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STUDY OF REINFORCEMENT ELEMENTS DISTRIBUTION EXEMPLIFIED BY COMPOSITE WITH AlSi11 MATRIX AND CARBON REINFORCEMENT

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Studies of the distribution of reinforcement structure elements in metal matrix composite materials on the basis of microscopic images and mathematical description have been presented.

Key words: *composites, reinforcing phase distribution, carbide fibre*

Studija o raspodjeli elemenata kompozita s matricom AlSi11 i ugljikom kao ojačanjem. Prikazana je studija o raspodjeli elemenata ojačanja structure u kompozitnim materijalima metalne matrice na temelju mikroskopskog nalaza i matematičkog opisa.

Ključne riječi: *kompoziti, raspodjela faza pojačanja, ugljična vlakna*

INTRODUCTION

Metal matrix composite materials belong to a group of materials whose technology has been developing very quickly in recent years. Those materials are so successful due to the possibility of obtaining favourable characteristics by skilful selection of reinforcement and matrix that are the components of a new different material [3]. It is important, however, for the reinforcing phase distribution (especially in case of composite casts made by saturation[1]) to be as even as possible. This ensures good quality of composite and is a very important element from the point of view of the strength of material [4].

Unequal distances between reinforcement, its heterogeneous distribution, may lead to a material damage; therefore it is important to show the method of control of this component [1].

The study of homogeneity should consist of two steps:
- examination of a composite structure with the most significant element of a reinforcing phase identification;
- establishing homogeneous distribution of reinforcement elements in a given area.

This study's aim was to check usability of images, obtained by microscopic examination, for the identification of a reinforcing phase in a cast, and to establish homogeneity of reinforcement elements distribution basing on the image analysis.

The evoluation of reinforcement elements distribution was performed with 'the systematic scanning' and two-factor variance analysis according to the procedure proposed in the work [5].

STUDY DESCRIPTION

The study was performed on the material made by saturating short carbon fibre reinforcing profiles with liquid alloy of AlSi11 (Figure 1.) under the pressure of 15 MPa

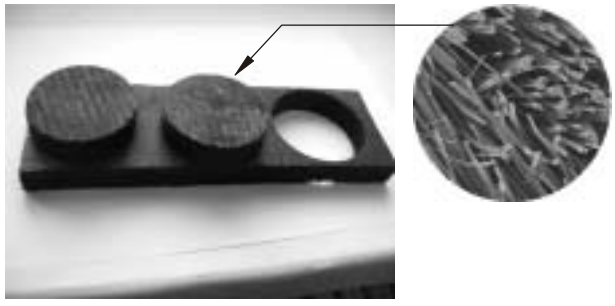

Figure 1. **Carbide fibre (macroscopic and microscopic studies, electron scanning, magn. ×100)**
Slika 1. **Ugljično vlakno (makroskopske i mikroskopske studije, elektronsko skeniranje, povećanje 100×)**

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[1] Metal cast saturated composites are made by saturating the reinforcement structure with liquid metal of matrix under pressure.

in the period of 300 seconds, keeping all requirements of the technology of casts produced by saturating with the method of liquid metal moulding [2].

Two areas selected at random with the dimensions of 10 × 6 mm were analysed, as shown in Figure 2.

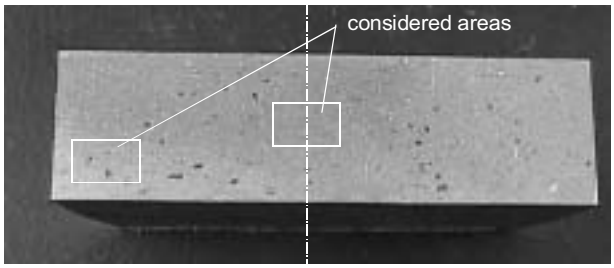
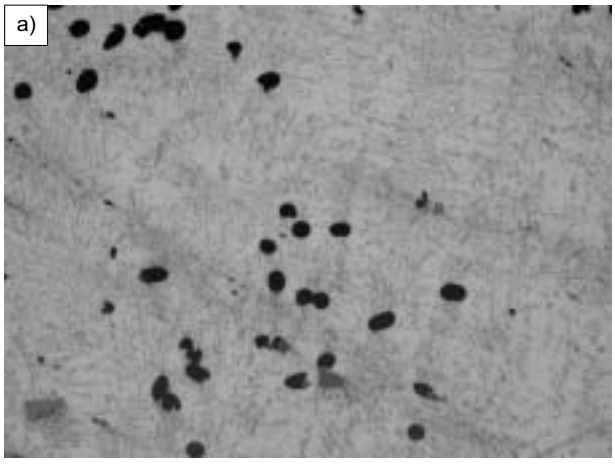


Figure 2. **Diagram showing considered areas on the cast cross-section**
Slika 2. **Dijagram promatranih površina na presjeku liva**



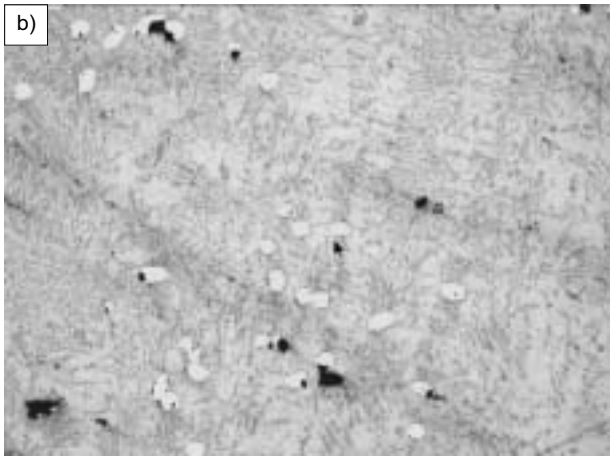


Figure 3. **Identification of reinforcing phase in the cast with silumin matrix: a) light microscopy magn. 125, b) computer image analysis (Aphelion)**
Slika 3. **Identifikacija faze pojačanja u lijevanoj matrici silumina: a) svjetlosni mikroskop, povećanje 100×, b) kompjuterska analiza slike (Aphelion)**

The reinforcing phase was identified by means of a light microscope (Neophot 2) in a magnification of 125 × (Figure 3.).

ASESSMENT OF HOMOGENEITY OF REINFORCEMENT ELEMENTS DISTRIBUTION

According to the method of 'systematic scanning' both rectangular study areas were divided into 60 fields ($n_r \times n_c = 6 \times 10$). In each of them measurements of the surface participation of reinforcement elements were made by a program for image analysis Aphelion. The results of those measurements are shown in Table 1.

Table 1. **Results of measurements of surface participation (%) of reinforcement elements plane sections in study areas**
Tablica 1. **Rezultati mjerenja participacije površine (%) presjeka ploštine elemenata ojačanja u područjima ove studije**

Area 1									
10,3	11,8	11,2	12,3	9,2	11,8	11,8	7,2	11,3	10,2
10,9	10,5	10,1	10,1	9,4	10,5	8,6	10,9	10,8	10,8
10,3	10,8	12,0	10,9	11,3	11,5	10,6	10,2	10,8	10,5
10,5	10,5	10,8	10,3	9,2	10,1	9,2	8,5	8,4	8,3
11,0	8,7	10,7	8,9	8,2	8,2	8,1	9,3	11,2	10,3
12,4	9,1	10,4	10,2	11,9	8,3	9,3	9,2	9,9	9,1
Area 2									
11,2	10,1	8,9	11,9	10,2	9,9	10,8	11,0	10,3	9,7
11,6	9,8	9,8	9,2	11,2	9,3	9,7	7,2	9,8	10,8
11,3	9,7	9,3	11,9	11,9	9,4	6,9	11,0	10,8	11,5
10,3	11,4	10,7	12,1	12,1	10,9	11,8	10,8	11,3	10,4
11,7	10,8	11,2	11,5	11,5	10,2	10,1	8,9	10,3	9,8
10,8	9,7	8,9	9,6	9,9	11,3	7,7	8,9	10,0	9,9

It is assumed in the method of 'systematic scanning' that reinforcement elements are distributed evenly if the surface participation of plane sections of those particles is the same in all fields of the analysis. The scale of the departure from this model is evaluation in this method by means of the variance analysis for two-factor (two-directional) data classification (without repetitions). Then, in this analysis there is a zero hypothesis that the surface participation is not significantly changed in the lines and columns of the study area. This hypothesis is verified by means of calculation of the values of statistics F_r and F_c (for lines and columns respectively) and comparing them with critical values. Critical values depend upon an adopted significance level ($\alpha = 0{,}05$) and the number of independent variables. Numbers of independent variables for F_r are respectively $n_r - 1$ and $(n_r - 1) \times (n_c - 1)$, whereas for F_c they are $n_c - 1$ and $(n_r - 1) \times (n_c - 1)$. If in both cases critical values are not exceeded, lack of grounds to reject the zero hypotheses is declared. This means that the surface participation of plane sections of reinforcement

elements is only the subject of statistically insignificant variations in the whole study area.

If one value of statistics *F* exceeds a given critical value, the zero hypotheses should be rejected. In this case, (line or column) banding in reference to the values of surface participation is observed.

If both values of statistics *F* simultaneously exceed given critical values, the zero hypotheses is rejected and chaotic and statistically significant variations of surface participation of reinforcing phase elements are established. In this case, reinforcing phase particles concentrations and subareas less filled with those elements cannot be excluded.

Statistical calculations were made for both studied areas and their results are shown in Tables 2. and 3.

Table 2. **Results of variance analysis for the evaluation of reinforcement elements distribution in area 1**
Tablica 2. **Rezultati analize odstupanja u procjenjivanju raspodjele elemenata ojačanja u području 1**

$\bar{A}_A$(r)	**10,71**	**10,26**	**10,89**	9,58	9,46	9,98	**10,15**
	10,2	**10,8**	**10,5**	8,3	10,3	9,1	9,87
	11,3	**10,8**	**10,8**	8,4	11,2	9,9	10,40
	7,2	**10,9**	**10,2**	8,5	9,3	9,2	9,22
	11,8	**8,6**	**10,6**	9,2	8,1	9,3	9,60
	11,8	**10,5**	**11,5**	10,1	8,2	8,3	10,07
	9,2	**9,4**	**11,3**	9,2	8,2	11,9	9,87
	12,3	**10,1**	**10,9**	10,3	8,9	10,2	10,45
	11,2	**10,1**	**12,0**	10,8	10,7	10,4	10,87
	11,8	**10,5**	**10,8**	10,5	8,7	9,1	10,23
	10,3	**10,9**	**10,3**	10,5	11,0	12,4	10,90
							$\bar{A}_A$(c)

F_r= 2,981; F(0,05;5;45) = 2,422
(significant differences among lines)

F_c= 1,503; F(0,05;9;45) = 2,096
(insignificant differences among lines)

It can be stated in view of the results of the variance analysis made for the first study area that reinforcement elements adopted band distribution in the direction of the shorter side of this area. This conclusion is suggested by average values for the lines. In order to unambiguously confirm this observation, additional calculations were performed separately for 3 top and 3 bottom lines. The following was obtained:

- top lines
  F_r = 0,935; F(0,05;2;18) = 3,555 (insignificant differences among lines),
  F_c = 0,922; F(0,05;9;18) = 2,456 (insignificant differences among columns);
- bottom lines
  F_r = 0,655; F(0,05;2;18) = 3,555 (insignificant differences among lines),
  F_c = 1,655; F(0,05;9;18) = 2,456 (insignificant differences among columns).

The above results prove that the studied area can be divided into two subareas (bands) significantly differing with the values of reinforcing elements surface participation. This fact was shown using different fonts in tables in Tables 2. and 3.

Table 3. **Results of variance analysis for the evaluation of reinforcement elements distribution in area 2**
Tablica 3. **Rezultati analize odstupanja u procjenjivanju raspodjele elemenata ojačanja u području 2**

$\bar{A}_A$(r)	10,40	9,84	**10,23**	**11,11**	**10,48**	9,67	**10,29**
	9,7	10,8	**11,5**	**10,4**	**9,8**	9,9	10,35
	10,3	9,8	**10,8**	**11,3**	**10,3**	10,0	10,42
	11,0	7,2	**11,0**	**10,8**	**8,9**	8,9	9,63
	10,8	9,7	**6,9**	**11,8**	**10,1**	7,7	9,50
	9,9	9,3	**9,4**	**10,9**	**10,2**	11,3	10,17
	10,2	11,2	**11,9**	**12,1**	**11,5**	9,9	11,13
	11,9	9,2	**11,9**	**12,1**	**11,5**	9,6	10,48
	8,9	9,8	**9,3**	**10,7**	**11,2**	8,9	9,80
	10,1	9,8	**9,7**	**11,4**	**10,8**	9,7	10,25
	11,2	11,6	**11,3**	**10,3**	**11,7**	10,8	11,15
							$\bar{A}_A$(c)

F_r= 2,851; F(0,05;5;45) = 2,422
(significant differences among lines)

F_c= 2,044; F(0,05;9;45) = 2,096
(insignificant differences among lines)

An identical statistical analysis was performed for area 2. The results of calculations were included in Table 3.

The general conclusion from the variance analysis for area 2 is the same as for area 1 - significant differences of reinforcement elements surface participation among lines and no such differences among columns. Higher average values A_A in lines 3 to 5 from the top can be seen. Variance analysis for this subarea indicates the lack of statistically significant differences both from the point of view of lines and columns (F_r = 1,907; F(0,05;2;18) = 3,555 and F_c = 0,987; F(0,05;9;18) = 2,456). This results from the fact that there is one horizontal band in this area (higher values of surface participation) located more or less in the centre of the area. Taking into consideration the random location of area 2 on the cast's section, it cannot be stated for sure that a little higher situation of this area could result in identical conclusions like for area 1 (two three-line bands: one with higher, the other with lower values of reinforcement elements surface participation).

Summing up the results of the performed statistical analysis, it may be assumed that the cast (composite) structure has a band character from the point of view of reinforcing

elements distribution. The bands are parallel to the longer side of the cast and they show alternately concentrated and less concentrated distribution of reinforcing particles.

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