Analysis of the Causes of the Non-Conformity of the Bearing Shell Casting Used on Rail Vehicles

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Abstract. Continuous improvement of the quality of manufactured products and monitoring of the production process is the key to the success of every company. Skillful use of available technologies and quality management instruments makes it possible to eliminate casting incompatibilities and prevent their recurrence in the future. The aim of the article was to analyze the types of defects occurring in castings, locate the areas with the most frequent occurrence of defects and identify the reasons for the presence of defects in castings of bearing housings used in railway vehicles. The paper presents the usefulness of a combination of quality management instruments for diagnosing material discontinuities in the analyzed castings.

Introduction

Castings are an essential part of any industry, and their quality is determined by the technical conditions of their acceptance [1-2]. The production of casting, and thus maintaining the high quality of the finished product, is related to several technological parameters that may affect the quality of the finished product. The problem occurring during the casting production process is the inability to control all the factors of the technological process simultaneously. One and the most crucial option affecting the quality and competitiveness of casting is to confirm that the casting is free from defects. [3-5].

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. [6]. 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 [7]. 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. Hence, it is justified and necessary to select appropriate technological parameters not only to stabilize the process but also to select appropriate quality management instruments contributing to the achievement of the desired level of quality and measurable organizational and financial benefits [8-10].

Analysis

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.

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.

Fig. 1. *Test subject – sink rolling bearing housing used in rail vehicles [11]*

The study was carried out on a batch of products cast in the 2nd quarter of 2021 in a Polish production company located in the southern part of the country.

The construction material used for gravity casting of the housing is ENAC-AlSi7Mg0. 6 (ENAC-42200) alloy. The chemical composition of the alloy and its mechanical properties is shown in Table 1.

Table 1. *Chemical composition and mechanical properties of AlSi7Mg0.6 alloy*

<table>
<tr><th colspan="11">Chemical composition of AlSi7Mg0. 6 alloy</th></tr>
<tr><td colspan="2">Element</td><td>Fe</td><td>Si</td><td>Mn</td><td>Ti</td><td>Cu</td><td>Mg</td><td>Zn</td><td>Others</td><td>Al</td></tr>
<tr><td rowspan="2">Value [%]</td><td>Min</td><td>-</td><td>6.50</td><td>-</td><td>-</td><td>-</td><td>0.45</td><td>-</td><td rowspan="2">each: 0.03; total: 0.01</td><td rowspan="2">remainder</td></tr>
<tr><td>Max</td><td>0.19</td><td>7.50</td><td>0.10</td><td>0.25</td><td>0.05</td><td>0.70</td><td>0.07</td></tr>
</table>

<table>
<tr><th colspan="10">Mechanical properties of alloy AlSi7Mg0,6</th></tr>
<tr><td colspan="2">Property name</td><td colspan="2">Tensile strength [Rm]</td><td colspan="2">Yield strength [R02]</td><td colspan="2">Elongation at break [A]</td><td colspan="2">Brinell hardness</td></tr>
<tr><td rowspan="2">Value [%]</td><td>Min</td><td>300</td><td rowspan="2">320</td><td>240</td><td rowspan="2">240</td><td>4</td><td rowspan="2">6</td><td>100</td><td rowspan="2">115</td></tr>
<tr><td>Max</td><td>350</td><td>280</td><td>6</td><td>115</td></tr>
<tr><td colspan="2">Unit of measure</td><td>[N/mm^2]</td><td>[Mpa]</td><td>[N/mm^2]</td><td>[Mpa]</td><td>[%]</td><td>[%]</td><td>[HB]</td><td>[HB]</td></tr>
</table>

Source: Own elaboration based on: [12]

AlSi7Mg0.6 alloy combines silicon and magnesium as alloying elements, which give very good mechanical properties [13]. The distinguishing feature of the alloy is its exceptional corrosion resistance, good weldability, and excellent machining properties [14-16]. For this reason, the alloy has been used in architecture, aviation, automotive [17-19], food and chemical industry, mechanical engineering, shipbuilding, models, and forms. [20-23].

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 realized control of castings was performed in accordance with the internal procedure of the company according to each production order.

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

Results of Analysis

Currently, in the analyzed company, each casting of rolling bearing housings used in railway vehicles is subject to a visual quality control carried out after the completion of each production operation. In order to minimize the number of castings verified as non-compliant, an analysis of the reasons for discards has been undertaken. The first step of the analysis was to determine the areas in the housing casting (Fig. 2), in which the most frequent irregularities occur and to determine the type of these defects. The preliminary analysis allowed us to identify 9 types of incompatibilities in the housing casting. The proposed instrument for an in-depth analysis of the defectiveness of castings was the Pareto-Lorenz analysis combined with the ABC method, whose aim is to specify the most significant inconsistencies in terms of the number of their occurrence and the severity of their effects (Fig. 3). In the Pareto Lorenzo diagram, the nonconformities have been marked as shown in Fig. 2.

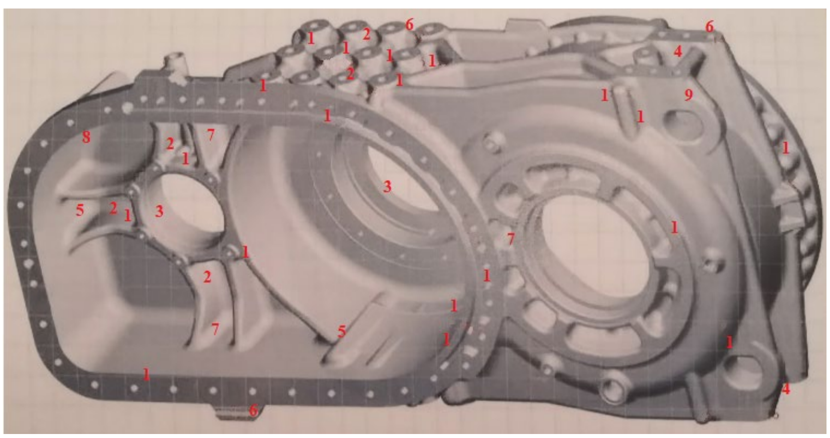

Fig. 2. *Rolling bearing housing casting used in railway vehicles to identify the most common areas of non-compliance (1 - shrinkage cavity; 2 - sanding; 3 - gas bladders; 4 - under casting; 5 - surface roughness incompatibility). 6 - mechanical damage; 7 - foreign material inclusions; 8 - peeling; 9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

The 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.

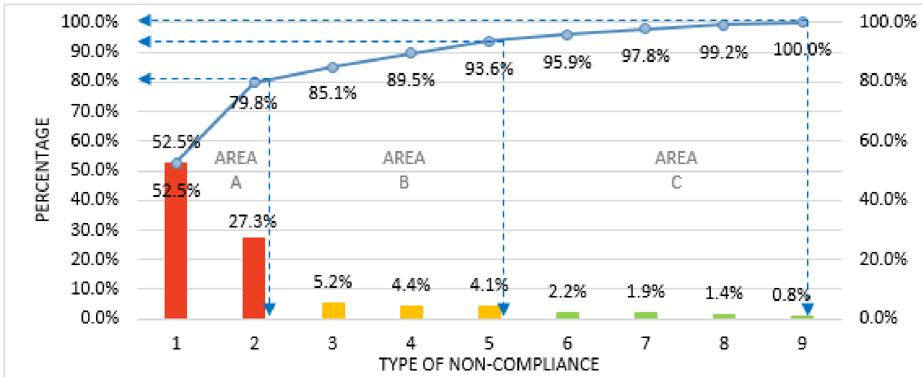

Fig. 3. *Lorenzo's Pareto Chart and ABC method for non-conformity of castings of rolling bearing housings used in railway vehicles*

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.

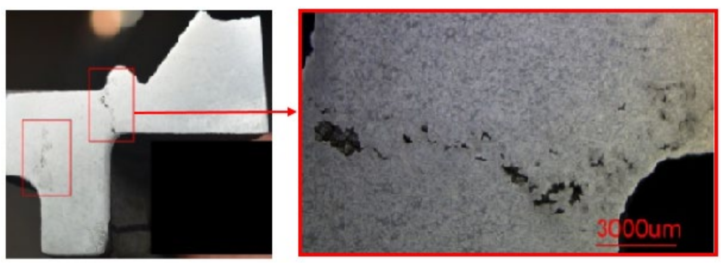

Fig. 4. *Survey results from the area of discontinuities - systolic cavity*

In order to reduce costs and make the right decision regarding the handling of non-compliant products, defects should be disclosed at the earliest possible stage of the production process, because then they generate lower costs than their detection at the time of final inspection. 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.

Data on the type of quality control in which the most inconsistencies with a given type of defect are detected and decisions on handling the non-compliant product are presented in Table 2. Table 2 uses the type of defect markings used in Fig. 2.

Table 2. *Percentage of decisions on handling non-compliant products*

The casting of bearing housing used in railway vehicles										
Type of defect		1	2	3	4	5	6	7	8	9
Quality control most often identifies non-compliance		X-ray method, UT	X-ray method	X-ray, PT, ET	Visual inspection	Using a contact profiler	Visual inspection	Visual inspection	Visual inspection	Visual inspection
Decision	Disposal of casting	76%	63%	71%	66%	8%	39%	64%	31%	0%
	Repair	6%	15%	11%	17%	81%	42%	29%	53%	100%
	Release for casting	18%	22%	18%	17%	11%	19%	7%	16%	0%

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.

Proposal for Improvement

As part of the in-depth analysis, it was decided to use a combination of quality management instruments, i. e. the brainstorming method and the Ishikawa diagram, to identify the causes of the most severe quantitative inconsistencies (systolic cavity and sanding) in the analyzed casting.

The brainstorming method was used to isolate all possible causes of incompatibilities in products and their hierarchy. The causes identified during the brainstorming session have been arranged in an Ishikawa diagram showing the interrelationship of causes causing a specific problem. Due to volume limitations, the article contains a part of the Ishikawa diagram containing the key causes of the most acute inconsistency - the systolic cavity, within the material (Fig. 5a) and the method (Fig. 5b).

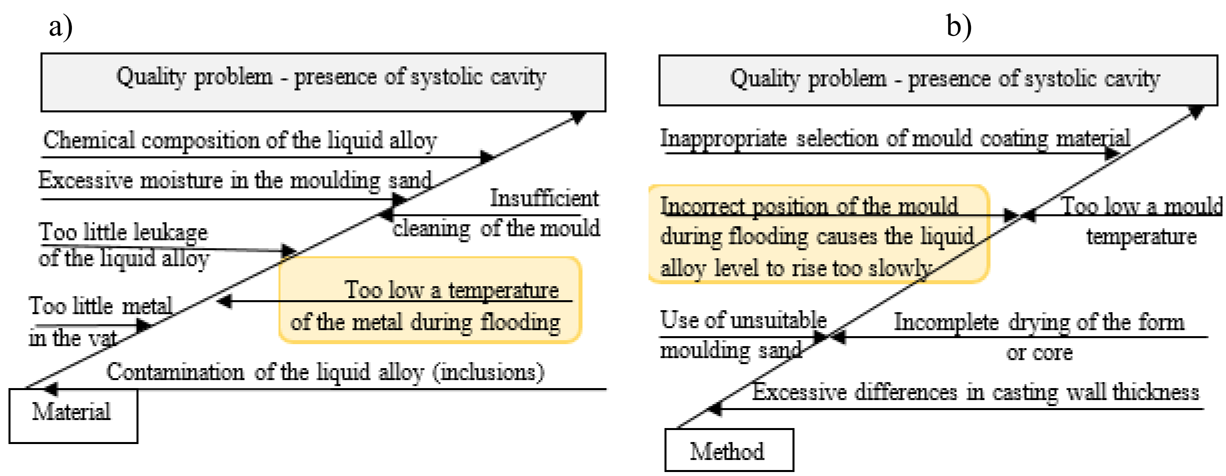

Fig. 5. *A fragment of the Ishikawa diagram showing the reasons f or the occurrence of the systolic cavity in the category "material" and "method".*

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.

Conclusion

Continuous monitoring of the production process and improvement of the quality of manufactured products is the key to the success of every company. The presented proposal for a detailed analysis of the types of incompatibilities in castings, locating the areas where the most common defects are located, and identifying the reasons for the presence of defects in castings contributes to their elimination and implementation of effective measures to prevent the occurrence of incompatibilities 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.

Further research will be related to the implication of the proposed sequence of casting defect analysis, which is an effective way of solving quality problems within the production of other products offered by the company.

The analysis presented in this paper may be useful in many areas of research (non-destructive testing [24], special alloys [25], implants [26], tribological tests [27], welding [28], and biotechnology [29]) and industrial production (special coatings [30, 31], laser surface treatment [32, 33], machine regeneration [34], power hydraulics [35], steel industry [36]), where failures and improper actions may appear and should be repaired by corrective activities.

so the presented method may be inspiring for many recipients. Regardless, it is a development impulse both for the methods of experimental data analysis [37-39] and for the analysis of possible failure scenarios [40, 41].

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