Materials Research Proceedings **17** (2020) 57-64 https://doi.org/10.21741/9781644901038-9

Applying a Traditional Casting Defect Classification to Categorize Casting Defects in Metal Matrix Composites with Saturated Reinforcement

GAWDZIŃSKA Katarzyna[1, a *], BRYLL Katarzyna[1,b], KOSTECKA Ewelina [1,c] and STOCHŁA Dorota [1,d]

[1]Maritime University of Szczecin, Faculty of Marine Engineering, Szczecin, Willowa 2 Street, 71-650 Szczecin, Poland

[a]k.gawdzinska@am.szczecin.pl, [b]k.bryll@am.szczecin.pl, [c]e.kostecka@am.szczecin.pl, [d]d.stochla@am.szczecin.pl

Keywords: Metal Matrix Composites, Saturated Composite, Casting Defects, Classification

Abstract. Traditional casting defects in metal-matrix composites with saturated reinforcement. This classification forms a casting defect group called "structure defects," while the remaining defect groups (shape defects and raw surface defects) under this new classification method include groups present in casting defects in traditionally cast materials. This group (structure defects) contains 5 subgroups, including both structural defects in traditionally cast materials, which correspond to structural defects in saturated composite castings, as well as defects specific to these castings. The proposed classification is still being refined.

Introduction

Metal composites are increasingly replacing traditional construction materials used in aviation and in the construction of machinery and equipment. This is due to the ability to obtain virtually any desirable functional properties using a composite material, such as a high damping factor, high resistance to abrasion, high Young's modulus, low specific weight, and low coefficient of thermal expansion which was generally widely described in classic books [1, 2], and detailed issues in conference papers, earlier [3, 4] and recently [5-8].

A composite is defined [1, 2] as an ideal material with a perfect structure; however, real composite materials, especially cast composites, usually have imperfect structures because they contain various defects [4, 5, 9-12]. These defects arise because castings have specific structures that are affected by the manufacturing process sequence. Classifying such material irregularities makes it possible to:

– identify them precisely,
– determine why they form,
– determine which manufacturing stage causes their formation,
– promptly take countermeasures.

For metal composite castings, especially those produced by saturation, there is no such classification [13-16]. The classification of casting defects of traditional materials (cast iron, cast steel, and non-ferrous metal alloys) is insufficient and must be supplemented with specific defects for metal composites. This problem, noticed during the manufacturing of castings from saturated metal composites, was the reason for creating such a classification in this paper.

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Findings and discussion

All metal castings have defects of various types and origins. We define a casting defect as a deviation in a material's structure and mechanical or physicochemical properties from its specifications [16]. Defects can be identified based on their features, which in turn leads to the creation of a *casting defect classification*. This classification is useful for:

1) transferring information in research work, during an educational process, or in a manufacturing process;
2) eliminating defective castings from further stages of a manufacturing process;
3) intervention aimed at removing the causes of defects from the manufacturing process.

As for the second case, the classification criteria of casting defects can be divided into three casting groups [14-19]:

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

- **Casting defect classification systems**

For castings made from traditional materials, there are standards, atlases or catalogues of defects [2, 14-21], which:

– enable unambiguous identification of defects;
– provide methods to detect them;
– determine why they form;
– suggest technological measures to prevent their formation.

Classification diagrams for casting defects are shown in Figure 1.

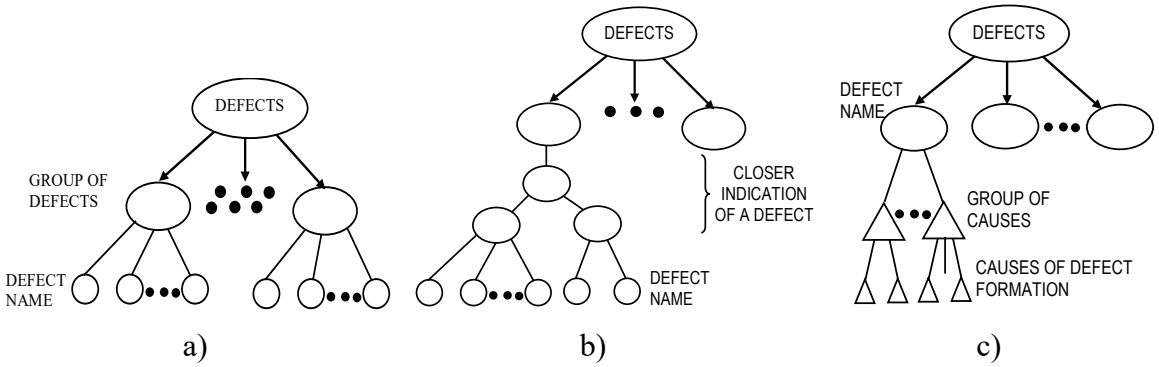

Figure 1. Classification diagrams for casting defects in classic materials [17-21] a – according to Polish standards; b – according to French standards; c – according to English and German systems.

In Poland, a division described in [18-19] is used, with two distinguished levels (Figure 1a). At the upper level, 4 defect groups are identified; at the lower level, each group is assigned defects with specific features that are given names which help unambiguously identify them. In the French foundry industry, a multi-stage structure is used [17, 20-21] whose first level contains 7 groups:

– outward growth of a metal;
– external and internal bubbles;
– discontinuities in a casting;

– surface defects;
– incompleteness of a product;
– inaccurate dimensions or shape;
– structural inclusions or anomalies.

The lowest level also contains the names of individual defects; however, between this level and the definition of a defect group, there are two intermediate levels containing additional features of the group or subgroup (Figure 1b). In this way, each defect is assigned certain characteristics to make it easier to identify its causes and take preventive actions [17, 20-21].

In the English and German literature, defects are classified in a different manner [17, 20-21]. The principle of this classification is presented in Figure lc. Defects are given names here, and they are assigned to cause groups and particular causes of defect formation. This division would be very convenient for identification, but some causes were defined somewhat inaccurately. Since several defects may have a common cause, this division may not always be used objectively.

Classification of casting defects according to Polish Standards

Polish classification of defects in metal castings is one of the few classifications covered by governmental standards. As presented in the review in the previous section, this classification is the simplest because of its two-stage arrangement. It also clearly divides defects in castings made of different materials. The features, wide availability, and familiarity of this classification in Poland make it necessary to refer to this classification while attempting to create another. Thus, any further classifications will be based on the standard Polish defect classification, making it necessary to elaborate on the Polish classification system. According to the Polish standard [19] and national studies [2, 13, 18-19], this classification contains 4 groups of defects, presented in Figure 2.

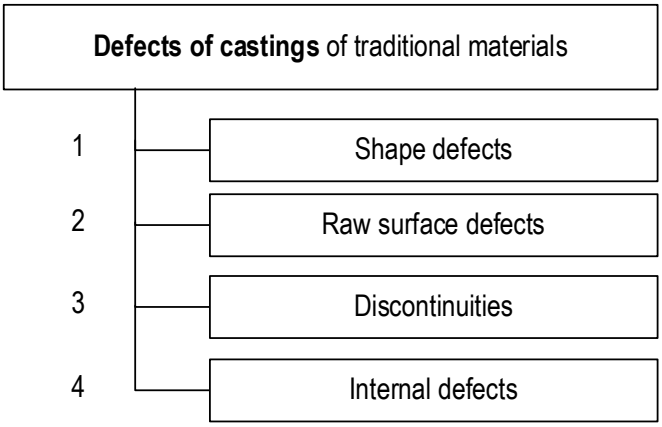

Figure 2. Defects in castings of traditional materials (e.g., cast steel, cast iron, non-ferrous alloys).

The order of defect groups is consistent with the sequence of operations in a casting acceptance by a quality control department. Shape defects are observed first, followed by raw surface defects, and discontinuities. Internal defects are detected during non-destructive and destructive testing and machining of castings. Each of the four groups is assigned certain defects, which are then marked with "W", and the type of material in which they occur is indicated in Table 1. The Polish Standard (PN-85/H-83105) also indicates the causes of defect formation. In

other studies [2, 3, 5, 8-18, 22-27], which properly extend this standard, methods of detection, description, and repair of defects were also found.

Table 1 Classification of defects in castings of traditional materials [19]

Defect name	**Marking**	**Occurrence:**
Group 1 – Shape defects		
Mechanical damage	W-101	all alloys
Misrun	W-102	all alloys
Knob	W-103	all alloys
Flash	W-104	all alloys
Mismatch (shift)	W-105	all alloys
Swelling	W-106	all alloys
Warping	W-107	all alloys
Group 2 – Raw surface defects		
Roughness	W-201	all alloys
External bubble	W-202	all alloys
Pitted skin	W-203	cast steel
Pock-marking	W-204	all alloys
Pinholes	W-205	all alloys
Shrinkage depression	W-206	all alloys
Cold lap	W-207	all alloys
Sand buckle	W-208	all alloys
Rat tails	W-209	all alloys
Sand holes	W-210	all alloys
Crush	W-211	all alloys
Contamination	W-212	all alloys
Scale	W-213	malleable cast-iron
Galling	W-214	non-ferrous metals
Partial melting (during annealing)	W-215	malleable cast-iron
Elephant skin	W-216	spheroidal graphite iron
Sweat	W-217	non-ferrous metals
Flowers	W-218	non-ferrous metals
Metal penetration	W-219	all alloys
Veins	W-220	all alloys
Burning-on (of sand)	W-221	all alloys
Sand holes	W-222	all alloys
Oxidation	W-223	non-ferrous metals
Peel	W-224	malleable cast-iron
Group 3 – Discontinuities		
Hot cracks	W-301	all alloys
Cold cracks	W-302	all alloys
Shrinkagcrack	W-303	all alloys
Annealing cracks	W-304	malleable cast-iron
Transgranular cracks	W-305	cast steel, non-ferrous metals

Group 4 – Internal defects		
Gas bubble	W-401	all alloys
Porosity	W-402	all alloys
Shrinkage cavity	W-403	all alloys
Microporosity	W-404	all alloys
Slag inclusion	W-405	all alloys
Sand drops	W-406	all alloys
Cold shots	W-407	all alloys
Foreign metal	W-408	all alloys
Segregation	W-409	non-ferrous metals
Coarse-grained structure	W-410	non-ferrous metals
Hard spots	W-411	cast iron
Gray spots	W-412	malleable cast-iron
White fracture	W-413	malleable cast-iron
Bright fracture	W-414	malleable cast-iron
Bright border	W-415	malleable cast-iron
Heterogeneity	W-416	all alloys

Summary

The literature concerning defects in metal matrix saturated composite castings is scarce, and a description of the quality of such castings requires unambiguous defect classification. In the technical literature, there is no such classification – only attempts – to which the authors have contributed [10, 28-29]. In publications on composite castings, these irregularities (defects) are often defined imprecisely [1, 5, 17, 22], and the descriptions often include several similar defects occurring at different stages of the manufacturing process, possibly due to various non-interrelated reasons. The only common feature of these defects is often their shape, size, form, etc.

The first two groups of defects and part of the third and fourth groups in castings made of conventional materials (Fig.2 and Table 1) and in composite castings, including saturated composites, are consistent with the previously presented defect identification methods. Metal saturated composite castings have a characteristic structure that results from the presence of reinforcement, most often fibres, located in the metal matrix and permanently connected with it.

The matrix and reinforcement can contact in locations where defects not present in conventional castings may appear. Some can be classified as a lack of continuity, e.g., a discontinuity at phase boundaries, while others are classified as internal defects, e.g., pores or defects in the matrix structure. Other defects are not found in traditional classifications and mainly include reinforcement and matrix defects or a combination of these components; however, they may also include pores if the matrix incompletely saturates the reinforcement. Hence, there is a need to develop a classification for specific defects of metal matrix composite castings with saturated reinforcement. Therefore, it was decided to develop a defect classification system which was an intermediate system between the Polish and French systems (Figure 1), dividing defects into groups, while shape defects and raw surface defects would correspond to the Polish classification. Due to the specific structures of composites, continuity defects, internal defects, and defect characteristics for saturated composites fell under a single group, which was divided into subgroups. However, making this division requires a detailed analysis of the manufacturing process of saturated metal composite castings, which should be performed concerning a possible defect formation during various stages of this process. “Structure defects”

would be the best-suited name for that group. The general structure of this classification is shown in Fig. 3.

The proposed classification, including both ontology and taxonomy, may be interesting not only in the material [30] area, but also in the mechanical [31-33] and technological [34, 35] area.

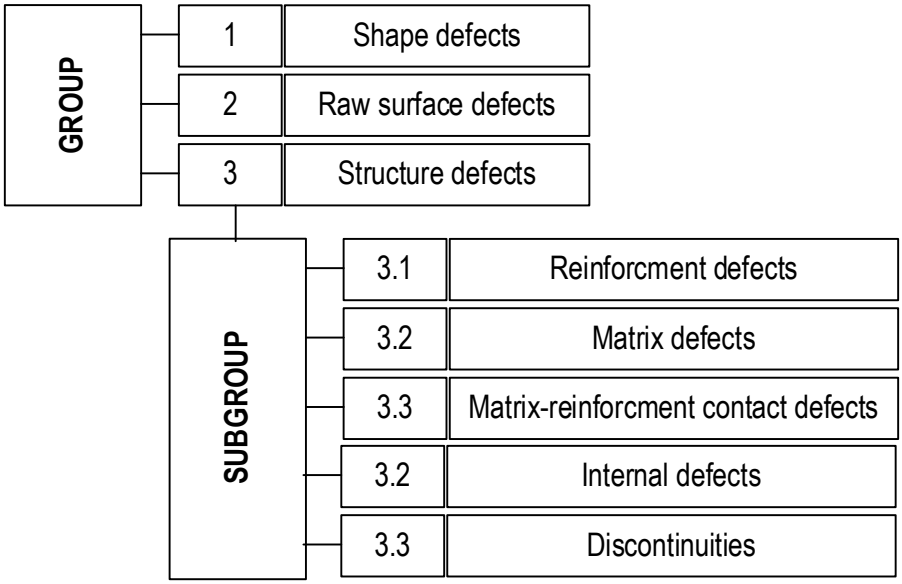

Fig. 3. Proposed classification of defects in saturated metal composite castings.

References

[1] T.W.Clune, P.J. Withers, An Introduction of Metal-Matrix Composites, Cambridge University Press 1993. https://doi.org/10.1017/CBO9780511623080

[2] J. Sobczak , Metalowe materiały kompozytowe, Instytut Odlewnictwa 1996.

[3] Z. Ignaszak, P.Popielarski, Sensitivity Tests of Simulation Models Used in Chosen Calculation Codes on Uncertainty of Thermo-Mechanical Parameters during Virtual Mechanical Stress Estimation for Ferrous Alloy Castings, Defect and Diffusion Forum 312-315 (2011) 758-763. https://doi.org/10.4028/www.scientific.net/DDF.312-315.758

[4] B. Anasori, E. Caspi, and M. Barsoum, Fabrication and Mechanical Properties of Pressureless Melt Infiltrated Magnesium Alloy Composites Reinforced with TiC and Ti2AlC Particles, Mater. Sci. Eng. 618 (2014) 511-522. https://doi.org/10.1016/j.msea.2014.09.039

[5] K. Gawdzińska, D. Nagolska, P. Szymański, Determination of duration and sequence of vacuum pressure saturation in infiltrated MMC castings, Arch. Foundry Eng. 18 (2018) 23-28

[6] M. Wiciak, T. Chwalczuk, A. Felusiak, Experimental investigation and performance analysis of ceramic inserts in laser assisted turning of Waspaloy, MATEC Web of Conf. 237 (2018) art. 01003. https://doi.org/10.1051/matecconf/201823701003

[7] T. Chwalczuk, M. Wiciak, A. Felusiak, P. Kieruj, An Investigation of Tool Performance in Interrupted Turning of Inconel 718, MATEC Web of Conf. 237 (2018) art. 02008. https://doi.org/10.1051/matecconf/201823702008

[8] Hajkowski J., Popielarski P., Sika R. (2018) Prediction of HPDC casting roperties made of $AlSi_9Cu_3$ alloy. In: Hamrol A., Ciszak O., Legutko S., Jurczyk M. (eds) Advances in Manufacturing. Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-319-68619-6_59

[9] D. Przestacki, T. Chwalczuk, The analysis of surface topography during turning of Waspaloy with the application of response surface method, MATEC Web of Conf. 136 (2017) art. 02006. https://doi.org/10.1051/matecconf/201713602006

[10] K. Gawdzińska, L.Chybowski, W. Przetakiewicz, Study of Thermal Properties of Cast Metal-Ceramic Composite Foams. Arch. Foundry Eng. 17 (2017) 47-50. https://doi.org/10.1515/afe-2017-0129

[11] A. Felusiak, T. Chwalczuk, M. Wiciak, Surface Roughness Characterization of Inconel 718 after Laser Assisted Turning, MATEC Web of Conf. 237 (2018) art. 01004. https://doi.org/10.1051/matecconf/201823701004

[12] Z. Ignaszak, P. Popielarski, J. Hajkowski, Sensitivity of Models Applied in Selected Simulation Systems with Respect to Database Quality for Resolving of Casting Problems, Defect and Diffusion Forum 336 (2013) 135-146. https://doi.org/10.4028/www.scientific.net/DDF.336.135

[13] P. Twardowski, M. Wiciak-Pikuła, Prediction of Tool Wear Using Artificial Neural Networks during Turning of Hardened Steel, Materials 12 (2019), art. 3091. https://doi.org/10.3390/ma12193091

[14] P.Szymański, M. Borowiak, Evaluation of castings surface quality made in 3D printed sand moulds using 3DP technology, Lecture Notes in Mechanical Engineering, Advances in Manufacturing II, Vol. 4 - Mechanical Engineering, pp 201-212. https://doi.org/10.1007/978-3-030-16943-5_18

[15] A. Alagarsamy. Defect Analysis Procedure and Case History. Ductile Iron News 2004.

[16] American Foundry Society.(2015). Analysis of Casting Defects. American Foundry Society, pp. 117-120.

[17] S. Kluska-Nawarecka, Metody komputerowe wspomagania diagnostyki wad odlewów, Instytut Odlewnictwa, Kraków 1999.

[18] Z. Falęcki, Analiza wad odlewów, Wyd. AGH, Kraków 1997.

[19] Polska norma PN-85/H-83105. Odlewy. Podział i terminologia wad.

[20] International Atlas of Casting Perfect, Internat. Comit. of Found Tech. Associat. American Foundrymen's Society 1986.

[21] International atlas of foundry defects. International Committee of Foundry Technical Associations. Committee of Metallurgy and Foundry Properties. English Edition 1974.

[22] T. Chwalczuk, D. Przestacki, P. Szablewski, A. Felusiak, Microstructure characterisation of Inconel 718 after laser assisted turning, MATEC Web of Conf. 188 (2018) art. 02004. https://doi.org/10.1051/matecconf/201818802004

[23] S. Wojciechowski, P. Twardowski, T. Chwalczuk, Surface roughness analysis after machining of direct laser deposited tungsten carbide, Journal of Physics: Conference Series 483 (2014) art. 012018. https://doi.org/10.1088/1742-6596/483/1/012018

[24] M. Kawalec, D. Przestacki, K. Bartkowiak, Jankowiak, M., Laser assisted machining of aluminium composite reinforced by SiC particle. ICALEO 2008 27th Int. Congress on Applications of Lasers and Electro-Optics (2008) 895-900. https://doi.org/10.2351/1.5061278

[25] S. Wojciechowski, D. Przestacki, T. Chwalczuk, The evaluation of surface integrity during machining of inconel 718 with various laser assistance strategies, MATEC Web of Conf. 136 (2017) art. 01006. https://doi.org/10.1051/matecconf/201713601006

[26] A. Bartkowska, A. Pertek, M. Popławski, D. Przestacki, A. Miklaszewski, Effect of laser modification of B-Ni complex layer on wear resistance and microhardness Optics and Laser Tech. 72 (2015) 116-124. https://doi.org/10.1016/j.optlastec.2015.03.024

[27] M. Kukliński, A. Bartkowska, D. Przestacki, Investigation of laser heat treated Monel 400, MATEC Web of Conf. 219 (2018) art. 02005. https://doi.org/10.1051/matecconf/201821902005

[28] K. Gawdzińska, Quality features of metal matrix composite castings, Arch. Metall. Mater. 58 (2013) 659-662. https://doi.org/10.2478/amm-2013-0051

[29] Gawdzińska K., Bryll K., Nagolska D., Influence of heat treatment on abrasive wear resistance of silumin matrix composite castings, Arch. Metall. Mater. 61 (2016) 177-182. https://doi.org/10.1515/amm-2016-0031

[30] L. Mosinska, K. Fabisiak, K. Paprocki, M. Kowalska, P. Popielarski, M. Szybowicz, A. Stasiak, Diamond as a transducer material for the production of biosensors. Przem. Chem. 92 (2013) 919-923.

[31] P. Krawiec, A. Marlewski, Profile design of noncircular belt pulleys. J. Theor. Appl. Mech. 54 (2016) 561-570. https://doi.org/10.15632/jtam-pl.54.2.561

[32] P. Krawiec, G. Domek, L. Wargula, K. Walus, J. Adamiec, The application of the optical system atos ii for rapid prototyping methods of non-classical models of cogbelt pulleys. MATEC Web of Conf. 157 (2018) art. 01010. https://doi.org/10.1051/matecconf/201815701010

[33] P. Krawiec, M. Grzelka, J. Kroczak, G. Domek, A. Kolodziej, A proposal of measurement methodology and assessment of manufacturing methods of nontypical cog belt pulleys. Measurement 132 (2019) 182-190. https://doi.org/10.1016/j.measurement.2018.09.039

[34] A. Bartkowska, M. Kuklinski, P. Kieruj, The influence of laser heat treatment on the geometric structure of the surface and condition of the surface layer and selected properties of Waspaloy. MATEC Web of Conf. 121 (2017) art. UNSP 03006. https://doi.org/10.1051/matecconf/201712103006

[35] P. Kieruj, M. Kuklinski, Tool life of diamond inserts after laser assisted turning of cemented carbides. MATEC Web of Conf. 121 (2017) art. UNSP 03011. https://doi.org/10.1051/matecconf/201712103011