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INVESTIGATION OF DISTANCE BY AUTOMATIC IMAGE ANALYZER

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ABSTRACT

The mechanical properties of fiber and grain reinforced composites are strongly influenced by the arrangement and mutual distances of the reinforcing components. The distance between particles is an important parameter characterising eutectic solidification. Several methods are known for the distance evaluation. This paper presents and compares currently used methods nowadays and a computer program serving this purpose developed by the authors. The structures of unidirectionally solidified fiber reinforced materials e.g. Al - 6.04 wt % Ni eutectic alloy can be well characterised with the help of this program.

Key words: distance, eutectic alloy, image analysis, microstructure, solidification.

INTRODUCTION

Several investigators have observed that the yield-, tensile- and creep strength of fiber reinforced composites change as a function of fiber distance (Chadwick, 1976; Fras et al., 1988). Therefore changing the fiber distance the mechanical properties of composites can be improved.

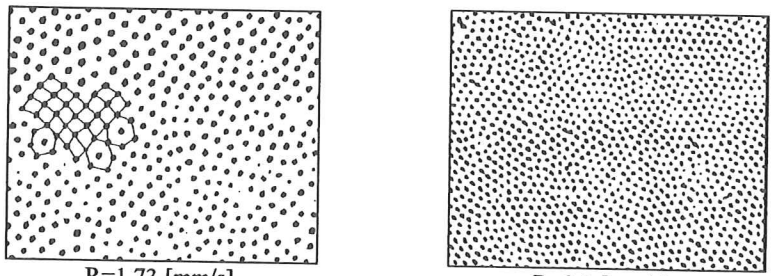

Fig. 1. Cross section of the Al_3Ni fibers, scanning electron microscope, 10 000X.

One way of producing fiber reinforced composites is the unidirectional solidification of eutectic melt. In the case of Al - 6.04 wt % Ni eutectic alloy we get Al_3Ni fiber reinforced in situ composite. Fig.1 shows SEM images of the cross section of two specimens solidified at

different interface velocity (R). It can be seen that the Al_3Ni fibers in some places have rectangular, elsewhere hexagonal, or random arrangement (Csepeli, 1994). Several different methods are known for evaluation of the fiber distances (Underwood, 1970). The aim of our investigation was to present and compare the different methods and to develop a computer program on the basis of our experiments.

THEORY

Using different distance evaluation methods several problems arise. Basically there are two ways for distance definition. In the first case we determine the distance between the gravity centres of the features (Fullman, 1953) while in the other case the distance between the surfaces of the features is evaluated (Underwood, 1970).

Measuring the distance between neighbouring features we count the number of features per unit area (N). The mean distance between nearest neighbours (λ_1) is:

$$\lambda_1 = \frac{C}{\sqrt{N}} \quad [\mu m] \tag{1}$$

where: N = number of features per unit area,
$C = 1$, if the arrangement of the features is rectangular,
$C = 1.075$, – " – – " – is hexagonal,
$C = 0.5$, – " – – " – is random.

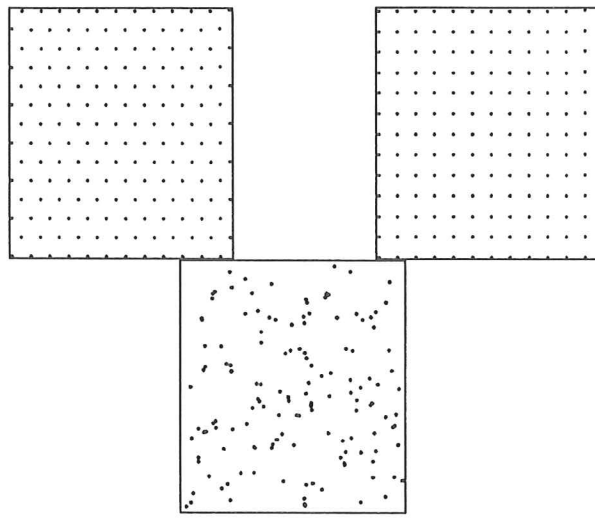

Fig. 2. The schematic pictures of different arrangements of particles.

In the second case, the picture of the features is converted into a binary form and by using the skeleton transformation we get a structure which depends on the arrangement of the features. If it is rectangular or hexagonal then we get squares or hexagons respectively. Fig.3

shows the skeleton of a random structure. The mean distance between the nearest neighbouring features can be estimated by the equivalent circle diameter (D_{eq}) of the obtained particles (λ_2):

$$\lambda_2 = D_{eq} \text{ [µm]} \tag{2}$$

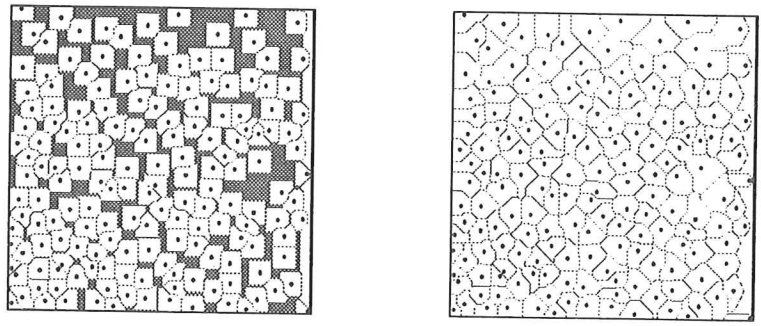

Fig. 3. Skeletonization of a random structure by Quantimet 570C.

In the third case we determine the co-ordinates of the gravity centres of particles with an image analyser and by processing data by a computer we can get the distance between the nearest neighbours (λ_3):

$$\lambda_3 = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \text{ [µm]} \tag{3a}$$

where: X_1, Y_1 = the co-ordinates of a selected particle,
Y_2, Y_2 = the co-ordinates of the nearest neighbouring particle.

The program calculates the distance between each particle and its nearest neighbour (Eq.3a) and the average of the these distances characterizes the structure. Moreover, the program is able to determine the mean distance between the particle and its surrounding neighbours:

$$\overline{\lambda_3} = \frac{\sum_{i=1}^{n} \lambda_3^i}{n} \text{ [µm]} \tag{3b}$$

where: λ_3^i = the distance between neighbouring particles (Eq. 3)
n = number of particles.

Fig. 4 shows the steps of the distance evaluation method proposed by the authors: (a) drawing a perpendicular to the line connecting a particle (O) and its nearest neighbour at half-way, (b) drawing similar perpendiculars between the particle (O) and other 15-20 particles around it, (c) we regard as neighbours the particles (⊗) belonging to the perpendiculars that form the smallest polygon around particle (O). The result of the evaluation process is shown in Fig. 5.

Similarly, the distance between the surfaces of the features can be measured in several ways. According to one of these ways the distance between surfaces (λ_4) can be expressed as:

$$\lambda_4 = 4\frac{(1-X_v)}{S_v} \text{ [μm]} \tag{4}$$

where: X_v = the volume fracture of the particles,
S_v = the surface of the particles per unit volume.

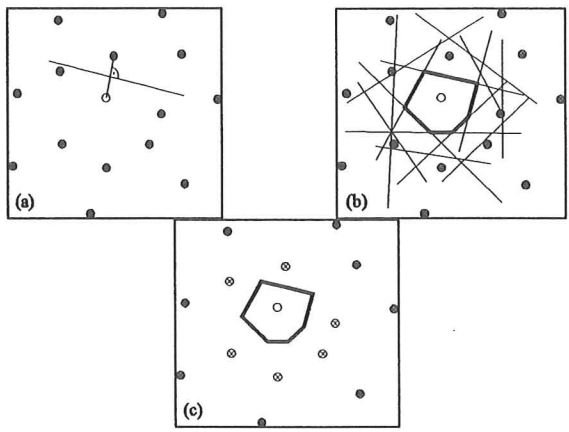

Fig. 4. The steps of the distance evaluation method.

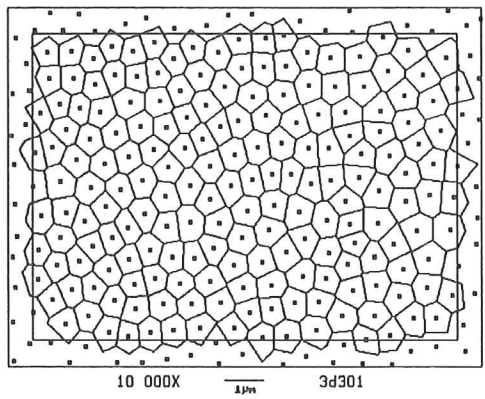

Fig. 5. The microstructure with calculated borders.

Using an image analyser there is another way to estimate the distance between the surfaces (λ_5). This method gives the average chord length in the matrix around the particles:

$$\lambda_5 = \frac{T_m}{L_h} \text{ [μm]} \tag{5}$$

where: T_m = the area of the matrix,
L_h = the length of the horizontal chords at the matrix/particle interface.

EXPERIMENTS

Al-6.04 wt% Ni alloys have been unidirectionally solidified under steady-state conditions as was described in detail in an earlier publication (Bárczy, 1993). The experimental parameters (the temperature gradient at the solid/liquid interface, G_L(K/mm) and the interface growth velocity, R(mm/s)) were determined using a measuring probe equipped with thermocouples. Longitudinal and transversal microsections were embedded into epoxy-resin and ground by SiC paper in four steps, then polished with diamond paste. The fibrous structure was examined on specimens etched in 1% HF solutions.

The fibrous structure of the specimen is shown in Fig. 1. The metallographic sections were analysed by an IBM compatible computer controlled image analyser (Quantimet 570 Operators Manual, 1991). To compare the different methods used for distance determination stylized pictures were made (Fig. 2).

RESULTS

First the stylized pictures were evaluated. The distances were determined by the methods described above, the results are shown in Table 1.

Table 1. Distances measured by different methods.

Method	Rectangular arrangement	Hexagonal arrangement	Random arrangement
$\lambda_1 = \frac{C}{\sqrt{N}}$ [μm]	1.00 **	1.05 **	0.51 **
$\lambda_2 = D_{eq}$ [μm]	1.10 *	1.07 *	1.11 *
$\lambda_3 = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$ [μm]	1.00* 1.00**	1.05 * 1.05 **	1.13 * 0.49 **
$\lambda_4 = 4\frac{(1 - X_v)}{S_v}$ [μm]	7.16	6.59	7.02
$\lambda_5 = \frac{T_m}{L_h}$ [μm]	6.66	6.07	6.64

* mean distance between neighbouring particles

** the distance of the nearest neighbour.

It is apparent from Table 1 that there are large differences between particle distances measured with different methods since in the same picture values of 0.49μm as well as 7.02μm were measured. It demonstrates the significance of indicating the correct definition of the distance determination. Calculation with Eq.1 is accurate only when the arrangement of the particles on the entire picture is rectangular, hexagonal or random.

The computer program developed by the authors is able to determine the distance even when different types of arrangements take place. It calculates the mean distance of the nearest neighbours (marked with * in Table 1) and the mean distance between neighbouring particles (marked with ** in Table 1).

Measuring on random arrangement pictures revealed that Eq. 1 can be used to calculate average distance between neighbouring particles with a constant $C \approx 1.3$. The calculation based on the skeletonization (Eq. 2) does not give an accurate estimation of this parameter. The distance between the interfaces is larger and does not depend on the arrangement.

Continuing our study, we investigated the distance between the fibers in Al_3Ni fiber reinforced in situ composite. It appeared that the volume fraction and the perimeter of the particles strongly depend on the sample preparation, etching and the quality of SEM images, so in this case we could not determinate the distance between the interfaces with adequate precision. The number of the fibers, however, could be measured in these pictures. Since the arrangement of the fibers refers to the conditions of the solidification, we calculated the distances between neighbouring fibers. The results are shown in Fig. 6 where the differences between the various methods are apparent.

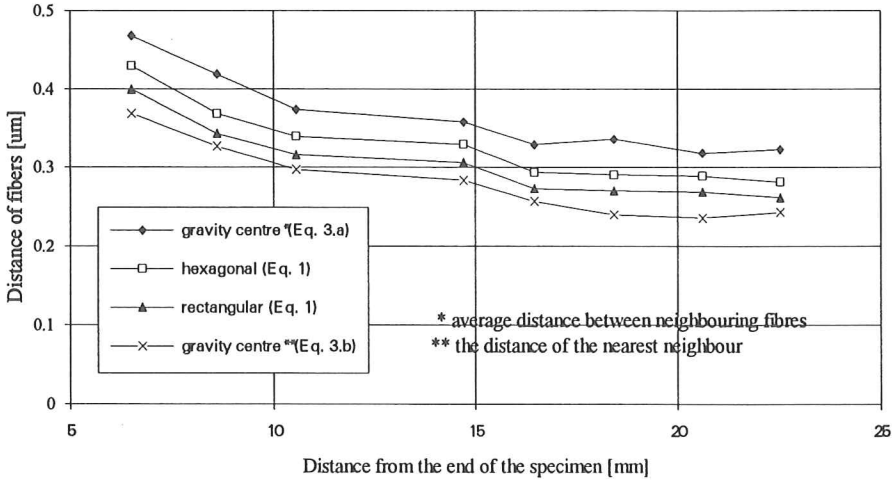

Fig. 6. The measured interfiber distances in Al_3Ni unidirectionally solidified in situ composite.

CONCLUSIONS

Distances of particles and fibers were measured using different known methods and a newly developed computer program. The conclusions are as follows:

(i) The measured interparticular distance is considerably dependent upon the applied method. For that very reason it is important to define the applied method in every case.

(ii) The frequently used constant C in equation (1) equals 1 only when the arrangement is ideally hexagonal. In this case the nearest neighbour distance is equivalent to the average value. When the arrangement is random as in real alloys, then C=0.5 for calculating the distance of the nearest neighbour and C≈1.3 for the average distance between neighbouring particles.

(iii) We can get most information measuring the co-ordinates of the gravity centers of the particles since from these data we can calculate the distance of the nearest neighbour and the average distance between neighbouring particles and it is possible to characterize the arrangement.

(iv) The best way of characterizing interfiber distances in fiber reinforced composites is measuring the average distance between neighbouring particles.

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