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STEREOLOGICAL AND FRACTAL ANALYSIS OF THE REINFORCING PHASE OF $AlMg4+Al_2O_3$ COMPOSITE IN THE AS-CAST AND AS-ROLLED CONDITION

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SUMMARY

The paper presents characteristics of the reinforcing phase of the $AlMg4+Al_2O_3$ composite in the as-cast and as-rolled condition. The investigations of typical stereological parameters have been extended by fractal analysis of the arrangement heterogeneity degree, based on the MST method. The influence of rolling on the stereological characteristics and heterogeneity degree was used.

1. INTRODUCTION

Composite materials on a light alloys matrix are characterized by very good mechanical and performance properties and find broader and broader application in the machines construction field. To form a product not only casting methods are used but plastic working is often applied as well. Therefore, the mechanical properties of composite materials reinforced by ceramic particles depend not only on the type of matrix, quantity of the reinforcing phase and the size of particles, but also on the production technology. The way of obtaining final product (e.g. rolling) may influence the stereological characteristics of the reinforcing phase, and thus, the mechanical properties as well as other characteristics, e.g. tribological. For that reason thorough investigations of the reinforcing phase characteristics are crucial; this concerns not only

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classical methods applied in quantitative metalography but also the use of new research tools provided by fractal analysis.

2. SUBJECT AND MATERIAL OF RESEARCH

The subject of the research if the reinforcing phase of the heterogeneous material AlMg4+Al_2O_3. Ingots of 35x60x100mm formed in gravity casting were subjected to rolling with interoperational heating (570°C, 5 min).

3. PURPOSE AND SCOPE OF STUDY

The purpose of the study are stereological and fractal analyses of the characteristics changes of the reinforcing phase of an as-cast and as-rolled composite.

Specimens for the research were taken from sections parallel (R) and perpendicular (P) to the axes of gravity casts ingots and to analogous rolling directions of the composite. The research was carried out with the use of OLYMPUS BX60M microscope interfaced with a computer image analyser VISILOG 4. The method of systematic scanning was applied; measurements were carried out on 40 fields for each of the sections. The results of the stereological investigations are presented in table 1.

Table 1. Stereological parameters of the reinforcing phase in a cast and rolled composite.
Tabela1.Parametry stereologiczne fazy zbrojącej w kompozycie odlewanym i walcowanym

V_V	N_A	L_A	$d_{śr}$	$\lambda_{śr}$	N_V	$D_{śr}$
[%obj]	[mm^{-2}]	[mm^{-1}	[μm]	[μm]	[mm^{-3}]	[μm]
4,27	21,3	3,35	46,6	919	317	67,9
4,30	34,3	4,23	36,5	710	656	52,4

δ	ξ	$\nu(P_L)$	$\nu(d)$	$\nu(A)$	$\nu(\delta)$	$\nu(d)$
-	-	-	-	-	-	-
1,04	0,82	0,211	0,635	1,523	0,27	0,14
1,17	0,81	0,237	0,490	1,156	0,31	0,16

The extension of the assessment of heterogeneity of the reinforcing phase particles arrangement was carried on the basis of fractal analysis, basing on the MST method. The minimal spanning tree method consists in searching for minimal covering of a set [1]. The minimal spanning tree is a unique arrangement of branches the total length of which is the smallest of all possible lengths.

Basic relations in the MST method are: an equation (1) describing the function of sum distribution s(m,τ) and a scaling law (2):

$$s(m,\tau) = \frac{1}{m}\sum_{i=1}^{m}\left[l_i(m)\right]^{-\tau} \quad (1)$$

$$s(m,\tau) = m^{q-1} \times const \quad (2)$$

where: m – number of branches in a randomly chosen set;
l_i – length of the spanning tree branches;
τ – arrangement heterogeneity function; q – set penetrating parameter.

Adjusting the scalar relation (2) for different "m"s chosen at random from the whole set, a heterogeneity function is obtained $\tau = f(q)$ [2]. The application of Legrendre's transformation with respect to the function $\tau(q)$ allows to obtain additional information about the heterogeneity degree of a set in the form of a multifractal spectrum. The completion of the above analysis is a "K" curvature of the $\tau(q)$ function. The results of heterogeneity assessment of Al_2O_3 particles arrangement for as-cast and as-rolled composites are presented in figures 1 and 2 and in table 2.

Table 2. Breakdown of the results of fractal analysis of heterogeneity of the reinforcing phase particles arrangement.
Tabela 2. Zestawienie wyników analizy fraktalnej niejednorodności rozmieszczenia cząstek fazy zbrojącej.

Material state	Cast composite			Material state	Rolled composite		
	D_0	$\Delta\alpha$	K		D_0	$\Delta\alpha$	K
GRC	1,992	1,90	0,0342	WRC	1,950	2,02	0,040
GPC	1,965	1,85	0,0350	WPC	1,754	1,14	0,028

4. ANALYSIS OF RESULTS

The stereological analysis of the material investigated showed no significant differences in stereological characteristics for basic parameters defined on parallel and perpendicular sections of an as-cast and as-rolled composite. As a result of rolling, however, considerable refinement of the reinforcing phase of Al_2O_3 was found, caused by crushing of particles conglomerates. A consequence of this fact is a decrease of the "d" diameter of the particles sections and the "D" diameter of the particles in alloy volume and a decrease of the average distance between particles „λ" as well as an increase of the values N_A, N_V, L_A. Moreover, after rolling, certain deterioration of the shape and particles elongation (ξ,δ) as well as their heterogeneity indices ($\nu(\xi)$,$\nu(\delta)$) is observed. Since the stereological evaluation of heterogeneity is conducted on the basis of relatively little precise coefficients, basing only on an analysis of standard deviations of the examined parameters, a fractal analysis of arrangement heterogeneity was introduced as a supplementary tool.

For the as-cast condition there is no diversity of the heterogeneity degree in the parallel (GRC) and perpendicular (GPC) section. Parameters of the multifractal spectrum D_0,$\Delta\alpha$ and the values of the „K" curvature of the heterogeneity function $\tau(q)$ differ only slightly. This allows to suppose that throughout the whole alloy volume there is the same degree of heterogeneity of AL_2O_3 particles arrangement. In a rolled composite, it is the perpendicular section (WPC) that is characterized by higher homogeneity, which is indicated by lower values: D_0,$\Delta\alpha$, K. The parallel section (WRC) shows high anisotropy of particles arrangement. This is confirmed by parameters: D_0, $\Delta\alpha$, K which stand for, respectively: the maximal global dimension D_0 of a set, heterogeneity degree $\Delta\alpha$ (the higher $\Delta\alpha$, the higher heterogeneity) and the curvature value "K" which is the measurement of the heterogeneity function deviation from a paradigm, the paradigm being a straight line characteristic of a structure homogeneous in respect of its arrangement.

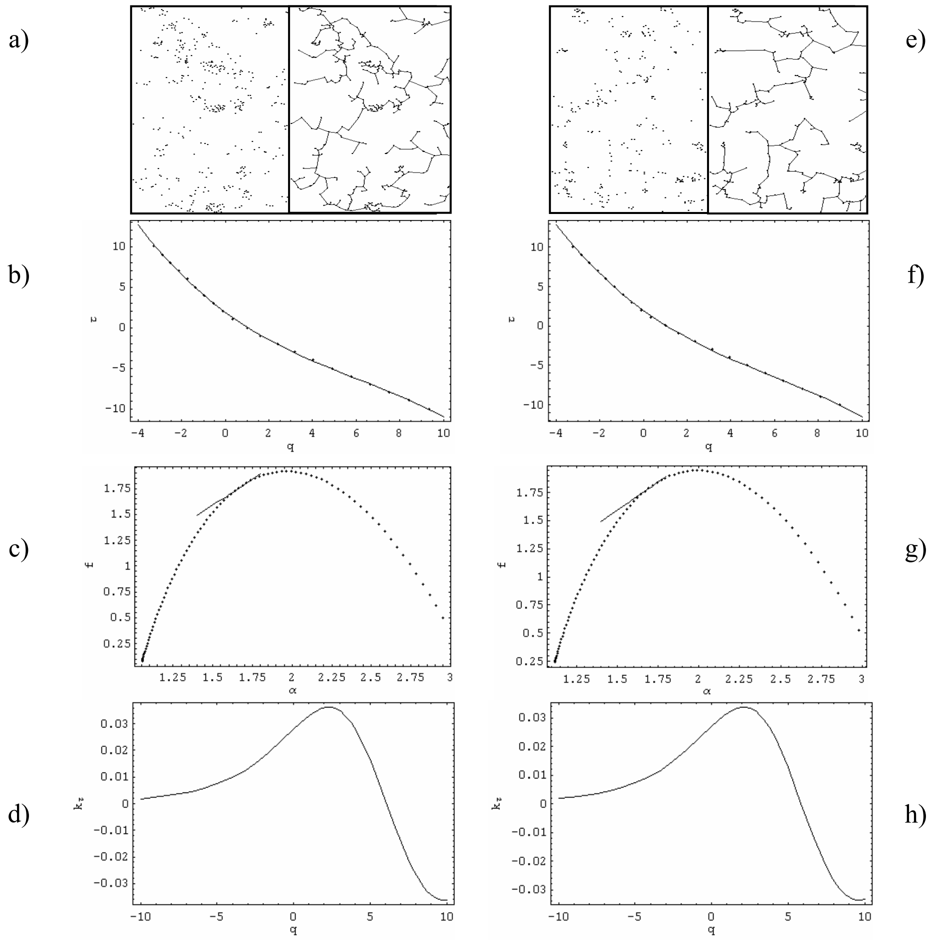

Fig.1. Results of the evaluation of heterogeneity of the reinforcing phase particles arrangement for the composite AlMgO4+Al_2O_3

a, e – structure of the set (centres of gravity) and minimal spanning tree for sections: perpendicular (GPC) and parallel (GRC); **b,f** – curve of heterogeneity function - $\tau(q)$; **c, g** – multifractal spectra; **d, h** – curvature of heterogeneity function;

Rys1. Wyniki oceny niejednorodności rozmieszczenia cząstek fazy zbrojącej dla kompozytu AlMgO4+Al_2O_3

a, e – struktura zbioru (środki ciężkości) i dendryt minimalny dla przekroju prostopadłego GPC i równoległego GRC; **b,f** –przebieg funkcji niejednorodności $\tau(q)$; **c, g** –widma multifraktalne; **d, h** –krzywizna funkcji niejednorodności;

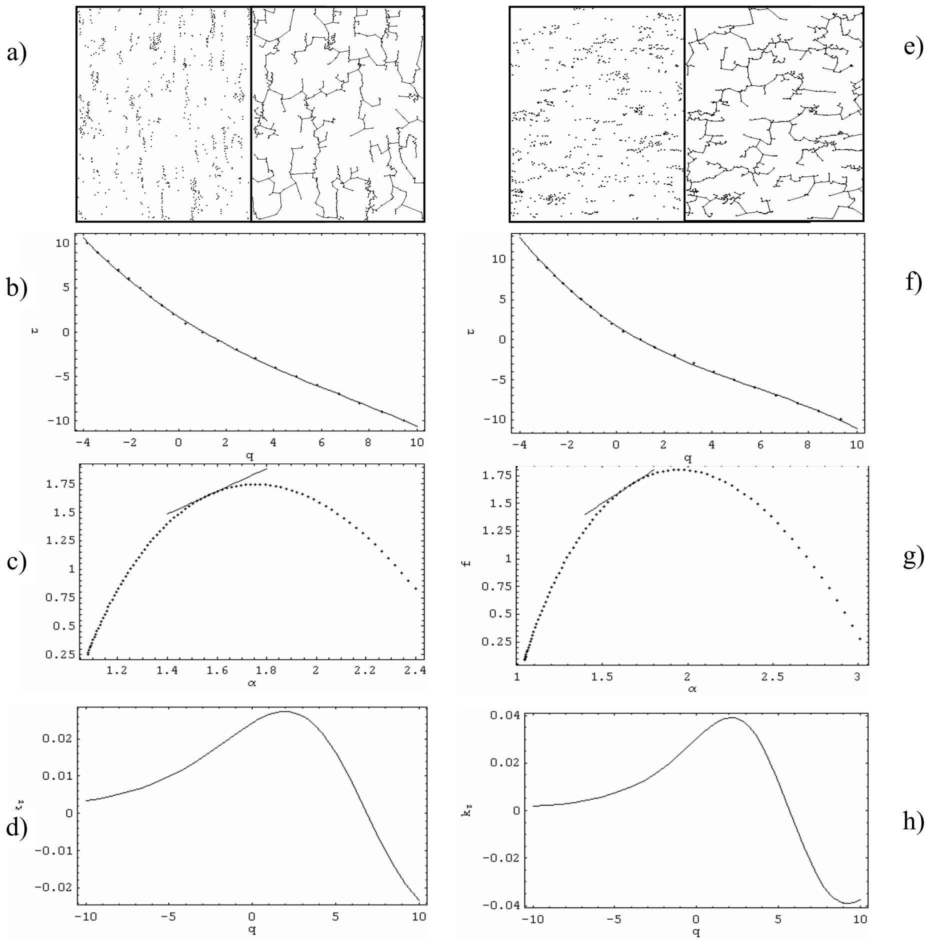

Fig.2. Results of the evaluation of heterogeneity of the reinforcing phase particles arrangement for the composite AlMgO4+Al_2O_3 in an as-rolled condition

a, e – structure of the set (centres of gravity) and minimal spanning tree for sections: perpendicular (WPC) and parallel (WRC; **b,f** – curve of heterogeneity function - τ(q); **c, g** – multifractal spectra; **d, h** – curvature of heterogeneity function;

Rys2. Wyniki oceny niejednorodności rozmieszczenia cząstek fazy zbrojącej dla kompozytu AlMgO4+Al_2O_3 w stanie walcowanym

a, e – struktura zbioru (środki ciężkości) i dendryt minimalny dla przekroju prostopadłego WPC i równoległego WRC; **b, f** –przebieg funkcji niejednorodności τ(q); **c, g** – widma multifraktalne; **d, h** –krzywizna funkcji niejednorodności;

5. SUMMARY

The stereological and fractal analyses of a dispersive phase in an as-cast and as-rolled composite show significant changes of the parameters characterizing the reinforcing particles. The particles do not undergo significant deformation themselves (inconsiderable changes of the shape heterogeneity), although, as a result of matrix deformation the heterogeneity of arrangement becomes distinct both in comparison with the cast and in mutually perpendicular sections of the material rolled. Whereas the principles of quantitative metallography allow for evident capturing of the changes of all most significant stereological parameters, the problem of heterogeneity of the particles arrangement is emphasised in a more clear-cut way by the fractal analysis presented in the paper, based on the MST method.

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ANALIZA STEREOLOGICZNA I FRAKTALNA FAZY ZBROJĄCEJ KOMPOZYTU $AlMg4+Al_2O_3$ W STANIE LANYM I PO WALCOWANIU

STRESZCZENIE

W pracy przedstawiono charakterystykę fazy zbrojącej kompozytu $AlMg4+Al_2O_3$ w stanie lanym i po walcowaniu. Badania typowych parametrów stereologicznych rozszerzono a analizę fraktalną stopnia niejednorodności rozmieszczenia, opartą na metodzie MST. Wykorzystano wpływ walcowania na charakterystyki stereologiczne i stopień niejednorodności.

Reviewed by prof. Józef Gawroński