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The use of combined quality management instruments to analyze the causes of non-conformities in the castings of the cover of the rail vehicle bearing housing

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Abstract
The most critical activities influencing the success of each company are continuous improvement of the quality of manufactured products and monitoring of the production process. Skillful use of available technologies and quality management tools allows for eliminating casting non-conformities and preventing their repetition in the future. The research aimed to analyze the types of defects occurring in castings, the location of their most frequent occurrence areas, and to identify the causes of defects in castings of bearing housings used in rail vehicles. The benefits of a combination of quality management tools for diagnosing material discontinuities in the analyzed castings are presented in this article.

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1. Introduction

Castings are an essential part of any industry and their quality is determined by the technical conditions of their acceptance (Łuszczak and Dańko, 2013; Pezda, 2017; Pacana et al., 2019; Ostasz et al., 2020). During the production of castings, several technological parameters affect the quality of the finished product. Unfortunately, in the production of castings, it is not possible to simultaneously control all factors of the technological process. The essential activity influencing the assessment of the quality and competitiveness of the product is the final confirmation that there are no defects in the casting (Kozakowski, 2001; Pacana et al., 2014; Poloczek and Kiełbus, 2016).

Inconveniences in aluminum castings are frequent problems causing a decrease in the strength of the casting and an increase in the costs of the technological process, thus influencing further mechanical processing and operation of the casting (Falecki, 1997). Quick determination of the type of defect, its cause, and place of occurrence has a significant impact on the course of the casting process and reduction of the number of defects. Currently used diagnostic methods in the casting control process are characterized by effectiveness depending on the type of the tested product, the sensitivity of the method depending on the type of object, and the place of defect occurrence (Łybacki and Zawadzka, 2008; Pysz et al., 2014; Siwiec et al., 2019). The aspect that hinders effective diagnostics is the great variety of shapes, often with a significant degree of complication, and the complexity of casting processes with a large number of parameters that can affect their course. This makes it difficult to clearly identify a diagnostic method that would be fast, simple and efficient, and applicable at every stage of casting production. Therefore, selecting appropriate technological parameters and quality management instruments is justified and necessary. Properly selected technological parameters will stabilize the process, and management instruments will contribute to the achievement of the intended level of quality and great benefits, both organizational and financial (Tybulczuk et al., 2006; Łybacki and Zawadzka, 2008; Pacana et al., 2016; Pacana et al., 2018).

The approach proposed here can also be effectively used to significantly improve quality in other industrial production processes (e.g. materials (Szczotok and Roskosz, 2005; Ulewicz et al., 2010; Radzymińska-Lenarcik et al., 2018), machinery (Radek, 2009; Pliszka and Radek, 2017; Danielewski et al., 2021; Kurp and Danielewski, 2022), rail (Radek and Dwornicka, 2020; Czyczuła and Rochel, 2021; Kalinowski et al., 2021; Regulski and Abramek, 2022), agricultural machinery (Lipiński and Wach, 2014; Lipiński, 2017; Radzajewski, 2021; Sawicki, 2021), automation (Morawski et al., 2021; Naik, 2021; Wysoczański et al., 2021)) and services (e.g. water supply (Bielski, 2021; Wójcicka, 2021), maintenance (Traneva et al., 2019a; Kubecki et al., 2021; Markovic et al., 2021; Słowiński et al., 2021)). The proposed concept of combining methods can also inspire data analysis methods, both parametric (Szczotok et al., 2017; Korzekwa et al., 2018) and non-parametric (Pietraszek et al., 2014), and even fuzzy (Pietraszek et al., 2016; Traneva et al., 2018; Traneva et al., 2019b) approaches. The presented approach has a very large application potential, which will be shown later in the article.

2. Analysis

2.1. Purpose of the study

The aim of the conducted research was to diagnose, at individual stages between operational quality control, the state of castings of rolling bearing housings used in railway vehicles and to indicate the areas of shielding in which most often there are discrepancies. In addition, the objective was to identify the causes of non-compliance in castings where appropriate corrective and preventive action could significantly reduce the occurrence of non-compliant castings.

2.2. Subject of the tests

The subject of research was the casting of rolling bearing housings used in railway vehicles. The finished castings are worth 110 kg and their dimensions are 504 x 480 x 356. The 3D model of the product is shown in Fig. 1.

The subject of the study was products from a production company located in the southern part of Poland. The production batch was completed in the second quarter of 2019.

Fig. 1. Test subject – sink rolling bearing housing used in rail vehicles; source: (Thoni Alutec Sp. z o.o., 2021)

2.3. Alloy characteristics

The construction material used for gravity casting of the housing is ENAC-AlSi7Mg0.6 (ENAC-42200) alloy. The chemical composition of the alloy is shown in Table 1. Mechanical properties of the casting alloy AlSi7Mg0.6 are presented in Table 2.

Table 1. Chemical composition of AlSi7Mg0.6 alloy; source: own elaboration based on (Pezda, 2017)

Element	Value (%)	
	minimal	max
Fe	-	0.19
Si	6.50	7.50
Mn	-	0.10
Ti	-	0.25
Cu	-	0.05
Mg	0.45	0.70
Zn	-	0.07
Others	each: 0.03; total: 0.01	
Al	remainder	

Table 2. Mechanical properties of alloy AlSi7Mg0.6; source: own elaboration based on (PN-EN 1706:2011)

Property name	Value (%)		Unit of measure
	minimal	max	
Tensile strength (Rm)	300	350	N/mm^2
	320		MPa
Yield strength (R0.2)	240	280	N/mm^2
	240		MPa
Elongation at Break (A)	4	6	%
	6		%
Brinell hardness	100	115	HB
	115		HB

AlSi7Mg0.6 alloy combines silicon and magnesium as alloying elements, which give very good mechanical properties (Briol, 2010). The distinguishing feature of the alloy is its exceptional corrosion resistance, good weldability, and very good machining properties (Julis et al., 2011; Salomon et al., 2017; Yang et al., 2019). For this reason, the alloy has been used in architecture, aviation, automotive (Brungs, 1997; Cavaliere et al., 2004; Pacana et al., 2019), food and chemical industry, mechanical engineering, shipbuilding, models, and forms (Hurtalová et al., 2011; Hurtalová et al., 2013; Poloczek and Kiełbus, 2016; Mueller et al., 2016).

2.4. Methods of the tests

In order to analyze the quality of the products, tests were conducted, the scope of which included verification of shape defects (on the internal surface of the casting), defects of the raw surface, continuity breaks and internal defects in the casting, and additionally marking the place of occurrence of non-compliance together with a precise determination of the type of identified non-compliance. The basis for the inspection of castings was the company's internal procedure. Controls were carried out in accordance with each production order.

The check was also subject to a visual check of the casting designation.

3. Results of analysis

In the analyzed company, each casting of rolling bearing housings used in rail vehicles is currently subject to visual quality control, performed at the end of each production operation. The causes of qualitative rejects were analyzed to reduce the number of castings classified as non-compliant. In the first stage of the analysis, the areas of the housing casting were identified (Fig. 2) where the defects occur most often, and the types of these defects were classified.

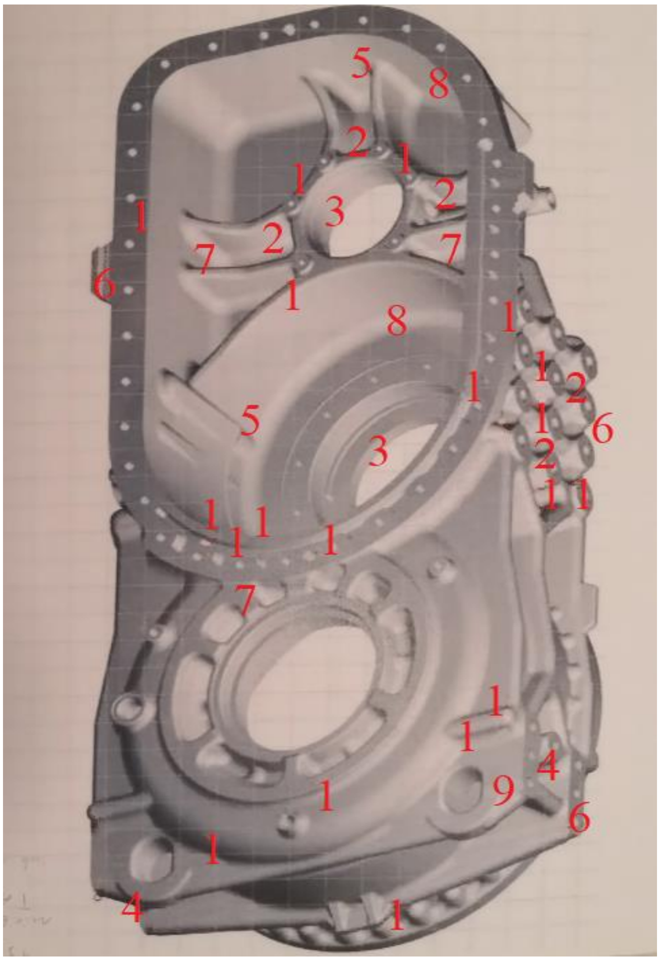

Fig. 2. Rolling bearing housing casting used in railway vehicles to identify the most common areas of non-compliance (1 - shrinkage cavity; 2 - sanding; 3 - gas bladders; 4 - under casting; 5 - surface roughness incompatibility). 6 - mechanical damage; 7 - foreign material inclusions; 8 - peeling; 9 - incorrect or illegible marking of the casting)

The preliminary analysis allowed us to identify 9 types of incompatibilities in the housing casting.

An in-depth analysis of the defectiveness of castings was carried out by combining the Pareto-Lorenzo analysis with the ABC method. Its purpose was to identify the most significant non-conformities and rank them in terms of the number of occurrences and intensity of the effects (Fig. 3). In the Pareto-Lorenzo diagram, the nonconformities have been marked as shown in Fig. 2.

The analysis of casting showed that the most important incompatibilities were systolic cavities (52.5%) and sanding cavities (27.3%). These defects contribute to 79.8% of all defects after the casting process. In accordance with the ABC method, area A, to which the listed non-conformities have been qualified, is determined as critical.

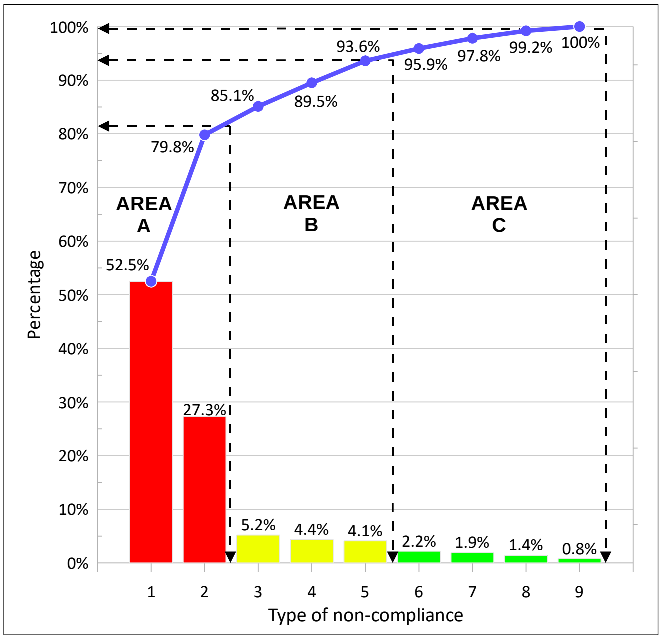

Fig. 3. Pareto-Lorenzo Chart and ABC method for non-conformity of castings of rolling bearing housings used in railway vehicles

Due to the number of skin cavities and crusts and the fact that the presence of specified nonconformities eliminates the product, the metallographic examination was performed to observe the nonconformities and analyze them. Fig. 4 shows one of the observed inconsistencies, which most often occurs in the casting of the casing – the dermal cavity.

Disclosure of defects at the earliest stage of the production process generates lower costs than their detection at the time of final inspection. Therefore, making the right decisions regarding handling non-compliant products as early as possible is crucial. Additionally, the disclosure of a defect in the place of its occurrence enables the application of effective corrective and preventive actions, which in the future may eliminate it.

Table 3 presents the types of quality control detecting the most inconsistencies related to a given type of defect and decisions on further handling the non-compliant product. Table 3 uses the type of defect markings used in Fig. 2.

The largest number of the most serious discrepancies in castings, i.e. systolic cavities and porosity, is detected during the initial control using the NDT X-ray method.

4. Proposal for improvement

The in-depth analysis resulted in a proposal to combine quality management instruments to identify the causes of the most serious quantitative inconsistencies (systolic cavity and sanding) in the analyzed casting. This included, among others, the brainstorming method, and the Ishikawa diagram.

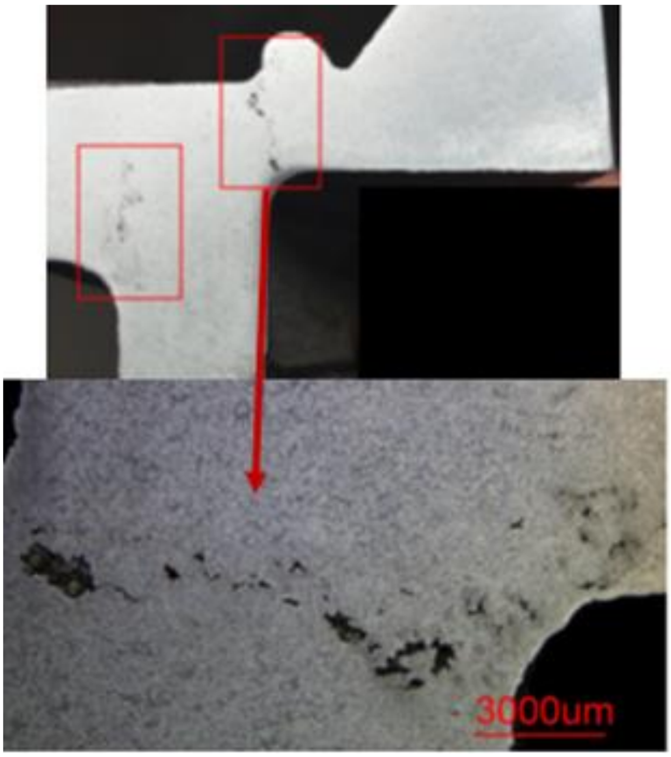

Fig. 4. Survey results from the area of discontinuities – systolic cavity

Table 3. Percentage of decisions on handling non-compliant products – the casting of bearing housing used in railway vehicles

Type of defect	Quality control most often identifies non-compliance	Decision		
		Disposal of casting	Repair	Release for casting
1	Initial inspection (X-ray method, UT)	76%	6%	18%
2	Initial inspection (X-ray method)	63%	15%	23%
3	Intermediate control (X-ray, PT, ET)	71%	11%	18%
4	Intermediate (visual) inspection	66%	17%	17%
5	Intermediate control (using a contact profiler)	8%	81%	11%
6	Intermediate inspection (visual)	39%	42%	19%
7	Intermediate inspection (visual)	64%	29%	7%
8	Intermediate inspection (visual)	31%	53%	16%
9	Intermediate inspection (visual)	0%	100%	0%

The brainstorming method was used to isolate all possible causes of non-compliance of products and define their hierarchy. The identified causes of non-compliance were then arranged on an Ishikawa diagram, which revealed the interrelationship of the causes that resulted in the problem.

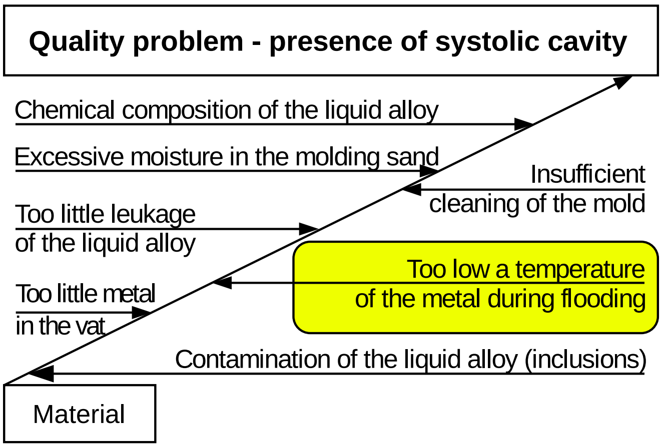

Fig. 5. A fragment of the Ishikawa diagram showing the reasons for the occurrence of the systolic cavity in the category "material"

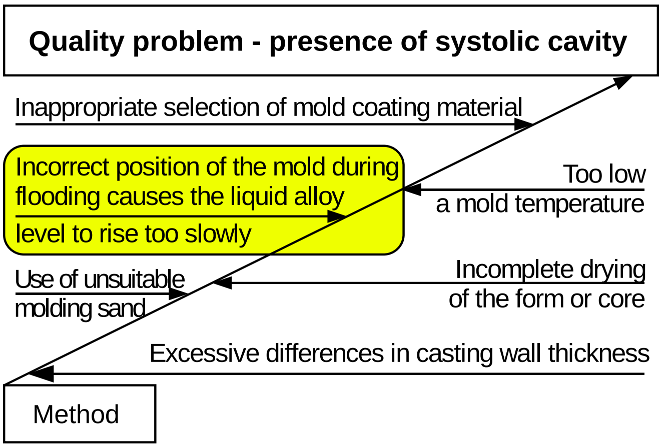

Fig. 6. A fragment of the Ishikawa diagram showing the reasons for the occurrence of the systolic cavity in the category "method"

Due to the volume limitations, the article contains only a fragment of the Ishikawa diagram showing the leading causes of the most critical nonconformity - the systolic cavity - in the material category (Fig. 5) and the method category (Fig. 6).

After analyzing the reasons for the presence of shrinkage cavities in castings, it was found that the main reason for the presence of shrinkage cavities in the material was too low a temperature of metal during flooding, while in the area of human beings the use of unsuitable molding sand was mentioned.

5. Conclusions

The key activities leading to the success of any company are continuous monitoring of the production process and improving the quality of manufactured products. The presented proposal includes a detailed analysis of the types of non-conformities in castings, the location of the most common areas of defect occurrence, and the identification of the causes of defects in castings. This contributes to the elimination of defects and the implementation of effective measures preventing the occurrence of non-conformities in castings. The key reason for the most important defect in the casting (shrinkage cavity) was too low a temperature of the metal during flooding and incorrect setting of the mold during flooding causes too slow an increase in the level of liquid alloy.

Possible further work will be related to implementing the proposed sequence of the analysis of casting defects in the production processes of other products offered by the analyzed company, as it is an effective method of solving quality problems.

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采用组合质量管理手段分析轨道车辆轴承座盖板铸件不合格原因

關鍵詞
质量控制
质量管理工具
帕累托-洛伦兹图
铸造缺陷

摘要
影响每家公司成功的最关键活动是持续改进制造产品的质量和监控生产过程。 熟练使用现有技术和质量管理工具可以消除铸造不合格并防止其在未来重复发生。 该研究旨在分析铸件中出现的缺陷类型、最常见区域的位置，并找出轨道车辆用轴承座铸件缺陷的原因。 本文介绍了在分析的铸件中诊断材料不连续性的质量管理工具组合的好处