one side the amount of the different phases or the size of the elements have a great influence [4]. But the relation (distance, position, spatial arrangement) between the elements or particles also has an effect on the properties of the metals or composite materials [5,6,7]. The typical spatial arrangements are grouped into several basic types, and within these types large numbers of variations are present [8]. For these sophisticated methods it is crucial to clearly describe the arrangements. The literature introduces more possible methods [9]. In this presentation the radial distribution function and the covariance of the micrographs are introduced and studied.

The radial distribution function basically counts particles inside circles with given radii. The centers of the circles are the different particles [10]. The implementation of the method is not fully related to the particles due to the finite dimensions of the image. Additionally, the basic method does not take the special arrangement effects into account that come from the different sizes of the particles. In this comparison the basic method is modified to show a complete description. The center of the circle is positioned to the center of the images because this position can provide the maximal radius. The radius of the circle is increased from 1 to the half the height of the image. The area is counted in pixels that are occupied by the particles. To get results similar to that in the literature, the areas of the particles within the circle are divided by the area of the circle. This area fraction as a function of the radius of the circle is studied. With this modification this function approximates the area fraction of the particles instead of 1. In this study the examined microstructures are made artificially.

The literature shows that this measurement is sensitive to the clustering of the particles. But an interesting question is how we can see the ordering in the results. Is this method sensitive to the size or

the shape of the particle, or not? Is this method able to reveal the orientation of whiskers? On one side this presentation examines this question.

The literature introduces and suggests the covariance of the images to reveal the ordering on the image, the ordered structure of the particles. In this method the original image is shifted with a translation vector and the union of the translated and the original image is calculated. This in implementation means that the coincident pixels are counted that belong to particles in both images at the given coordinate. The number of the coincident pixels as a function of the amount of shift is analyzed. The direction of the translation vector in case of spherical particles is preferably on the side of the image. The magnitude of the vector in this case is 1 pixel. If the particles are ordered the covariance function will be periodic. This description shows that the covariance of the images is better in studying the ordering.

While comparing the two methods, questions may arise here as well. How does this method behave when clustering occurs? Which orderings can be detected by this method? How can we handle the orientation of whisker-like particles? In this presentation this method is also examined in light of these questions.

During the manufacturing of the composite materials the description of the arrangement of the phases has a great importance. It is known that one method, one number is not enough to clearly describe the spatial relation between the particles. One method can reveal one aspect of the arrangement, but it is necessary to see the effect of another aspect of the arrangement in the given result. In a recent study the effect of the order and the randomness in the arrangement are studied with the radial distribution function and the covariance of the images. This comparison gives the answer of that questions which are in the focus of interest and cited above.

Methods

The analysis was performed on artificial images. The main strategy was to examine as many cases as possible. The simulated structures were composite structures. The morphology of the reinforcing phase was either small spheres or whiskers. The initial structures were in every series the regular ordered phase with uniform size e.g. circles in a square grid. Then the size of the spheres is randomized in a predefined range. The size of the range is increased along the series. Another strategy was the randomization of the position of the uniform spheres. Finally, both, the size and the position are determined in a random manner. In the cases of whiskers, the length varied in a different extent. Additionally, the orientation of the artificial particles rotated according to a random rotation matrix. During the series the regular structure shifts towards a random structure. The radial distribution function of the structures, and the covariance of the images were examined. The effects of the extent of distortion were analyzed.

The size of the images was 1024x768. The basic description of the particle model: particle diameter is 20 px, distance of the particles in the grid is 50 px. The distance of the whisker center of mass in the grid is 100 px, the length of the whiskers is 80 px and the width of the whiskers is 6 px.

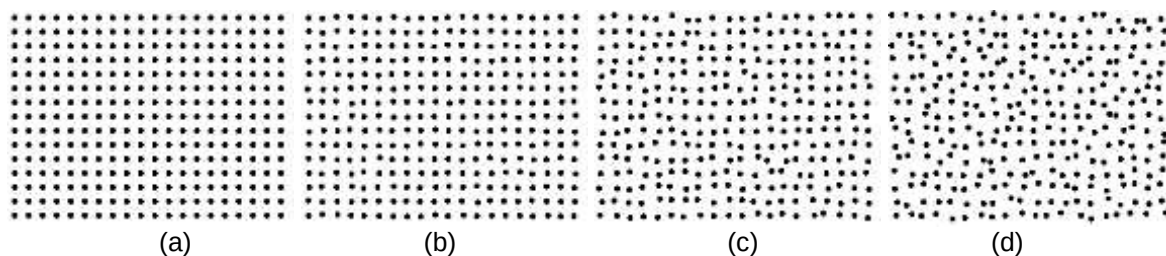


Fig. 1. The distortion of the regular structure of the particles. The particles are represented by uniform discs with 20 px diameter. The distance between the center of the discs is 50 px in (a) image. The position of the discs is randomized within a range of ± 5 px (b), ± 10 px (c), and ± 20 px (d).



(a) (b) (c) (d)

Fig. 2. The distortion of the regular structure of the whiskers. The particles are represented by 80 px long 6 px wide ellipsoids. The distance between the centers of the whiskers is 100 px. The orientation of the whiskers is randomized within a range of $\pm 0^\circ$ (a), $\pm 15^\circ$ (b), $\pm 30^\circ$ (c), $\pm 60^\circ$ (d).

The orientation distribution functions and covariance functions along the width of the images are calculated and compared to each other. The effects of the randomness of different parameters were in focus as it is shown on figure 1 and 2. The distortion of the images is described by a range of random changes.

Results and discussion

First the size of the particle in the regular grid is studied as a reference. The irregularities of this regular arrangement will be studied in the following in a comparison to the regular grid. The uniform changes in the diameter of the discs result in narrower peaks (figure 3(a)) which is trivial according to method. However, introducing a random variation in the diameter, the height of the peaks decreases with nearly the same half width. The higher the variation becomes in the diameter, the more it decreases the height of the peaks (figure 3(b)).

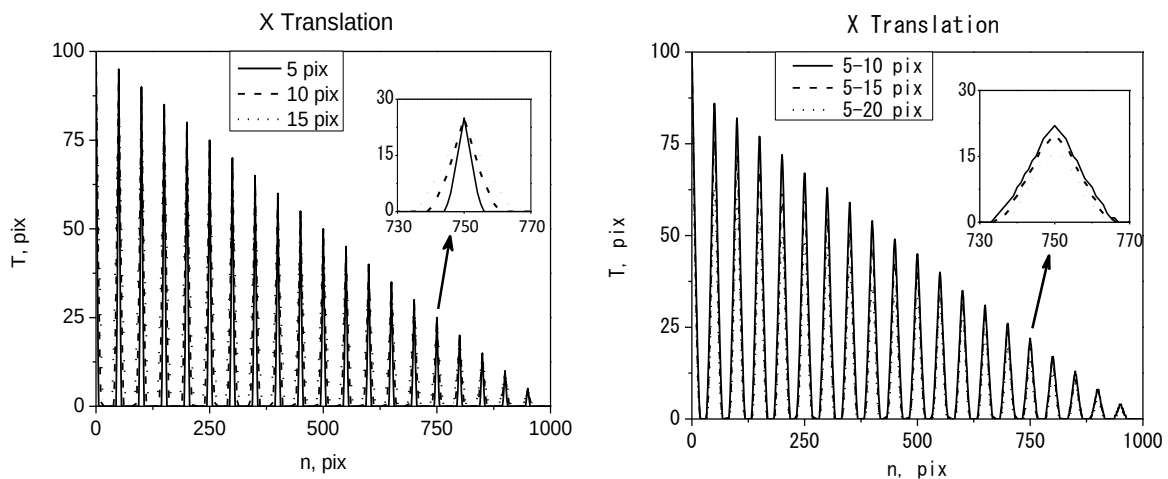


Figure 3. Covariance function of the images with objects with different uniform diameters (a), and the images with objects with randomly changed diameters (b). T denotes the number of the pixels which belongs to a particle in both image in the same position, n is the magnitude of the translation vector along the width of the image (X direction).

As seen in both cases the shape of the radial distribution functions is not sensitive to the changes of the diameters. The absolute values are differing due to the different area fractions, of course. The difference between the uniform and random changes is that the function in the case of random changes of the diameters is not as smooth.

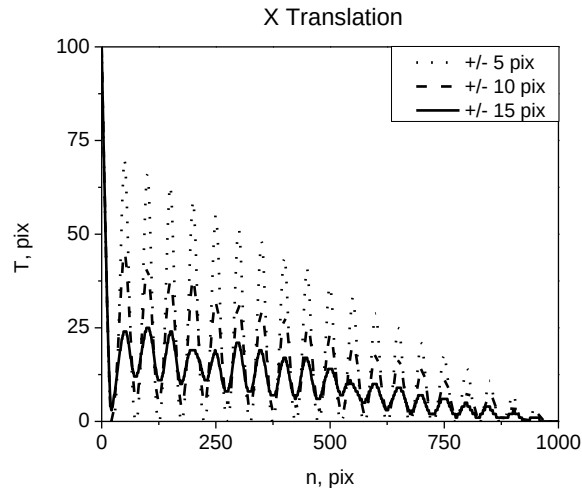


Figure 4. Covariance function of the images where the position (distance) of the objects is distorted randomly. The covariance functions also give the original periodicity at high level of distortion.

The smoothness of the curves is related to the average distance of the objects. If the average distance of the objects is large, an oscillation of the radial distribution function can be observed due to the large matrix volume between the particles. The measured results of the artificial microstructures show this. If the distance of the objects is distorted in a random manner, the covariance functions of the images can realize the minimal ordering. On the images where the random arrangement can be seen with naked eye, the covariance function shows the periodicity. The analysis of the covariance function shows a periodicity of the microstructure. As large of the distortion in the position of the particles as low the amplitude of the covariance function. Additionally, the covariance function gives the original periodicity of the particles without distortion in all case (Figure 4).

In case of whiskers the two main parameters are the length and orientation of the whiskers. In case of regular ordered structure, the radial distribution function and the covariance function show the same behavior as above. If the orientation of the whiskers is rotated randomly in a range, the covariance function changes. This shows the same periodicity, but the intensity, the number of identic pixel decreases (figure 5(a)). In the radial distribution functions small peaks can be discovered which is related to the average distance of the whiskers. But it is not enough to provide characteristics about the orientation and arrangement of the whiskers. When the orientation, length and position are varied randomly at the same time, the information of both functions are lost, and the covariance function shows a random distribution (figure 5(b)).

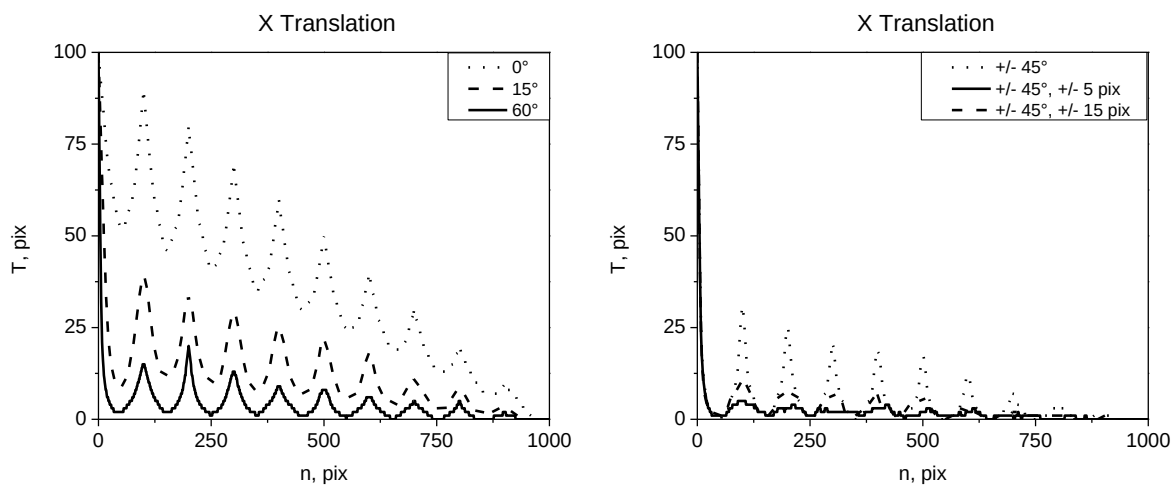


Figure 5. Covariance function of the images where the orientation of the whiskers is distorted randomly (a) and the orientation, position and length the whiskers are distorted (b).

The covariance function and the radial distribution function reveal two different kind of aspect of the arrangement of strengthening phase in a composite material. The covariance function shows that the

particles built-up a regular structure or not. For example, it is good for examine an in-situ composite structure. The radial distribution function shows a clustering of the particles. This method is good for qualifying a composite which made by a powder metallurgical method. The discussed examples show that the covariance function can reveal a low level of ordering, but the radial distribution function shows this arrangement as uniform. The radial distribution function is developed to test the clustering. This behavior of the function is also tested. Artificial microstructures were developed where the objects are clustered in four groups around four cluster centers. The objects are discs with a uniform diameter. The possibilities of the positions of the objects were calculated by a Gaussian which position of the maxima shifted to the cluster center. The variance of the Gaussian is changed: 50, 100, 200 px. The 50 px of variance gives four independent groups. At 100 px of variance the groups almost touch each other. The 200 px of variance shows a nearly uniform random arrangement with naked eye.

The covariance function cannot be evaluated, as periodicity in the structure does not exist. But the radial distribution function shows a different nature (Figure 6). This is a modified version of the original radial distribution function as it was described in the introduction, but it also clearly shows the existence of clustering and can be define the level or strength of the clustering. In the case of regular or random distribution the function is monotone function, T increasing continuously as a function of the radius. When clustered arrangement is built-up, plateau(s) can be seen on the curves. Due to the arrangement of the particles in the simulated images the largest plateau exists at the beginning of the function. As strong the clustering (small inner distances in the clusters) the plateau as wide. This function also shows the clustering on that image where the human vision is not able to discover it, as it was introduced in the case of covariance function. If the original and the modified versions of the radial distribution function are compared, the original method could be more effective because it considers every relation. But this method can evaluate a larger area in the image and provides the desired results.

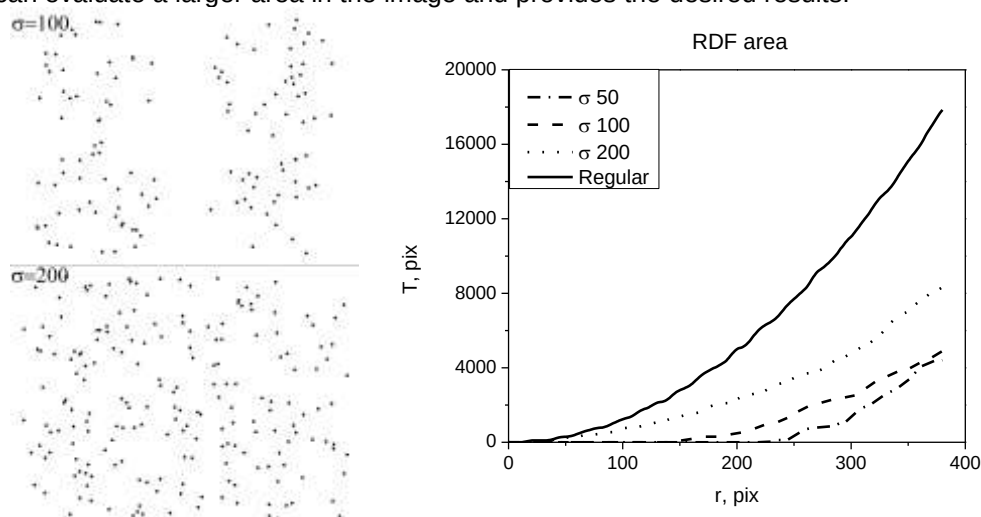


Figure 6. The radial distribution function of the images with clustered objects.

Summary

Artificial images were developed to model the microstructure of composite materials reinforced with particles and whiskers. The ordering and clustering of the particles are examined with covariance functions and radial distribution functions. The tests show that the covariance functions can reveal small degrees of ordering in the microstructure and give information about the periodicity of the arrangement. This method works in the case of both particles and whiskers. The radial distribution functions evaluate this microstructure as a uniform random arrangement. Minor serrations can be observed in the radial distribution function if the distance is too large between the objects. In case of clustering, the covariance functions cannot give enough information about the arrangement, but the radial distribution function reveals the small levels of clustering. The tests show that both methods are useful in evaluation for testing the microstructure of composite materials.

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