

## ANALYSIS OF DEFECTS FORMATION IN AS-CAST METAL SATURATED COMPOSITES

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In research into the porosity of casts from metal saturated composites there is a need to identify the pores. Problems encountered here are connected with the following: - the difficulty in differentiating the pores from other structure components of materials, - the necessity of differentiating the porosity types resulting from non-saturation, gas occlusion and gas emission during coagulation and contraction of the matrix. The report presents research results conducted to identify the pores by means of computer image analysis with the application of an analyzing scanning computer.

**Key words:** *casts, metal matrix composites, defects*

**Analiza nastanka grešaka u zasićenim kompozitnim metalima u lijevanom stanju.** U istraživanju poroznosti na ljevovima metala od zasićenih kompozita postoji nužnost određivanja poroznosti. Problemi koji se ovdje susreću su povezani sa slijedećim: - teškoćama u razlikovanju pora od drugih strukturnih sastavnica materijala; - potreba za razlikovanjem vrsta poroznosti zbog nezasićenosti plinske poroznosti i emisijom plinova tijekom zgrušavanja i stezanja matrice. Izvješće predstavlja rezultate istraživanja provedenog radi određivanja pora kompjutorske analize slike uz primjenu kompjutorskog skenera za provođenje analize.

**Ključne riječi:** *lijev, kompoziti metalne matrice, greške*

### INTRODUCTION

The description of saturated metal-matrix composites casts requires appropriate unambiguous classification of defects. There is no such a classification in the technical literature. One can find in publications concerning these casts differing or imprecise depiction of those defects [1-4]. The descriptions often include several similar defects that occurred at different stages of a technological process or as a result of various non-related causes. The only common feature of those effects is their shape, size, form, etc.

There are standards, charts, or catalogues for casts made of classic materials, which [3], [5-9]:

- allow to unambiguously identify defects,
- present the methods of their detection,
- give causes of their occurrence,
- suggest technological means that prevent their occurrence.

Those classifications are constructed according to the patterns presented in Figure 1. The Polish classification presented in Figure 1. distinguishes four groups of defects:

- 1) defects of shapes,
- 2) defects of raw surface,
- 3) breaks of continuity (cracks),
- 4) internal defects.

First two groups of defects and part of the third one for casts made of classical materials and composite casts, including saturated composites, comply with the previously mentioned information concerning the identification and technology.

Saturated metal-matrix composites casts have a characteristic structure resulting from the presence of reinforcing elements, most frequently fibres, located in a metallic matrix and firmly attached to it. The attachment of a matrix and reinforcement generates specific defects occurring in classical casts. Some of them could be classified as defects of continuity, e.g. discontinuity on the phase boundary, some of them as internal defects, e.g. porosity or defects of the matrix structure. Other defects have no place of their own in classical classifications. There is a need to work out the classification of specific defects. The basis of this classification must be the analysis of the technological process of saturated composites casts from the point of view of the conditions of defects generation. Carrying out this analysis is the purpose of this paper.

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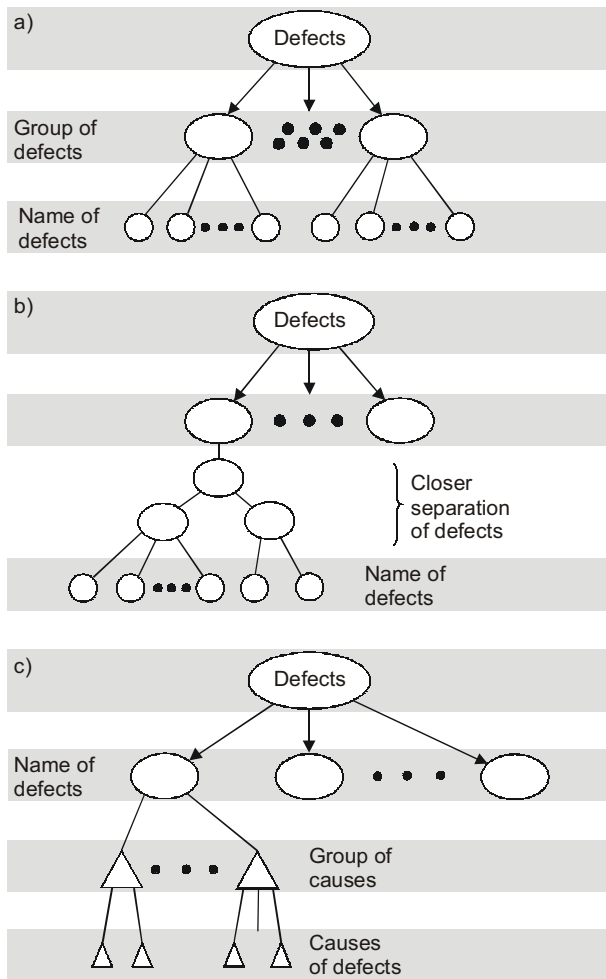


Figure 1. Patterns of defects classification of classic materials casts [3], [5, 6], [9]: a) according to Polish standards, b) according to French standards, c) according to English and German systems  
 Slika 1. Primjer klasificiranja grešaka klasičnih ljevova od materijala [3], [5, 6], [9]: a) prema poljskim standardima, b) prema francuskim standardima, c) prema njemačkom i engleskom sustavu

**THE INFLUENCE OF THE TECHNOLOGY OF CASTS MADE OF SATURATED METAL MATRIX COMPOSITES ON THE POSSIBILITY OF DEFECTS OCCURRENCE**

The diagram of technological process of composite casts has been presented in Figure 2. On its basis seven stages, which can be attributed to the occurrence of specific cast defects, can be distinguished.

**Stage I is the preparation of reinforcement.** Defect of heterogeneity of the reinforcement elements, which characterize shape and dimensions; heterogeneity of the distribution of the reinforcement elements; foreign matters in the structure of the reinforcement; and the defects resulting from inappropriately prepared surface of the reinforcement may occur at this stage. The consequence of the last

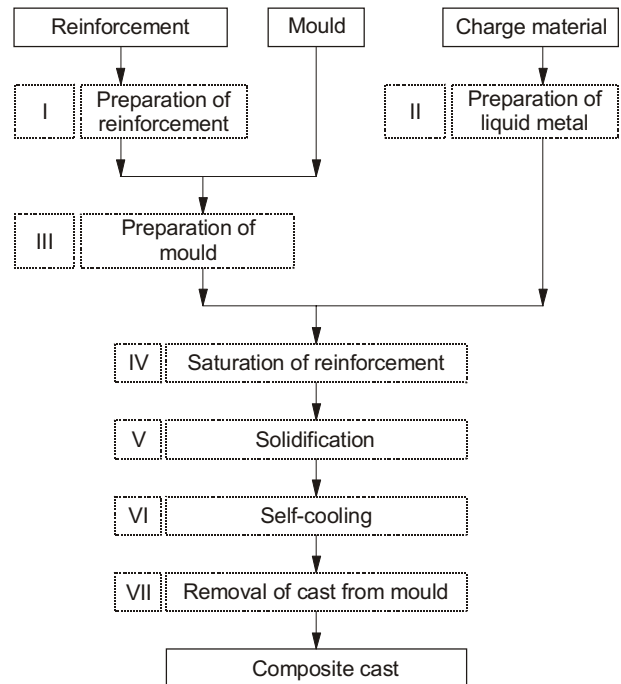


Figure 2. Diagram of technological process of saturated metal-matrix composites casts  
 Slika 2. Dijagram tehnološkog procesa dobivanja zasićenih ljevova metal-matrica kompozitima

irregularity may be other defects, e.g. inappropriate attachment of the reinforcement to the matrix. This group is only characteristic of the composites discussed here. Examples of cast defects formed as a result of irregularities that occur at this stage are presented in Figure 3.

**Stage II, which is the preparation of liquid metal,** influences casts metal matrix structure. Apart from this

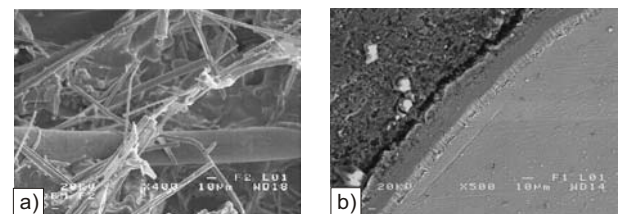


Figure 3. Examples of defects that occurred as a result of irregularities at stage I (inappropriate preparation of reinforcement):  
 a) heterogeneity of shapes and dimensions of the reinforcement structure (reinforcement: short fibres  $Al_2O_3/SiO_2$ , matrix AlSi11 alloy) - electron microscopy,  
 b) fragile phases on the matrix-reinforcement interface (reinforcement: long fibre NiCr steel, matrix AlSi11 alloy) - electron microscopy  
 Slika 3. Primjeri grešaka nastalih zbog nepravilnosti u fazi I (neadekvatna priprema pojačavanja):  
 a) raznovrsnost oblika i dimenzija ojačane strukture (ojačana vlaknima  $Al_2O_3/SiO_2$ , matrica legure AlSi11) - elektronski mikroskop,  
 b) krta faza međuprostora između ojačane matrice (ojačane duž vlakana NiCr čelika, matrica AlSi11 legure) - elektronski mikroskop

stage, the structure is also determined by the process of a cast crystallization, whose significant factor is also the presence of reinforcement in solidifying metal. In connection to this, composite matrix defect cannot be seen solely as the result of the preparation of liquid metal and thermal

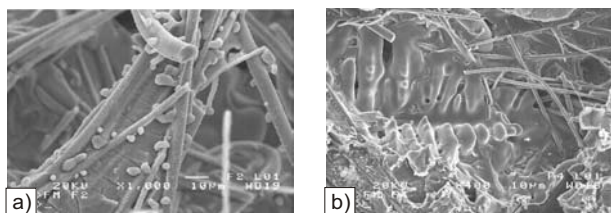


Figure 4. Examples of defects resulting from irregularities at stage II (melting of metal):

- a) nucleation of untypical phases on reinforcement elements (reinforcement  $Al_2O_3/SiO_2$ , matrix AlSi11) - electron microscopy,
- b) inappropriate shape of phases (reinforcement  $Al_2O_3/SiO_2$ , matrix AlSi11) - electron microscopy

Slika 4. Primjeri grešaka nastalih zbog nepravilnosti u fazi II (taljenje metala):

- a) Nukleacija netipičnih faza na ojačanim elementima (ojačavanje  $Al_2O_3/SiO_2$ , matrica AlSi11 - elektronski mikroskop,
- b) Nepoželjni oblik faza (ojačavanje  $Al_2O_3/SiO_2$ , matrica AlSi11) - elektronski mikroskop

conditions of crystallization - they must also take into account the presence of reinforcement, which may have nucleation influence on crystallizing phases of the matrix. It concerns both the phases that are the effect of an alloy composition and inclusions and blowholes. The result of irregularities at this technological stage may be such defects as e.g.: gaseous pores, inappropriate shape of phases,

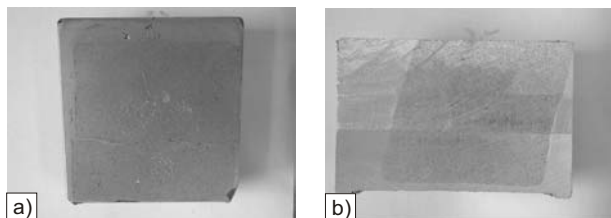


Figure 5. Example of defects resulted from irregularities at stage III (preparation of a mould):

- a) deformation of reinforcing structure (reinforcement carbon fibre, matrix AlSi11) - macro,
- b) inappropriate location of reinforcement structures (reinforcement carbon fibre, matrix AlSi11) - macro

Slika 5. Primjeri grešaka nastalih zbog nepravilnosti u fazi III (priprema kalupa):

- a) izobličenosť strukture (ojačana ugljičnim vlaknima, matrica AlSi11) - makro metoda,
- b) nepoželjna lokacija ojačane strukture (ojačana vlaknima ugljika, matrica AlSi11) - makro metoda

coarse grain structure, foreign solid phases, untypical nucleation phases on reinforcement elements, chemical segregation (Figure 4.).

**Stage III is preparation of a mould.** Main activities here are preparation of a mould cavity, mould assembly,

and establishment of its temperature. Those activities influence the defects of shape, raw surface, reinforcement position, and matrix structure (Figure 5). Those defects may be considered by means of classification of cast defects for classical material. Mould temperature also influences the process of saturation of reinforcement by the matrix, crystallization, and self-cooling of a cast. Then, it influences the structure of a composite cast.

**Stage IV in the technological process of casts made of the discussed materials is saturation.** This stage is characteristic only and exclusively of saturated metal-matrix composites casts. Defects that occur in this process are not identifiable by means of any classification of classic materials casts' defects. Irregularities that may occur dur-

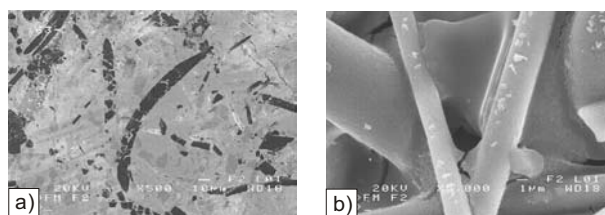


Figure 6. Example of defects that occur at stage IV (saturation):

- a) cracks of reinforcing structure (reinforcement  $Al_2O_3/SiO_2$ , matrix Wood's alloy) - electron microscopy,
- b) insufficient saturation (reinforcement  $Al_2O_3/SiO_2$ , matrix Wood's alloy) - electron microscopy

Slika 6. Primjer grešaka koje nastaju koje nastaju u fazi IV (zasićenje):

- a) Pukotine na strukturi ojačavanja (ojačavanje  $Al_2O_3/SiO_2$ , matrica Woodova slitina) - elektronski mikroskop
- b) nedovoljno zasićenje (ojačano s  $Al_2O_3/SiO_2$ , matrica Wood-ova slitina) - elektronski mikroskop

ing the process of saturation are: insufficient saturation, occluded gaseous pores, and heterogeneity of reinforcement structure elements distribution (Figure 6.).

**Solidification is stage V of the technological process of saturated metal-matrix composites casts.** Defects that

Table 1. Possibilities of defects classification  
 Tablica 1. Mogućnosti klasificiranja grešaka

No.	Stage of technological process that is a source of a defect	Possibility of defects classification according to	
		standards and catalogues for classic casts	catalogues of special defects of composites casts
1	Preparation of reinforcement	-	+
2	Preparation of liquid metal	+	+
3	Preparation of mould	+	+
4	Saturation	-	+
5	Solidification	+	+
6	Self - cooling	+	-
7	Removal of cast from mould	+	-

Table 2. Defects of structure of saturated metal-matrix composites casts and stages of their occurrence  
 Tablica 2. Greške strukture ljevova kompozitnih zasićenih metalnih matrica i stupanj njihovih pojavnosti

No.	Defect	Stage of defect occurrence	Remarks
<b>1. DEFECTS OF REINFORCEMENT</b>			
K.1.1	Heterogeneity of shapes and dimensions of reinforcement structure elements	<ul style="list-style-type: none"> <li>production of reinforcement</li> </ul>	_____
K.1.2	Heterogeneity of reinforcement structure elements distribution	<ul style="list-style-type: none"> <li>production of reinforcement</li> <li>saturation of reinforcement</li> </ul>	_____
K.1.3	Foreign body in reinforcement structure	<ul style="list-style-type: none"> <li>production of reinforcement</li> </ul>	_____
K.1.4	Deformation of reinforcing structure	<ul style="list-style-type: none"> <li>preparation of reinforcement</li> <li>mould assembly</li> <li>saturation of reinforcement</li> </ul>	_____
K.1.5	Inappropriate location of reinforcing structure	<ul style="list-style-type: none"> <li>mould assembly</li> </ul>	_____
K.1.6	Lack of required reinforcement coating	<ul style="list-style-type: none"> <li>preparation of reinforcement</li> </ul>	_____
K.1.7	Lack of continuity of reinforcement structure	<ul style="list-style-type: none"> <li>production of reinforcement</li> <li>preparation of reinforcement</li> <li>saturation of reinforcement</li> </ul>	_____
<b>2. DEFECTS OF MATRIX</b>			
K.2.1	Coarse grain structure	<ul style="list-style-type: none"> <li>melting of metal</li> <li>solidification</li> </ul>	inappropriate chemical composition of charge
K.2.2	Inappropriate phase composition	<ul style="list-style-type: none"> <li>melting of metal</li> </ul>	inappropriate chemical composition of charge
K.2.3	Segregation of matrix components	<ul style="list-style-type: none"> <li>solidification</li> </ul>	_____
K.2.4	Inappropriate shape of phases	<ul style="list-style-type: none"> <li>solidification</li> <li>melting of metal</li> </ul>	_____
K.2.5	Foreign solid phases metallic non-metallic	<ul style="list-style-type: none"> <li>melting of metal</li> <li>solidification</li> </ul>	_____
<b>3. POROSITY</b>			
K.3.1	Insufficient saturation	<ul style="list-style-type: none"> <li>saturation of reinforcement</li> </ul>	_____
K.3.2	Gaseous pores: <ul style="list-style-type: none"> <li>occluded</li> <li>separated</li> </ul>	<ul style="list-style-type: none"> <li>saturation of reinforcement</li> <li>melting of metal</li> </ul>	_____
K.3.3	Micro-shrinkage	<ul style="list-style-type: none"> <li>solidification</li> </ul>	_____
<b>4. DEFECTS OF ATTACHMENTS OF MATRIX TO REINFORCEMENT</b>			
K.4.1	Presence of short phases	<ul style="list-style-type: none"> <li>preparation of reinforcement</li> </ul>	_____
K.4.2	Lack of transition zone	<ul style="list-style-type: none"> <li>preparation of reinforcement</li> <li>saturation of reinforcement</li> </ul>	this defect concerns only composites that require transition zone
K.4.3	Lack of continuity of material structure	<ul style="list-style-type: none"> <li>self-cooling</li> </ul>	_____

can occur here are: defects of shape, defects of raw surface, defects of matrix, porosity. In the first two cases and in part of the third one to characterize defects of those casts we can use the classification for the materials of the type of cast iron, cast steel, and non-ferrous metals alloys, considering interaction of reinforcement with the matrix. In case of some

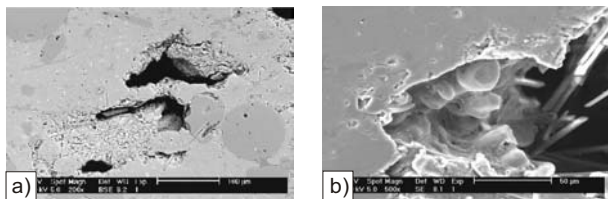


Figure 7. Example of defects that occur at stage V (solidification):  
a) contraction porosity (reinforcement  $Al_2O_3/SiO_2$ , matrix AlSi11) - electron microscopy,  
b) matrix components segregation (reinforcement  $Al_2O_3/SiO_2$ , matrix AlSi11) - electron microscopy

Slika 7. Primjeri grešaka koje nastaju u fazi V (skrutnjivanje):  
a) Poroznost zbog stezanja (ojačanje  $Al_2O_3/SiO_2$ , matrica AlSi11) - elektronski mikroskop,  
b) Segregacija komponenti matrice (ojačanje  $Al_2O_3/SiO_2$ , matrica AlSi11) - elektronski mikroskop

matrix defects and porosity, the defects should be identified by means of specific classification for defects of saturated metal-matrix composites casts. In Figure 7. examples of defects that occur at the stage of solidification, specific for saturated composites casts were presented.

#### Stage VI of the technological process is solidification.

During this stage defects of interruption of continuity type can occur. They can be considered according to standards and charts appropriate for classic materials casts, with regard to the structure of saturated metal-matrix composites, e.g. lack of continuity of the material structure (Figure 8.).

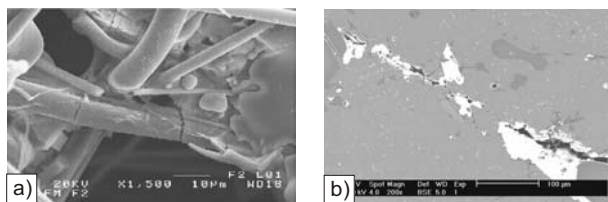


Figure 8. Example of defects that occur at stage VI (solidification):  
a) discontinuity (reinforcement  $Al_2O_3/SiO_2$ , matrix Wood's alloy) - electron microscopy,  
b) discontinuity (reinforcement  $Al_2O_3/SiO_2$ , matrix Wood's alloy) - electron microscopy

Slika 8. Primjeri grešaka koje se pojavljuju u fazi VI (skrutnjivanje):  
a) Diskontinuitet (ojačanje  $Al_2O_3/SiO_2$ , matrica Woodova slitina) - elektronski mikroskop,  
b) Diskontinuitet (ojačanje  $Al_2O_3/SiO_2$ , matrica Woodova slitina) - elektronski mikroskop

**Stage VII is removal of a cast from mould.** Defects occurring at this stage are the same in cases of defects of casts of saturated metal-matrix composites and in defects of casts of classic materials (Figure 9.).

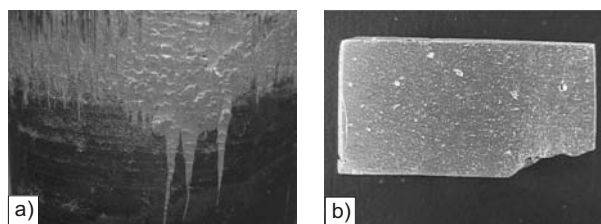


Figure 9. Example of defects that occur at stage VII (removal of cast from mould):  
a) defect of surface (reinforcement  $Al_2O_3/SiO_2$ , matrix AlSi11) - macro,  
b) defect of casting (reinforcement  $Al_2O_3/SiO_2$ , matrix AlSi11) - macro

Slika 9. Primjeri grešaka koje se pojavljuju u fazi VII (skidanje lijeva skalupa):  
a) Greške na površini (ojačanje  $Al_2O_3/SiO_2$ , matrica AlSi11) - makro,  
b) greška u lijevanju (ojačanje  $Al_2O_3/SiO_2$ , matrica AlSi11) - makro

## CONCLUSION

Analyzing the possibilities of occurrence of defects at various stages of the technological process of saturated metal-matrix composites casts it was established that:

- it is possible to identify part of the defects by means of appropriate norms, charts, and catalogues for classic casts;
- remaining defects, characteristic of saturated composites casts, are possible to be identified only by means of specially prepared classification.

Table 1. presents the possibilities of classification of defects that occur at individual stages of the technological process. Symbol '+' in both columns means that defects may occur at this stage. Some of those defects must relate to classic casts defects, and some of them is characteristic of saturated composites casts.

Table 2. presents suggested defects characteristic of saturated metal-matrix composites casts and indicates stages of the defects occurrence. This group was commonly named as structure defects.

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