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Classification of Structure Defects of Metal Matrix Castings with Saturated Reinforcement

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Abstract

Definition of a composite [1] describes an ideal composite material with perfect structure. In real composite materials, structure is usually imperfect – composites contain various types of defects [2, 3–5], especially as the casted composites are of concern. The reason for this is a specific structure of castings, related to course of the manufacturing process. In case of metal matrix composite castings, especially regarding these manufactured by saturation, there is no classification of these defects [2, 4]. Classification of defects in castings of classic materials (cast iron, cast steel, non-ferrous alloys) is insufficient and requires completion of specific defects of mentioned materials. This problem (noted during manufacturing metal matrix composite castings with saturated reinforcement in Institute of Basic Technical Sciences of Maritime University Szczecin) has become a reason of starting work aimed at creating such classification. As a result, this paper was prepared. It can contribute to improvement of quality of studied materials and, as a consequence, improve the environment protection level.

Keywords: Composite castings defects, Classification

1. Introduction

All metal castings have defects of various type and origin. A defect in a casting is every deviation of material properties, structure, mechanical and physicochemical properties from obligatory requirements [6]. Features of defects allow their identification, which in turn is a basis for creation of *casting defect classification*.

This classification is useful for:

1) Transfer of information in research work, during educational process and manufacturing process;
2) Elimination of defective castings from further stages of manufacturing process, which is of great significance in environment protection;
3) Intervention activities aimed at removing causes of defect formation from the manufacturing process.

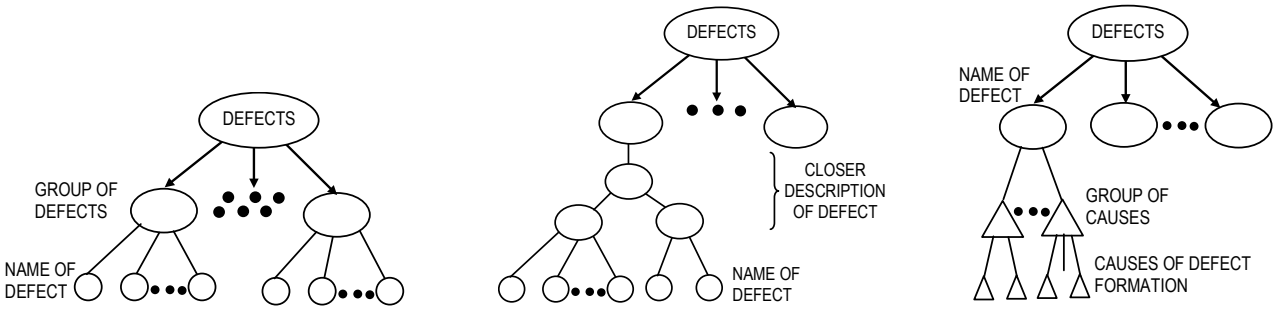
Regarding the second case, a criterion of classification of defective castings is a division of castings into three groups [6-8]:

a) good castings (without defects or with acceptable defects),
b) castings with reparable defects,
c) castings with disqualifying defects.

For castings made out of classic materials, there are standards, atlases or catalogues of defects [6-9], which:

d) enable unequivocal identification of defects;
e) contain methods of their detection;
f) give causes of their formation;
g) suggest technological means to prevent their formation.

Schemes of classification of these castings are shown in the fig. 1.



a) b) c)

Fig. 1. Schemes of classification of defects in castings of classic materials [9]
a – according to Polish standards, b – according to French standards, c – according to English and German system

In Poland, a division described in [6, 10-12] is valid, with two distinct levels (fig. 1a). In the upper level, there are 4 groups of defects. In the lower level, each group is assigned with defects of specific features. These defects are named to allow their unequivocal identification.

In French foundry, a multi-level structure has been accepted [9-14]. In the first level, 7 groups are present with the following names:

- outer metal gain;
- inner and outer cavities;
- breaks in casting continuity;
- surface defects;
- incompleteness of the product;
- inaccuracy of dimension or shape;
- inclusions or anomalies of structure.

The lowest level also contains names of particular defects, but between this level and the defect group definition level, two intermediate levels are present, containing also features of given group or subgroup – figure 1b. This way, each defect is assigned with a certain characteristics, facilitating indication of causes and preventive measures [9, 14].

Classification of defects in the English and German literature is quite different [8-9, 15-17]. A principle of this division is presented in the figure 1c. Names of defects are present in the upper level and they are assigned with groups of causes and then particular causes of defect formation. From the identification standpoint, this division would be very convenient, if not for the fact that some of the causes are defined inaccurately. Some of them can cause several defects, so this division cannot always be used objectively.

2. Classification of casting defects in the Polish Standards

Polish classification of defects of metal castings is one of the rare classifications falling under governmental standards. As presented in the introduction, this classification is the simplest one due to its two-level arrangement. Its additional feature is a clear division of defects in castings of different materials. Specified features, along with general accessibility and acquaintance of this classification in Poland are reasons that indicate a need to refer to this classification while attempting to create any other one. That is why further considerations will be made on the basis of defect classification contained in the Polish Standards. Consequently, a more detailed description of the classification is necessary. According to the Polish standard [10] and in national elaborations [6-7, 11, 18-20], this classification contains 4 groups of defects, presented in the figure 2.

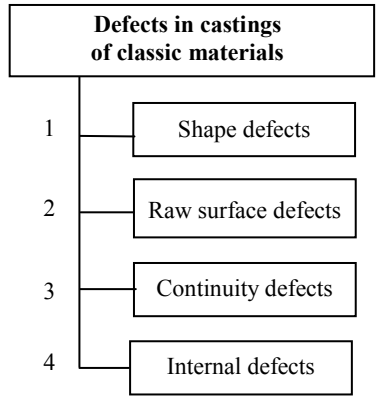


Fig. 2. Defects in castings of classic materials
(cast iron, cast steel, non-ferrous alloys)

Order of defect groups corresponds with order of operation of a casting acceptance process by the technical control division. First, shape defects are indicated, then the raw surface defects and continuity defects. Internal defects are detected during non-destructive and destructive testing and also during machining. Particular defects are assigned to each of the four groups, marked with the symbol (W) and type of material in which they occur is indicated [6-11].

The Polish Standard contains also approximate causes of defect formation. In different elaborations [9, 11, 21-23], which are a proper extension of this standard, one can also find methods of detection of formed defects.

3. Assessment of possibility of application of defect classification for classic castings (according to PN-85/H-83105) for classification of metal matrix composite castings with saturated reinforcement

The literature concerning defects in metal matrix saturated composite castings is sparse and description of quality of these castings requires unequivocal classification of defects. In technical literature, this classification is practically non-existent, except for attempts made by the authors [24-25]. In publications concerning the composite castings, lots of various and unprecise definitions of these irregularities (defects) are present [2-5]. Descriptions often contain several similar defects, formed during different stages of manufacturing process or caused by various, non-related reasons. The only common feature of these defects is often their shape, size, form etc.

First two groups, but only a part of third and fourth group of defects in castings of classic materials [10] and composite castings, including composites with saturated reinforcement, are compatible from the standpoint of previously presented information, concerning the defect identification. Castings of metal saturated composites have, however, a specific structure, resulting from the presence of reinforcing elements, most often fibers, localized in the metal matrix and permanently connected with it.

Connection between the matrix and the reinforcement can be a place where defects not present in classic castings may appear. A part of them could be classified as continuity breaks, e.g. phase boundary discontinuities, another part could be named internal defects, e.g. porosity or defects of the matrix structure. Other defects cannot be found in classic classifications. Among these, one should list especially defects of reinforcement, matrix and connections between these components, but also e.g. pores resulting from incomplete saturation of reinforcement by the matrix. Consequently, there is a need for creation of classification of specific defects of metal matrix composite castings with saturated reinforcement.

To address this matter, a defect classification system intermediate between the Polish and the French system was decided to be applied (fig. 1). It would comprise of divisions of defects into groups, while shape defects and raw surface defects would correspond with groups from Polish classification. Because of the specificity of the composites structure, continuity defects, along with internal defects and defects characteristic for saturated composites could fall under one group, divided into subgroups. Making this division requires very specific analysis of the manufacturing process of metal matrix composites with saturated reinforcement, performed because of possibilities of defect formation on various stages of this process. Structure defects would be the best suited name for the proposed group. The scheme of described classification is shown in the fig. 3.

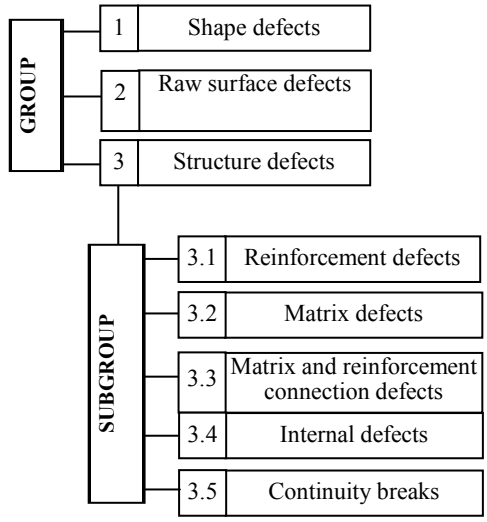


Fig. 3. Structure of classification of defects in metal matrix saturated composite castings

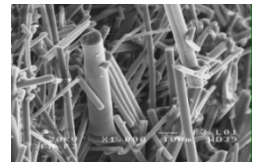
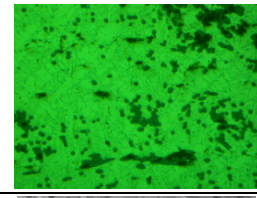
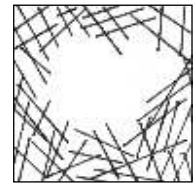
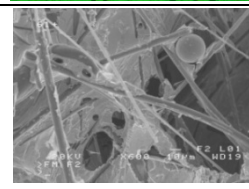
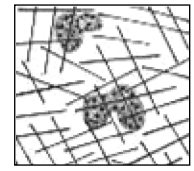
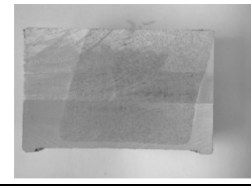
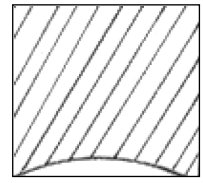
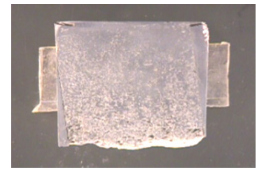
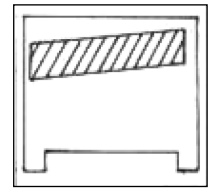
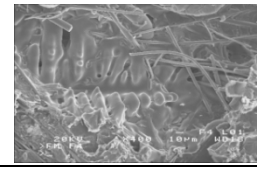
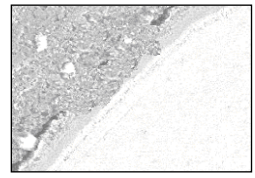
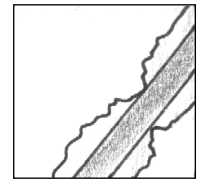
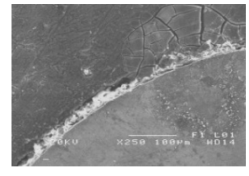
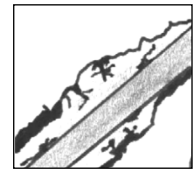
4. Summary

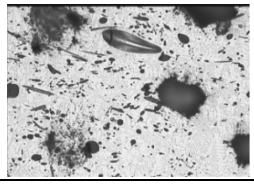
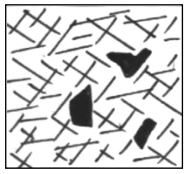
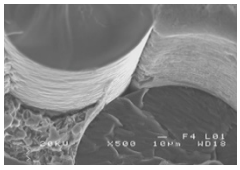
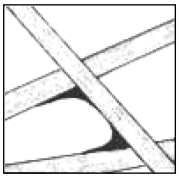
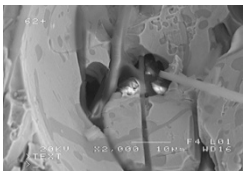
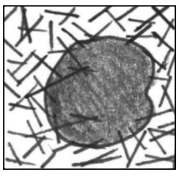
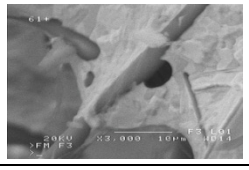
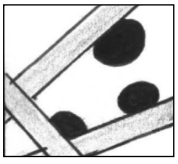
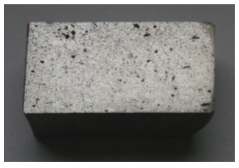
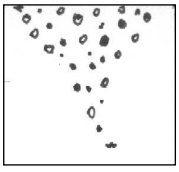
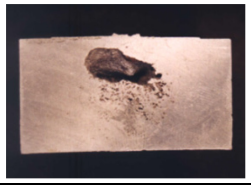
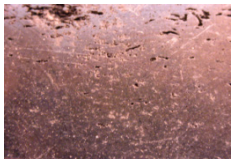
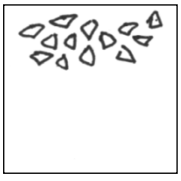
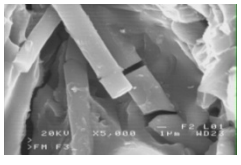
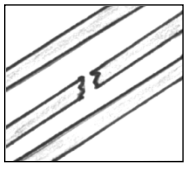
This paper presents the classification of defects of structure of metal matrix composites with saturated reinforcement. This classification forms a group in the general classification of casting defects. This group is named structure defects. Other groups of defects (shape defects and raw surface defects) falling under the classification correspond with groups present in casting defect classification for classic materials (according to PN-85/H-83105 – figure 2). This group (structure defects) consists of 5 subgroups, including both defects of structure in castings of classic materials which correspond to defects of structure in castings of metal matrix saturated composites and defects specific to these castings. Classification of structure defects occurring in metal matrix composite castings with saturated reinforcement is presented in the table 1. The arrangement of the table is the same as in the Polish Standard [10]. Each defect has its designation, is classified to an appropriate subgroup of structure defects in castings of metal matrix saturated composites and a scheme is supported with an example of a defect.

4.1. Causes of formation of defects in metal matrix composite castings with saturated reinforcement and methods of their detection

Table 1 is complemented with the table 2, which contains a list of causes of formation of structure defects in castings of metal matrix composites with saturated reinforcement and proposed methods of their detection. Prevention of appearance of defects described in this paper may be ensured by high quality of reinforcing structure, matrix and a trusted producer. Unfortunately, it is often related to increased price (which is very high in case of reinforcing phase, e.g. carbon fiber). That is why quality control of castings of this material group is so important.

Table 1. Classification of defects in castings of metal matrix composites with saturated reinforcement

Designation	Defect subgroup	Defect	Definition	Defect appearance (example)	Graphical designation (scheme)
3.1	Reinforcement defects	3.1.1 Inhomogeneity of shape and dimensions of the reinforcement elements	Diversified length, width and fiber shape		
		3.1.2 Inhomogeneity of distribution of the reinforcement elements	Varied density of fibers in different areas of reinforcement		
		3.1.3 Foreign matter in the reinforcement	Impurities formed during reinforcement manufacturing		
		3.1.4 Deformation of the reinforcing structure	Improper shape of the reinforcing structure		
		3.1.5 Improper localization of the reinforcing structure	Displacement of reinforcement structure in the casting volume		
3.2.	Matrix defects	3.2.1. Improper matrix structure	Foreign phases, undesirable dendritic structure, presence of phases of variable chemical constitution, coarse grain structure		No scheme possible because of variety of materials and matrix structures
3.3.	Matrix and reinforcement connection defects	3.3.1 Lack of the transition zone or its discontinuity on the matrix – reinforcement boundary	Visible lack of appearance of longitudinal band – transitional zone differing with color and constitution from the structure of reinforcement and matrix		
		3.3.2 Brittle phases on the matrix – reinforcement boundary	Continuous or discontinuous brittle phases on the matrix – reinforcement boundary		

Designation	Defect subgroup	Defect	Definition	Defect appearance (example)	Graphical designation (scheme)
3.4.	Internal defects	3.4.1 Inclusions	Precipitations of chemical constitution and structure different from the matrix or reinforcement		
		3.4.2 Unfilled reinforcement spaces	Free spaces in reinforcement fibers contact zones		
		3.4.3 Occluded gas bubbles	Pores of shape similar to spherical, present in whole volume of the casting, with increased dimensions in isolated areas of the casting		
		3.4.4 Separated gas bubbles	Gas bubbles of regular, spherical shape		
		3.4.5 Gas porosities	Small clusters of pores of spherical shape		
		3.4.6 Shrinkage cavities	Irregular discontinuities of the material, cavity usually of conical shape, often with developed, rough surface		
		3.4.7 Shrinkage porosities	Dense cluster of small cavities with sharp contours and rough walls		
3.5.	Breaks in continuity	3.5.1 Fractures of reinforcement elements	Break, crack, lack of fiber continuity		

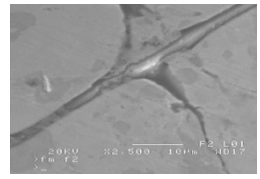
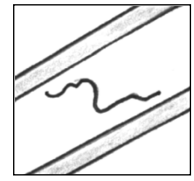
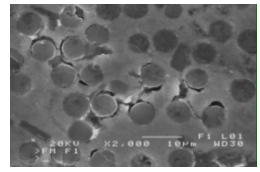
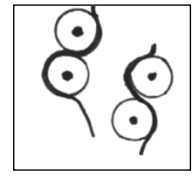
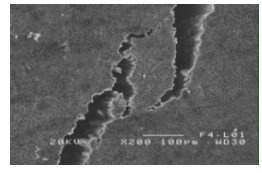
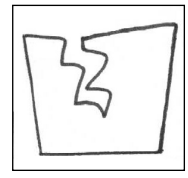
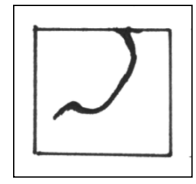
Designation	Defect subgroup	Defect	Definition	Defect appearance (example)	Graphical designation (scheme)
		3.5.2 Matrix fracture	Discontinuities in matrix material		
		3.5.3 Fractures on the matrix – reinforcement boundary	Lack of connection between matrix and reinforcement		
		3.5.4 Hot crack	Narrow, sometimes branched crevice going through whole volume, visible on the casting surface in form of a scratch		
		3.5.5 Cold crack	Narrow crevice going through whole volume, visible on the casting surface in form of a regular scratch		

Table 2. Causes of formation and methods of detection of defects in castings of metal matrix saturated composites

Designation	Defect subgroup	Defect	Causes of formation	Methods of detection
3.1	Reinforcement defects	3.1.1 Inhomogeneity of shape and dimensions of the reinforcement elements	Bad quality of the reinforcement.	• Microscopic examinations: – light-based, – scanning electron. • Microtomography. • Computer image analysis.
		3.1.2 Inhomogeneity of distribution of the reinforcement elements	Mechanical damage, bad quality of the reinforcement, e.g. uneven quantity of fibers.	• Microscopic examinations: – light-based, – scanning electron. • Microtomography. • Computer image analysis.
		3.1.3 Foreign matter in the reinforcement	Bad quality of the reinforcement	• Microscopic examinations: – light-based, – scanning electron. • X-ray microanalysis.
		3.1.4 Deformation of the reinforcing structure	Mechanical damage. Too high pressure or flow velocity of the matrix metal.	• Macroscopic examination.
		3.1.5 Improper localization of the reinforcing structure	Displacement of reinforcement structure in the mold.	• Macroscopic examination. • Radiography. • Ultrasonic flaw detection.
3.2.	Matrix defects	3.2.1. Improper matrix structure	Too high or too low temperature of the metal matrix, improper chemical constitution of the metal matrix, improper or lack of modification. Improper temperature of the mold.	• Microscopic examinations: – light-based, – scanning electron. • Computer image analysis. • X-ray microanalysis.
3.3.	Matrix and reinforcement	3.3.1 Lack of the transition zone or its discontinuity	Improper preparation of the fiber, impurities, e.g. not degreased reinforcement.	• Microscopic examinations: – light-based, – scanning electron.

Designation	Defect subgroup	Defect	Causes of formation	Methods of detection
	connection defects	on the matrix – reinforcement boundary		• X-ray microanalysis.
		3.3.2 Brittle phases on the matrix – reinforcement boundary	Mutual harmful interaction of reinforcement and metal matrix, exceeding thickness of the transitional zone.	• Microscopic examinations: – light-based, – scanning electron. • X-ray microanalysis.
3.4.	Internal defects	3.4.1 Inclusions	Impure charge material, improper chemical constitution. Improper process of melting and refining. Erosion of mold or its coating, caused by using wrong materials or too high flow velocity of matrix metal.	• Microscopic examinations: – light-based, – scanning electron. • X-ray microanalysis. • Radiography and ultrasonic flaw detection.
		3.4.2 Unfilled reinforcement spaces	Too low saturation pressure, too low temperature of reinforcement, matrix metal or mold, high value of the wetting angle.	• Gravimetric examination. • Microscopic examination: – light-based, – scanning electron.
		3.4.3 Occluded gas bubbles	Improper feed of matrix metal, too high velocity of saturation, too low temperature of reinforcement, matrix metal or mold.	• Macroscopic examination. • Gravimetric examination. • Microscopic examination: – light-based, – electron scanning. • Microtomography. • Computer image analysis. • Radiography and ultrasonic flaw detection.
		3.4.4 Separated gas bubbles	Impure charge material. Improperly prepared matrix material, improper melting or refining.	• Macroscopic examination. • Gravimetric examination. • Microscopic examination: – light-based, – electron scanning. • Microtomography. • Computer image analysis. • Radiography and ultrasonic flaw detection.
		3.4.5 Gas porosities	Impure charge material. Improperly prepared matrix material, improper melting or refining.	• Macroscopic examination. • Gravimetric examination. • Microscopic examination: – light-based, – electron scanning. • Microtomography. • Computer image analysis. • Radiography and ultrasonic flaw detection.
		3.4.6 Shrinkage cavities	Improper feeding, caused by errors in construction of the casting or the mold or improper thermal conditions.	• Macroscopic examination. • Gravimetric examination. • Microscopic examination: – light-based, – electron scanning. • Microtomography. • Radiography and ultrasonic flaw detection.
		3.4.7 Shrinkage porosities	Improper feeding, caused by errors in construction of the mold or improper thermal conditions.	• Macroscopic examination. • Gravimetric examination. • Microscopic examination: – light-based, – electron scanning. • Microtomography. • Computer image analysis. • Radiography and ultrasonic flaw detection.
3.5.	Breaks in continuity	3.5.1 Fractures of reinforcement elements	Too high saturation pressure or flow velocity of the metal matrix. Internal stresses inside the casting, too intense mold cooling, too late removal of the casting out of the mold, abrupt cooling of the casting after removing it from	• Microscopic examination: – light-based, – electron scanning.

Designation	Defect subgroup	Defect	Causes of formation	Methods of detection
			the mold.	
		3.5.2 Matrix fracture	Internal stresses inside the casting caused by improper mold construction, improper mold temperature, too intense mold cooling, too late removal of the casting out of the mold.	• Microscopic examination: – light-based, – electron scanning.
		3.5.3 Fractures on the matrix – reinforcement boundary	Internal stresses inside the casting, improper mold temperature, too intense mold cooling, too late removal of the casting out of the mold, abrupt cooling of the casting after removing it from the mold.	• Microscopic examination: – light-based, – electron scanning.
		3.5.4 Hot crack	Internal stresses inside the casting, improper mold temperature, too intense mold cooling, too soon removal of the casting out of the mold.	• Macroscopic examination. • Microscopic examination: – light-based, – electron scanning. • Radiography and ultrasonic flaw detection.
		3.5.5 Cold crack	Internal stresses inside the casting caused by construction of the casting or the mold, improper mold temperature, too intense mold cooling. Damaging the casting during knocking out or straightening.	• Macroscopic examination. • Microscopic examination: – light-based, – electron scanning. • Radiography and ultrasonic flaw detection.

The proposed classification of structure defects appearing in castings of metal matrix composites allows to:

- complement the classification of defect in castings of traditional materials of the group of defects characteristic for castings being a concern of this paper,
- unequivocally define defects characteristic for castings of studied composites,
- be complemented by possible defects not taken into consideration thanks to its open character.

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