Computer programs to model three dimensional structure of the MMC

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Abstract

This study presents two computer programs contributing to the spatial description of the composite alloy structure. In one program the structure of an alloy suspension composite is generated (reinforced with SiC particles) on the basis of the results of metallographic measurements, while the other program visualizes the model obtained in the pseudo-3D space. The work is part of research aimed at the description of quality parameters of metallic composites.

Key words: Composite alloys, Reinforcement, Spatial modelling.

1. Introduction

Aluminium alloy matrix composites are very promising materials [1, 2]. By proper selection of the reinforcement phase and matrix it is possible to obtain composite materials that have desired mechanical and thermal properties.

The manufacturing of cast composites significantly differs from traditional casting [3]. The presence of the reinforcement phase may cause various type defects that do not exist in 'pure' metal matrix. This is particularly visible in the case of suspension composites made by the mechanical mixing method [4, 5]. It is a real challenge to describe the distribution of the reinforcement phase in alloys produced by this method. It is very important in research on composite quality description to include their evaluation [6].

The structure of materials is three dimensional. Fully quantitative characteristics of the structure are only possible when parameters describing elements of 3D space are available. In the case of non-transparent specimens, such as metal suspension composites, it is impossible to determine these parameters directly.

The basic tool used in investigations of material structures is a metallographic microscope [7, 11]. Therefore, the quantitative description of the structure is based on an analysis of a planar metallographic specimen [12]. Three groups of quantitative metallography methods may be distinguished in terms of complexity:

- measurement of basic parameters in a two-dimensional space, such as the area fraction, or the distribution of objects on the plane (comprehensive description of the 2D space),
- determination of parameters describing the 3D space based on plane measurement results (stereology),
- direct measurement in the 3D space by serial cuts or 3D reconstruction (e.g. by a tomograph).

A fast development of computer tomography we have witnessed in recent years may soon result in the tomograph being

the best tool for quantitative metallography [13, 14]. At present stereology still takes the lead.

Stereology is a science with methods permitting not only the quantitative description of 3D sets of solids based on the results of measurements and calculations of planar sections of these solids, but also, although in a limited scope, the reconstruction of a given set. This is relatively easy when examined objects can be modelled by simple solids, and their distribution in space is random [15]. The problem has been solved best for mono- and poly-dispersion system of spheres in the space [12, 15, 16]

Stereology knows various methods of reconstructing such a system of particles. The best-known are Spektor's method [12, 16, 17], Scheil-Schwartz-Saltikov method [15, 18–20] and Saltikov's method of the inverse of diameters [18]. The first two methods allow to build distributions of a number of spheres of various diameters based on measurements of, respectively, chords and diameters of their planar sections. In the method of the inverse of diameters only three parameters of the distribution are determined. These include: number of particles in 1 mm^3 (N_V), mean spatial diameter $(\overline{D})$ and standard deviation of diameters $s(D)$ [12, 16–20].

The particles of reinforcement phase in composite materials usually satisfy only one of the previously mentioned conditions necessary for their correct reconstruction based on the measurements of their planar sections. That is because they can be modelled, avoiding a significant error, by a set of spheres [12, 16,17]. However, the description of such a set by methods offered by classical stereology will not be complete, as it does not take account of non-homogenous distribution of reinforcement particles, which is typical of composites. Therefore, these authors will present a spatial model of the examined composite created by generating relevant tools (programs) and their instructions. This study is part of research on the description of composite alloy quality parameters [5–6, 20–21].

2. Creation of a composite model

While making a spatial model of the examined composite an attempt was made to minimize the previously mentioned restrictions (see Chapter 1).

The following assumptions have been made:

- the model will be a cube with a side length of 10,000 conventional units composed of 1000 smaller cubes laid in 10 layers,
- the specimen whose structure is to be modelled, will be cut into 10 slices of identical thickness,
- each slice will be prepared as a metallographic specimen,
- each recorded image of the structure, with an area A, will be divided into 100 measurement squares,
- the following will be determined in each i-th measurement square: area fraction of reinforcement phase particles $A_A(i)$, number of particles in 1mm^2 $N_A(i)$. Then the particles will be transformed into circles with an equivalent area and their diameters $d_j(i)$ will be determined,
- reinforcement particles revealed in each of the squares will be represented in the model as a set of spheres homogenously distributed in the cube, whose position in the

model corresponds to the position of measurement square in the specimen,
- when the number of specimens is smaller than 10, the structure in the model layer that does not have a corresponding metallographic specimen in the sample is taken as an averaged structure of the nearest layers – representations of the structure revealed on metallographic specimens,
- volume fraction of spheres modelling reinforcement phase particles in an i-th cube will be estimated from the area fraction of these particles in an i-th measurement square
- $V_V(i) = A_A(i)$,
- number of spheres in an i-th cube $N_V(i)$ will be determined from this formula:

$$N_V(i) = \frac{2}{\pi \cdot A} \sum_j d_j^{-1}(i) \qquad (1)$$

following Saltikov's method of the inverse of diameters [12, 17–18],
- mean spheres diameter $\overline{D}(i)$ in an i-th cube will be calculated from Mirkin's relation [12, 17]:

$$\overline{D}(i) = \frac{N_A(i)}{N_V(i)} \qquad (2)$$

3. Description of the problem

Modelling of a particle-reinforced composite structure has been divided into two tasks. First, the structure is generated on the basis of measurement data obtained from metallographic specimens, while the second task is aimed at the visualizatin of the model obtained in the pseudo-3D space. Each of the tasks is executed by a separate program.

The name of **GESTKO** program stands for generating the structure of a composite (*Generowanie Struktury Kompozytu*).

The main window of the program is shown in Fig. 1.
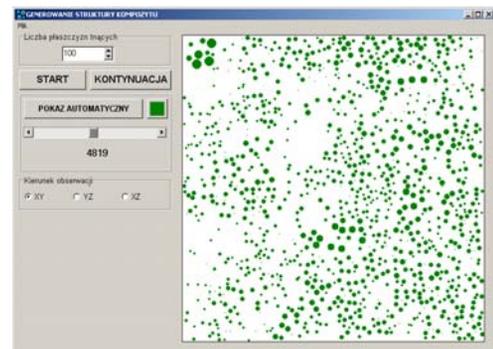
Fig.1. Main window of the **GESTKO** program

After clicking Plik (File) in the menu the following window appears, allowing to communicate with other data carriers.
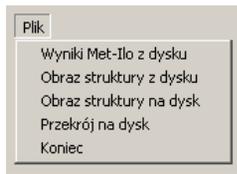
Fig. 2. Main menu of **GESTKO**, menu file – command list

The first of the available procedures permits introducing the results of measurements executed by the Metilo program [22]. Once the procedure is activated, the user puts in the number of specimens from which the structure will be modelled. Then subsequent files with measurement results are selected from the window that appears.
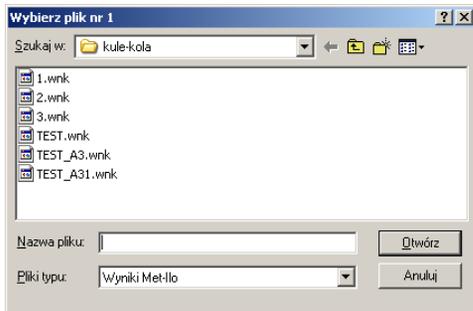
Fig. 3. Window „OTWÓRZ" (OPEN) of **GESTKO**, loading in the files with results

Thus the data for structure modelling are loaded into the program. The button ***START*** initiates the process of structure generation. How the process progresses can be observed on the bar placed under the main window where the generated structure will be displayed. The generating process can be stopped at any moment, then continued again after clicking ***KONTYNUACJA***. The generated structure is saved on the disk in the form of files with GAW extension (as developed by the authors). These files contain information on the coordinates and diameters of all generated spheres in the model.

Planar sections of the generated structure can be displayed in the dedicated field of the main window. The **GESTKO** program features a number of methods and options of image display. The round buttons in the field ***Kierunek obserwacji*** (direction of viewing) the user may select which model plane he wants to see. Clicking ***POKAZ AUTOMATYCZNY*** (automatic display) will display as many planar sections evenly distributed in way of the axis perpendicular to the screen plane as were chosen in the field ***Liczba płaszczyzn tnących (number of cutting planes)***. There is an option of choosing any plane for display by properly shifting the scroll bar placed under the button ***POKAZ AUTOMATYCZNY***. The label under the scroll bar shows the coordinate of the plane being displayed.

The other program has been called **Wizualizacja (Visualization)**. It is used for displaying pseudo-3D images of the structure saved in a GAW file and for saving the images obtained in the bitmaps (BMP) format. The main window of the program is given below.
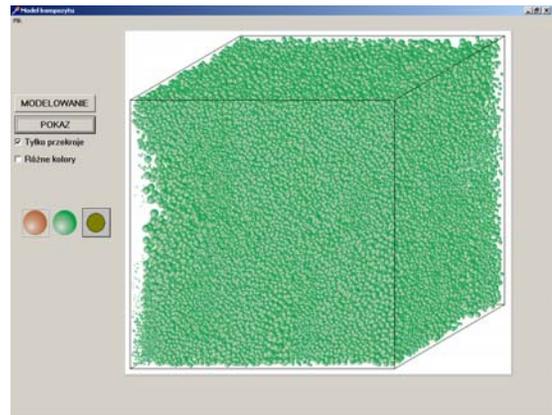
Fig. 4. Spatial model of a metallic composite obtained by the **WIZUALIZACJA** program

After clicking the file button (***Plik***) from the main menu bar the following window pops up on the screen:
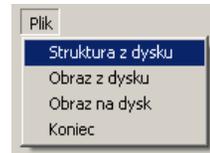
Fig. 5. Main menu of **WIZUALIZACJA** program, menu file – command list

The first function available in this window enables loading data contained in a GAW file. If the folder with GAW files includes another file of the same name with a BMP extension instead of GAW, then the image stored in the file will be loaded and displayed, too, in the dedicated field of the main window. Two other functions are used for loading an image from a data carrier or recording on it a spatial image of the generated structure model.

By pressing the button ***MODELOWANIE*** (modelling) we can start the procedure of creating a 3D image of a model stored in a GAW file. Choosing one of the spheres below defines the colour of spheres in the model

When the user selects the option: ☑ **Różne kolory** (different colours), spheres with a diameter larger than or equal to the mean length are displayed green in the model, while the others are red.

Pressing the button **POKAZ** (SHOW) displays planar sections of the model showing its subsequent XZ planes. The colour of the cutting plane and sphere cross-sections can be chosen by clicking the circle or square within the main window ☐ (Fig. 4).

Planar sections can be shown in two ways. When the option ☑ **Tylko przekroje** (sections only) is chosen, the cutting plane will only show planar cross-sections of the spheres. Otherwise, the spheres cut by the plane will also be depicted. Example images of the two options are shown below.
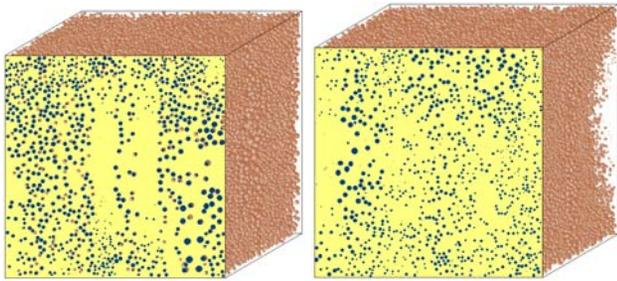
Fig. 6. Planar section of subsequent composite model planes,
obtained by **WIZUALIZACJA** program

4. Conslusions

The above description of the operation of tools proposed by the authors allows to create a spatial model of an examined material. It will also be useful in a description of quality parameters (e.g. homogeneity of reinforcement distribution in the alloy volume) of other composite materials with particulate reinforcement. Further work on the description of composite alloy structure of a model will be reported in future publications.

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