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Description of Surface Topography of Metal Matrix Composite Castings

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Abstract

The paper presents studies of topography of the metal matrix composite castings using profilography, confocal microscopy and atomic force microscopy. The examined materials were composites from the ex-situ group, manufactured by the saturation of reinforcement (aluminosilicate or carbon) with the liquid aluminum alloy (AlSi9 or AlSi11). The materials were observed on the various surface state, resulting from different stages of preparation of the polished section for the metallographic microscopy. The composite surface was analyzed with particular attention paid to areas of connection between the composite matrix and reinforcement.

Keywords: Metal matrix composites, Surface Topography, Profilography, Confocal microscopy, Atomic force microscopy

Introduction

Metal matrix composites have been used worldwide as an engineering material for many years. They are widespread thanks to their good mechanical properties, low specific gravity, relatively easy forming and possibility of obtaining elements of various range of dimensions. Diversity of methods of the MMC manufacturing and possibilities of changing their properties dependently on the input products is, without doubt, their main advantage [1-4].

However, regardless of the manufacturing method, joining the metal matrix with the reinforcement is related to influence of high temperatures (especially when casting is concerned), which can cause hard to control reactions on the matrix-reinforcement boundary and defects of various types. It can influence the structure of the casting surface and mechanical, operational or economical properties of the composite [5-7].

One of the most simple methods for manufacturing process control is the metallographic microscopy. It allows to reveal cohesion breaches, structure inhomogeneity and grain size of the examined material. These studies are not always useful, especially in the composite castings, because of image analysis only in the flat cross-sections,. Preparation of the polished sections is also difficult, mostly due to the specific character of the composite material, with structure consisting of at least two phases of different physical and chemical properties, which in most cases causes faster wear of one of the phases (the matrix), tearing the reinforcement out of the matrix etc. These can be the causes of additional surface defects. Therefore, a guarantee of a good image of the examined material is an appropriate preparation of the polished section and control of its surface.

This paper presents three methods of examination of quality of the sample surface at the moment of preparation of the polished section: the profilography, the confocal microscopy and the atomic force microscopy. The described studies were aimed at evaluation of the surface topography of the composite castings with application of these methods.

Research material

Studies on evaluation of the surface quality were carried out on the metal matrix composite castings out of the ex-situ group [3-6, 7]. The castings for studies were manufactured by saturation of the reinforcement with the liquid metal of the matrix with various pressure, maintaining all processing requirements, in accordance with [3]. The matrix material was an aluminum alloy (AlSi9 or AlSi11) in all cases, while the reinforcement was the aluminosilicate fiber ($Al_2O_3SiO_2$) and the carbon fiber (C). The state of surface of the studied composites was diversified, as a result of various stages of the polished section preparation (cutting, grinding, polishing).

Description of surface topography of the MMC

For description of surface quality of the metal matrix composites, the following examination methods were used: profilometry, confocal microscopy and atomic force microscopy [7-9].

Profilometry is the simplest and the cheapest of the described techniques, which makes is the most widespread method allowing to gather information about the geometrical structure of a surface. Gathering of the profilograms allows to obtain information about the surface quality of the examined materials – in this case the metal matrix composites. Scheme of the measurement technique is presented in the Fig. 1.

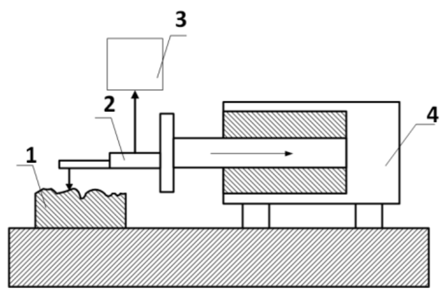


Fig. 1. Principle of measurement of the surface roughness and waviness with the contact method: 1 – measured object, 2 – measuring head, 3 – feed mechanism, 4 – signal recording [9]

The studies were carried out using the mechanical linear method, using the contact profilometer SURFTEST 301 by the MITUTOYO company. The measurement was conducted in accordance with PN-EN ISO 4288:2011E. The signal obtained on the distance of 1250 μm allowed to describe the sample surface irregularities and their depth. Recorded deviations for the studied samples were described using the R_a parameter (average surface roughness described as an arithmetic mean of the total size of deviations of the measured profile height from the average value).

Exemplary profilograms are presented in the Fig. 2.

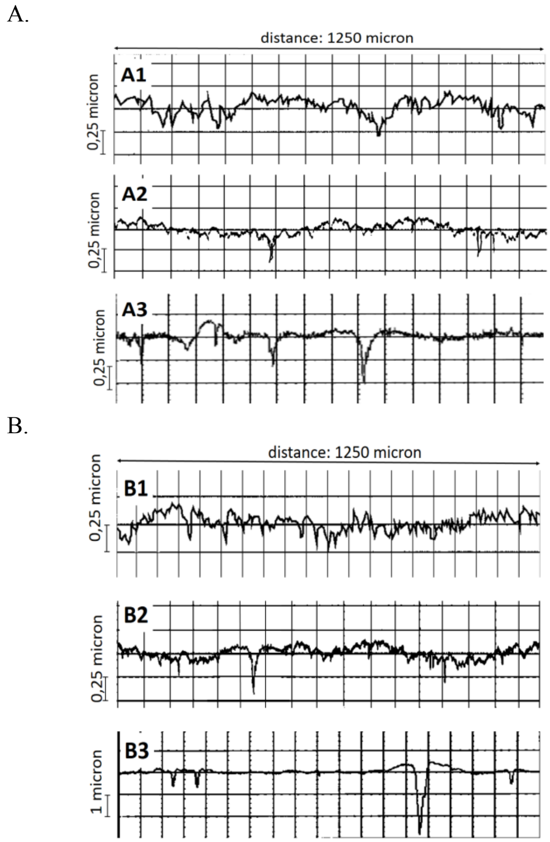


Fig.2. Typical profiles of the cross-sections: A. composites $AlSi11/Al_2O_3SiO_2$ and B. AlSi11/C; A/B.1 - cutting, A/B.2 - grinding, A/B.3 - polishing

Another method used in the research was the confocal microscopy, which is a kind of light microscopy, characterized by increased contrast and resolution and possibility of observation of objects in the three-dimensional mode. It is used to obtain high-quality images or image reconstructions in three dimensions. Concept of the confocal microscopy in comparison with the traditional light-based is removing the light which came outside of the focal plane, near the detector entrance. The confocal microscope consists of two separate parts (Fig. 3) – an optical microscope and a confocal microscope. The microscope contains two detectors (a CCD camera and a photomultiplier). As a light source, a white diode is used. The scanning is carried out basing on the blue laser diode with the wave length of 408 nm. Thanks to the XY scanner build on the basis of the MEMS technology (Micro Electro Mechanical System), the laser scanning confocal microscope OLS 3100 has the XY plane resolution of 120×120 nm, resolution in the Z axis – 10 nm with maximal zoom of 120x – 14400x.

In the research, the laser scanning confocal microscope OLS 3100 by the OLYMPUS company was used. The samples were measured in the real time. The measurement consisted in scanning of the selected area of the examined object plane by plane, moving in the Z axis from the lowest marked plane to the highest one. As a consequence, three-dimensional reconstruction of the scanned object is created (Fig. 4 and 5).

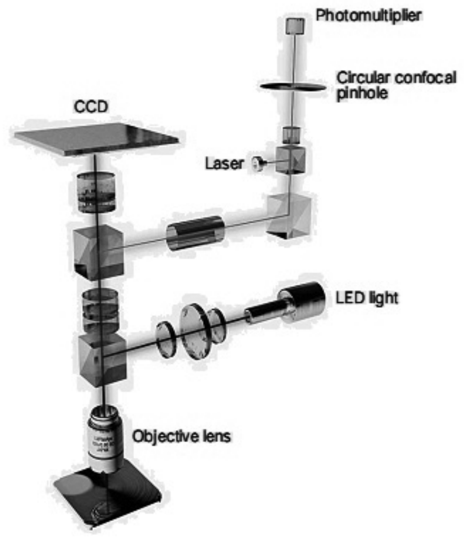
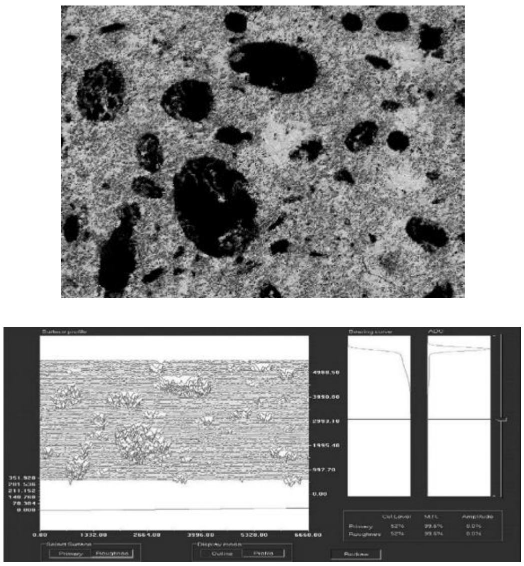


Fig. 3. Scheme of the laser scanning confocal microscope OLS 3100 produced by the OLYMPUS company [8]



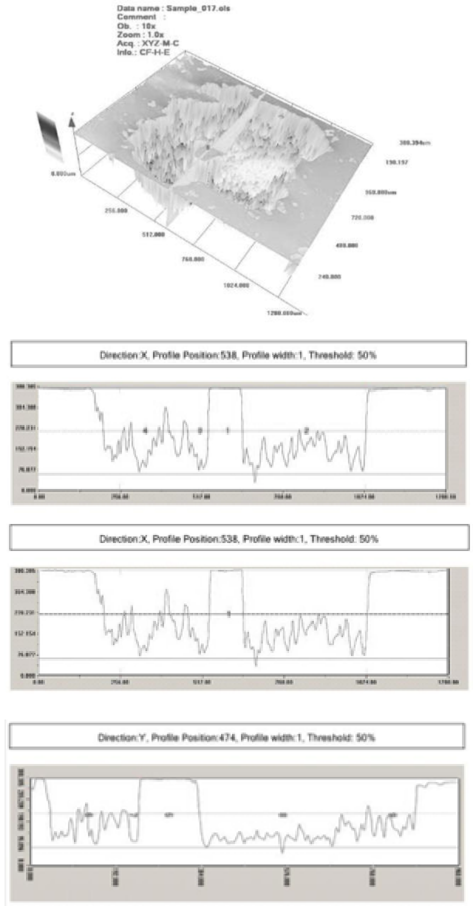
#	Judge	SPp	SRp	SPv	SRv	SPz	SRz
1		38.332	38.332	300.292	300.292	338.624	338.624

SPc	SRc	SPa	SRa	SPq	SRq	SRzjis
49.297	49.297	14.252	14.252	26.885	26.885	193.892

Fig. 4. The examined void area – report with measured surface roughness parameters (composite: $AlSi11/Al_2O_3SiO_2$), confocal microscopy

The third method of description of the surface quality used in the presented work is the atomic force microscopy (AFM) in the contact mode.

Scheme of the deflection detection is presented in the Fig. 6.



#	Judge	Width[um]	Max.	Min.
1		107.726	576.082	263.172
2		385.278	576.082	263.172
3		65.289	576.082	263.172
4		248.361	576.082	263.172
5		135.356	577.355	280.347
6		171.936	577.355	280.347
7		26.192	577.355	280.347
8		374.235	577.355	280.347
9		100.178	577.355	280.347
#		9	9	9
Average		179.395	576.789	272.714
Max.		385.278	577.355	280.347
Min.		26.192	576.082	263.172
Range		359.086	1.273	17.175
Sigma		129.906	0.671	9.052
3*Sigma		389.719	2.013	27.157

Fig. 5. Studied void – report with measured parameters of the examined object (distances between objects inside the sample were estimated), composite: $AlSi11/ Al_2O_3SiO_2$, confocal microscopy

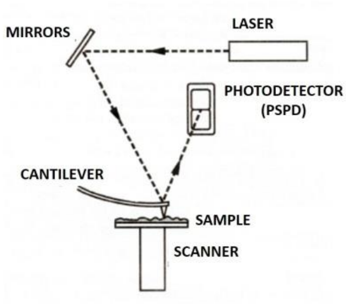


Fig. 6. Scheme of detection of deflection of the small lever (AFM) [9]

The described research was conducted at the AGH University of Science and Technology in Cracow. For the research, the AFM Explorer microscope was used (ThermoMicroscopes, with the Vecco SPMLab 5.01 software) in the contact mode, the measurements were performed with the scanning speed of 3 lines per second and resolution of 300×300 pixels. The AFM studies were performed for different scanning areas -20×20 µm, 50×50 µm and 100×100 µm. Additionally, the AFM software allows to statistically process the obtained profiles for the whole scanned surface, their analysis in the selected areas or lines and determination of many profile parameters with high accuracy (e.g. R_p – maximal profile height above the main line, R_t – maximal peak-bottom difference for the profile or its maximal values R_{pm}, R_{tm}).

The Figure 7 presents an exemplary ATM image of the composite casting.

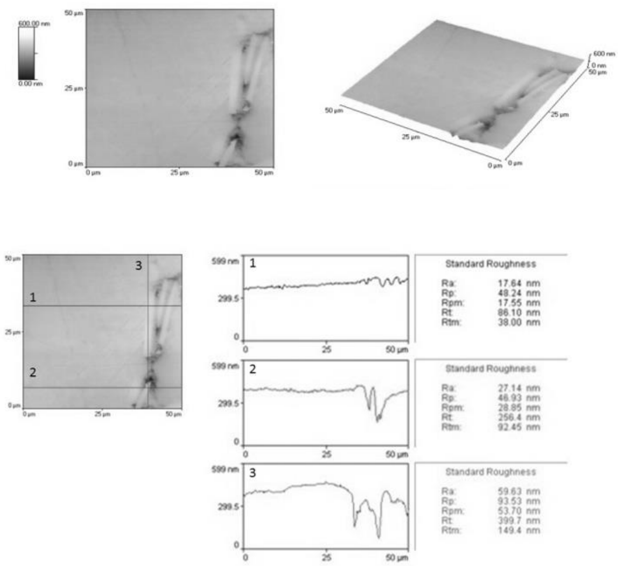


Fig. 7. Exemplary AFM image for the polished section out of the AlSi11/ $Al_2O_3SiO_2$ composite

Conclusions and summary

During consecutive stages of polished section preparation, the surface roughness of all samples decreases (Fig. 8, 9). For samples after the grinding, it can be observed that the geometrical structure is anisotropic, related to manipulation of the sample during change of granularity of the abrasive paper during the grinding process.

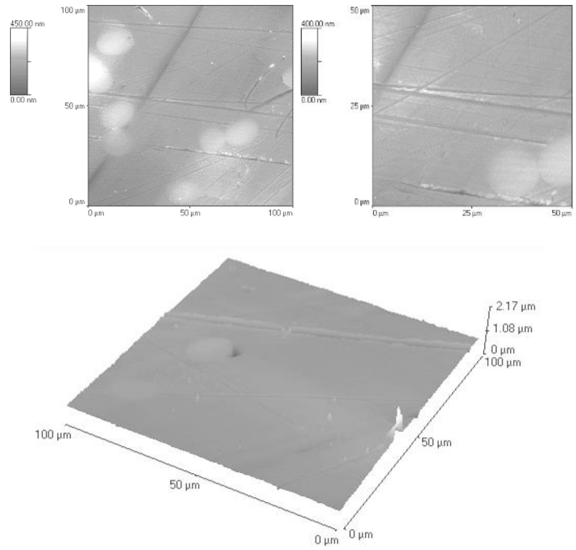


Fig. 8. Exemplary ATM images of the metal matrix of the composite materials after the grinding process (AlSi11/C composite)

In the Fig. 8, random, repeatedly unordered lines can be observed, forming a grid shaped by the individual abrasive grains. A distinctive property of the grinded surfaces is the decreasing crossing angle of particular grooves. Simultaneously, the basic direction of traces left by abrasive grains is statically maintained.

For samples after polishing, in case of profilography (Fig. 2), some peaks can be observed, probably corresponding to a porosity occurring on the examined polished sections. This porosity appeared during the metal composite casting process and is a material defect. This assumption is confirmed by the Fig. 4 (confocal microscopy) and the Fig. 10 (AFM).

However, the profilograms cannot be interpreted unequivocally, as peaks indicating the diversified roughness can be a result of chipping of the reinforcing phase (Fig. 11), occurring in the grinding or polishing process, or other defects formed during the material processing, e.g. incomplete bonding of the matrix with the reinforcement [7-8] (Fig. 7 and 9B3). The differences in the surface topography of the composite casting can also result from the improper preparation of the polished section. The soft matrix phase is frequently "rubbed away" as a result of prolonged polishing of the section (Fig. 12 and 13), creating a distinct threshold in front of the reinforcing phase.

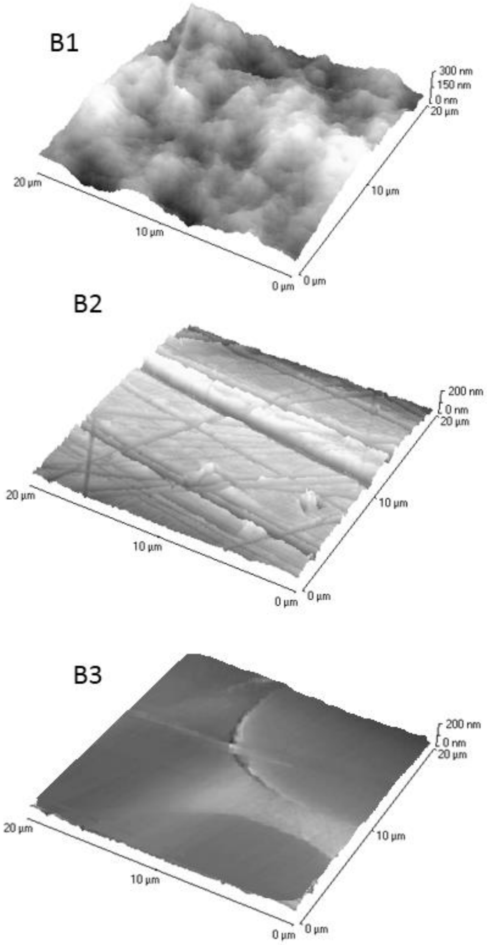
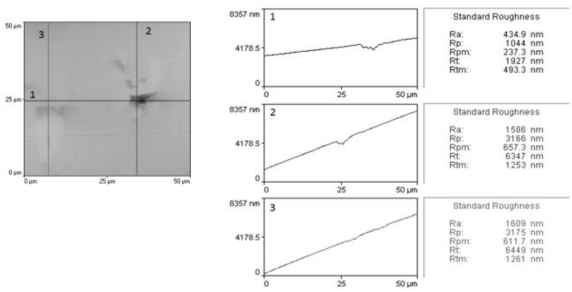


Fig. 9. Exemplary AFM images for the composite sample AlSi11/C after different stages of the polished section preparation (B1 - cutting, B2 - grinding, B3 - polishing)



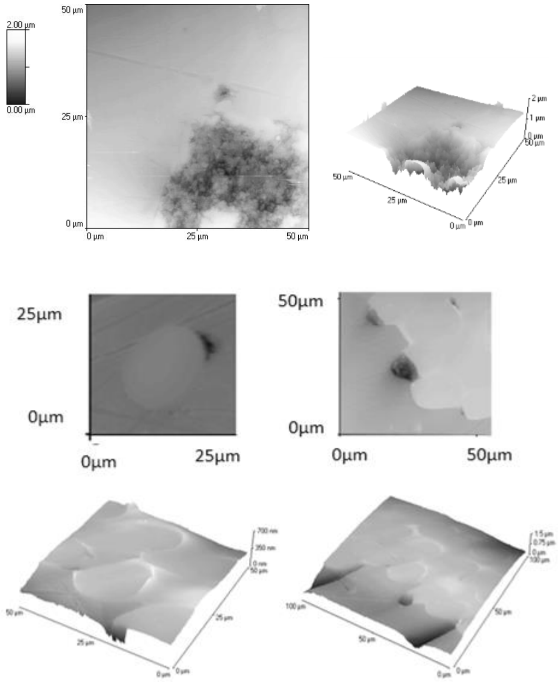


Fig.10. Porosity of the composite casting (AlSi11/C composite), AFM

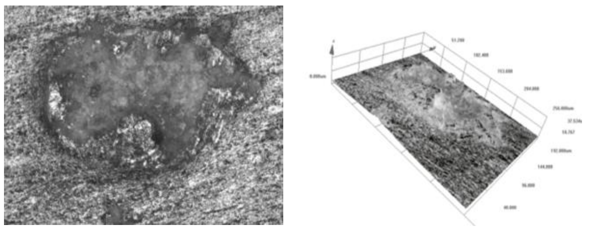
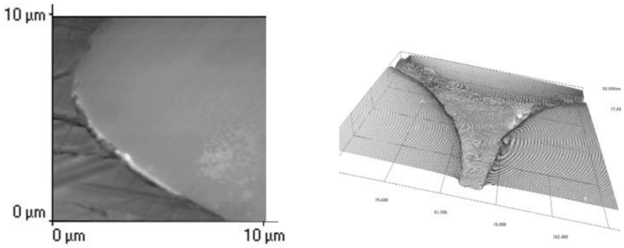
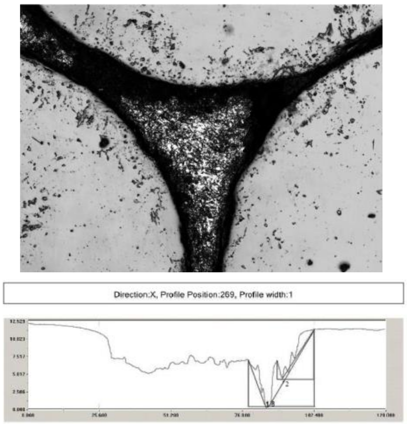


Fig.11. Chipping of the reinforcing phase (composite AlSi9/ $Al_2O_3SiO_2$)



a. b.

Fig. 12. Exemplary image: a. AFM, b. confocal microscopy – showing a susceptibility of the matrix material on the faster wearing (AlSi11/C composite)



#	Jud ge	Width	Height	Length	Angle	Upper	Lower
1		6.334	6.558	9.118	45.994	6.956	0.000
2		2.027	2.496	3.215	50.921	0.060	0.255
3		15.962	10.719	19.227	33.882	28.668	0.051
4		11.275	6.950	13.245	31.650	10.713	0.536
#		4	4	4	4	4	4
Average		8.900	6.681	11.201	40.612	11.599	0.211
Max.		15.962	10.719	19.227	50.921	28.668	0.536
Min.		2.027	2.496	3.215	31.650	0.060	0.000
Range		13.935	8.223	16.012	19.270	28.609	0.536
Sigma		6.037	3.362	6.751	9.325	12.205	0.243
3*Sigm		18.111	10.086	20.252	27.974	36.614	0.730

Fig. 13. Studied void – report with measured parameters of the examined object; composite: AlSi11/C, confocal microscopy

The traditional profilometry allows to gather static information regarding quality of large examined areas. It is the only non-destructive method (out of the methods described in this paper), but it does not give information about causes of the formed irregularities by possibility of surface imaging, which is a big difficulty during the result analysis. The atomic force microscopy allows to compensate the mentioned flaws of the profilography, unequivocally indicating (e.g. by observation of mapping of the selected areas) size of the discontinuities, pores and their depth. The AFM is essentially the more advanced profilography, allowing three-dimensional operation. Both precision and measurement resolution are significantly higher, but depth determination is still limited by the measuring system geometry. The AFM observation is effective only for low-size areas. Quality of the prepared polished sections in case of the AFM does not influence the observation of the material structure itself and allows distinction between the phase components (Fig. 8 and 10), which is obviously related to the magnification possibilities – capabilities of the electron microscope. In the confocal microscopy there is no possibility to obtain such large magnification as in the case of AFM, but the composite topography can be determined in a more precise way, it is also possible to e.g. examine voids in the composite casting (porosity) and estimate geometrical parameters of this object, such as: shape (3D), depth, width, volume and areas (Fig. 5) on a long measurement distance (Fig. 4). Obtained reports from the conducted examinations can be used for the further analysis, such as directional orienting. An important feature of this method is also a description of the surface topography in a way "above the level" (Fig. 11). There is no possibility of such an evaluation in case of profilography and AFM.

For evaluation of the surface quality of the manufactured composites, the best way is to join all the described methods. The profilography can be used e.g. for preliminary measurements of the surface topography, while the confocal microscopy and AFM can be used for imaging and evaluation of the surfaces topography along with their structure.

The conducted studies also allow to conclude that preparation of the polished sections is a difficult and time-consuming task, mostly because of different properties of the individual phases in the composite material and it can affect the casting surface topography. The other important conclusion is that the surface quality of the studied castings is also influenced by defects from the polished section preparation phase.

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