IMPROVING THE QUALITY OF CASTINGS USED IN LIGHT VEHICLES

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Abstract

The research objective was to diagnose aluminum gearbox castings using the proposed diagnosis methodology and pro-quality analysis. The study identified the most severe non-conformity (in terms of frequency of occurrence and its consequences) – the sandblasting within the casting base. The presence of forming compounds in the liquid melt contributing to the most severe non-conformity was identified as the critical cause of the loss of quality stability of the process. So far, no pro-quality analyses have been performed in the company using a sequence of quality management methods. As a result, the implemented corrective actions have not led to the full achievement of quality objectives, which indicates the validity of the actions taken. Combining the analysis of types of nonconformities and quality management methods is a universal way to facilitate supervision and ensure appropriate product quality. Further studies will refer to the performance of pro-quality analyses for other products offered by the company.

Keywords: Mechanical engineering, quality engineering, quality management, casting

1. INTRODUCTION

Currently, foundry companies are looking for solutions to ensure their sustainable success and stable position in the market [1,2]. An essential element for almost every industry is castings. The production of which, while maintaining high quality, involves monitoring a considerable number of technological parameters [3,4] affecting the quality of the final product [5,6]. A significant difficulty occurring during the realization of the casting process is the impossibility of simultaneous control of all factors of this process. The completion of production in the casting technology is associated with many difficulties that cause the formation of inconsistencies in products. A significant variety of material discontinuities appearing in castings is a consequence of the specificity of casting manufacturing technology, which consists of technological operations related to the design and then manufacturing of the casting mold and the technology of melting the liquid alloy [7, 8]. The high quality of the obtained castings may also determine the quality of the special coatings [9,10] applied later, particularly corrosion resistance [11].

Due to the increase in the complexity of the manufactured structures and thus the increase in the requirements for the used components, it has become necessary to perform technical and material tests. In terms of ensuring a certain level of quality of casting products, an important issue is control, both about the process itself and the correctness of casting manufacturing [12]. Therefore, choosing the proper technological parameters [13,14] that steer the process and control methods in inter-operational and final quality control is necessary. The effective detection of nonconformities in aluminum products is one of the crucial steps in the casting process improvement activities. As a part of the quality stabilization of the process, it is necessary to eliminate the source causes of the nonconformities occurrence thanks to the tests, analyses of the results, and implementation of adequate corrective actions [15]. Such an approach enforces and implies an appropriate selection of both the technological parameters stabilizing and improving the process and the choice of adequate methods and tools of quality management, positively affecting the achievement of the expected level of product quality and, thanks to that, the organizational and financial benefits [16]. In the literature on the quality assurance of production processes, the issue of the implementation of quality analyses supported by individual instruments and tools of quality management is not uncommon [17]. In this regard, the literature also indicates the creation of models for optimizing the course of production processes [18]. However, there is still a noticeable lack of studies presenting integrally configured methods of detection and pro-quality analysis that would support the performance of in-depth causal reviews of production – identifying the root cause of nonconformities. Given this, it is reasonable to develop a diagnostic-analytical model based on the sequential adjustment of activities that enable detecting and investigating nonconformities in castings in combination with quality management methods. The output from one tool is the input to the next.

2. ANALYSIS

2.1. Aim and scope of the study

The research aimed to diagnose aluminum gearbox castings using the proposed diagnosis methodology and pro-quality analysis. The diagnosis was carried out within the interoperative and final quality control framework. The activities that had been undertaken within the research framework also included the identification of areas most exposed to the occurrence of non-conformities and the analysis of the origin of the causes of defects in castings. Due to the loss of stability in the production process and thus a significant increase in the identified non-conforming products – an increase of 5.5% compared to the past quarter was recorded. The analysis referred to castings made in Q4 2021. Quality control of castings included verifying the product structure and surface using non-destructive testing and visual inspection.

2.2. Object of the study

The research subject was a casting of a gearbox used in light vehicles in the automotive industry. The research object, 600 mm x 500 mm x 150 mm, is cast from an AlSi7Mg0.3 alloy by gravity using sand molds. The AlSi7Mg0.3 alloy (EN AC-42200) used in the company is applied to cast medium-loaded engine parts with complex shapes. Due to such elements as silicon and magnesium, the alloy shows relatively good mechanical properties [19]. The alloy is characterized by exceptional resistance to corrosion and excellent machining and welding properties [20]. For this reason, the alloy is used in automotive, architectural, aerospace, food and chemical industries, mechanical engineering, shipbuilding, and molds and models [21].

2.3. Conduct of the study

No quality analyses have been carried out in the foundry up-to-date to identify the root causes of non-conformities in castings. In the framework of stabilizing the manufacturing process, the decision was made to perform quality analyses. A team of experts was appointed in the following composition: foundry manager, quality manager, chief technologist, and complaint specialist.

To maintain an appropriate level of quality of the offered products, tests were carried out using appropriately selected quality management tools. The output data obtained from one used method constituted the input element for the analyses performed with the subsequent tool in the applied sequence. **Figure 1** shows the methodology of the integrally configured stages of the quality analysis.

Specifying the quality problem that occurred, the loss of stability in the manufacturing process of the aluminum gearbox housing, was the first step of the analysis. As part of this step, quality control cards were analyzed, and verification of nonconformities identified in the castings was performed, along with the determination of their location within the product. Subsequent methodologies concerned the analysis of the causes of nonconformities. They included the execution of a matrix diagram, a brainstorming session correlated with the ABCD - Suzuki method, and the application of the 5W2H method. The matrix diagram presenting relations between nonconformities occurring in products allowed one to identify the most serious (in the context of effects and severity) nonconformities. The brainstorming session carried out by the team of experts allowed to indicate the potential causes of nonconformities, while the ABCD - Suzuki method made it possible to indicate the potential causes of the problem.

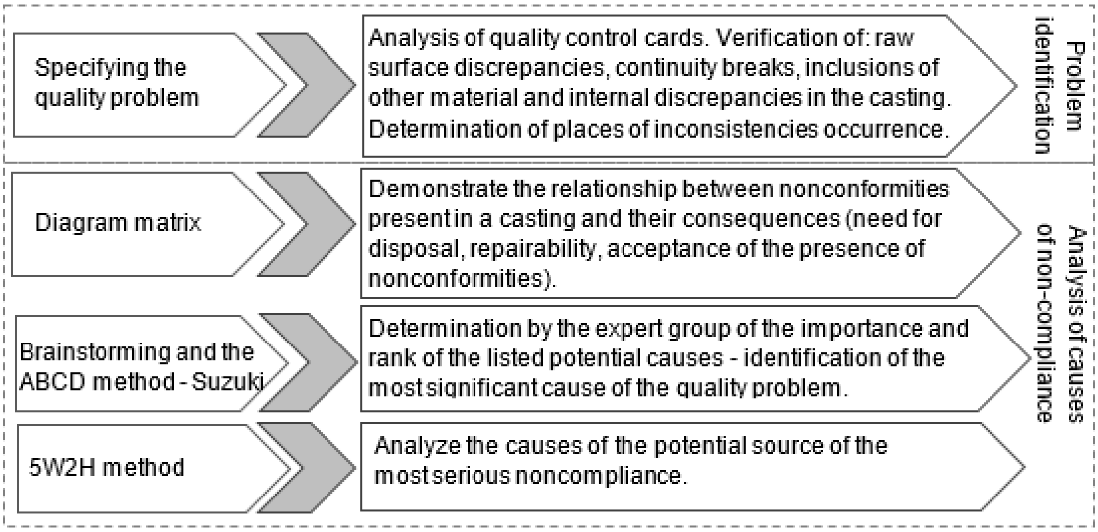

Figure 1 Methodology of non-conformance analysis and identification of its source

The last step of the analysis involved the implementation of the 5W2H method. This method consists of asking seven appropriate questions to specify and examine the root cause of non-conformity occurrence.

3. RESULTS

The first step of the analysis was to identify the areas in the casting (**Figure 2**) where the most common defects occur, along with the type of these defects.

Figure 2 Identification of critical areas of the analyzed casting together with the determination of non-conformities: 1 - underfill; 2 - shrinkage cavity; 3 - gas bubbles; 4 - hot cracks; 5 - ripples; 6 - sandiness; 7 – a dimensional inconsistency; 8 - mechanical damage; 9 - cold cracks; 10 - foreign material inclusions; 11 - incorrect or illegible marking of the casting

To reduce the level of costs related to nonconformities in products, they should be detected within the first stages of quality control of the production process. Effective and early detection, together with an effective analysis of areas and causes of nonconformities, enables the implementation of adequate corrective and preventive actions. Therefore, the research results were analyzed in the context of the specificity of the performed quality control. To analyze the relations occurring between the frequency of occurrence of particular nonconformities and their effects classified into categories: the necessity of utilization and the possibility of repair. The analysis result is presented in the matrix diagram (**Figure 3**). The study of the effects of the quality control of the gearbox casting allowed us to classify the types of identified non-conformities into four groups:

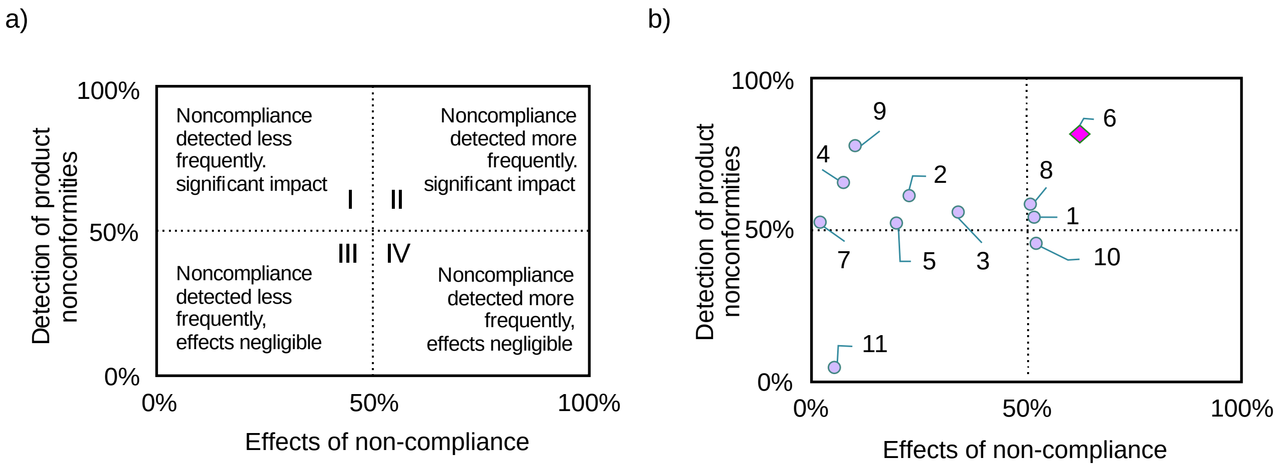

Figure 3 Matrix diagram showing the relationship between the frequency of the detection of nonconformities and the severity of the consequences of a defect a) illustrative diagram, b) result of the analysis.

- I - product nonconformities with a relatively low degree of occurrence and relatively high importance of their effects: shrinkage cavity, gas bubbles, hot casting cracks, shrinkage porosity, size inconsistency, cold casting cracks.
- II - product non-conformities with a relatively high degree of occurrence and relatively high significance of their effects: underfill, sandiness, mechanical damage.
- III - product non-conformities of relatively low degree of occurrence and relatively low importance of their consequences: wrong or illegible product marking.
- IV - Non-conformities of the product with a relatively high degree of occurrence and relatively low significance of the effects of inclusion of foreign material.

A series of frequencies of detected inconsistencies of aluminum castings within quality control is presented in equation 1:

$$f6 > f9 > f4 > f2 > f8 > f3 > f1 > f7 > f5 > f10 > f11 \qquad (1)$$

According to the analysis results, the nonconformity marked as number 6 (sandiness) is identified most often (81.5%). At the same time, the effects of the presence of this nonconformity are the most serious (62.2%). The data confirm the actions' importance undertaken in relation to identifying the causes of nonconformities. The sand build-up in the castings most often took a spongy form, firmly adhering to the mold, irregularly shaped growth.

The next step of the analysis is to conduct a brainstorming session by a team of experts about the most severe nonconformity - the occurrence of sandiness in castings. The result of the session is the identification of potential causes of nonconformities so that, using the ABCD - SUZUKI method, it is possible to indicate their importance and rank. The result of the indications is presented in **Table 1**.

Table 1 ABCD-Suzuki method for the problem-presence of wettability in aluminum castings

Symbol	Cause of non-compliance	The rank of the criteria										Adjusted sum of meanings	Number of unmarked replies	Rank indicator	Rank
		1	2	3	4	5	6	7	8	9	10				
A	Excessive amount of inactive fractions in the forming compound	0	4	4	4	2	1					41	13	3.15	6
B	Insufficient compactability of the compound	1	5	5	2		1	0				34		2.62	3
C	Forming compound in liquid melt	4	4	3	3	2						29		2.23	1
D	Too many lumps in the compound	3	3	6	2	1						31		2.38	2
E	Too high a content of shiny carbon carriers.	0	3	6	3		1			0		42		3.23	7
F	Too fast pouring of mold	0	1	7	1	3	2	0				52		4.00	9
G	Uneven mold compaction		3	6	2	1	1	0				43		3.31	8
H	Insufficient plasticity of forming compound	0	3	6	3	2	1					41		3.15	5
I	Poor charge quality (impurities)	0	5	2	6	0						40		3.08	4

The analysis revealed that the three most important causes of the discontinuity were, in order of importance: the presence of forming compound in the liquid melt, too many lumps in the forming compound, and insufficient compactability of the forming compound.

In the next step, the working group set up to solve the problem conducted a Gemba Walk and then performed a 5W2H analysis to accurately characterize the potential root cause of the problem (**Table 2**).

Table 2 5W2H method for the potential root cause – the presence of molding compound in liquid melt

Question		Answer
Who?	Who has detected the problem?	Foundry employee carrying out quality control
What?	What is the problem?	Particles of sandiness on the surface and in the casting of the product
Why?	Why is this a problem?	Not conforming to standards - disqualification of product
Where?	Where was the problem detected?	In the area of gearbox casting base
When?	When was the problem detected?	During inter-operational control
How?	How was the problem detected?	During visual inspection, luminescence, and after observation of microstructure
How much?	How big is the problem?	15% of non-conforming products manufactured in Q4 2021

The analysis shows that the key reason for the presence of sandiness in the gearbox casting was the presence of forming compounds in the liquid melt. It was concluded that the discrepancy was most often identified by the foundry department employee performing quality control of castings. The area where the highest amount of mordanting was determined was the casting base. After the working team carried out the Gemba Walk, it was found that the reason for the appearance of the nonconformity was the lack of a stand instruction concerning the preparation of molds for the casting process.

4. CONCLUSION

The methodology of detailed quality analysis of aluminum castings presented in the study, combined with the application of quality management tools holistically, contributes to identifying the root cause of the quality problem. This allows proposing and implementing effective corrective and preventive actions contributing to maintaining the stability of the production process. The analysis of the quality problem, which was the loss of stability of the production process of gearbox castings, indicated that the most significant (in terms of frequency of occurrence and consequences) non-conformity was the presence of sandiness in the area of the casting base. The brainstorming session and the ABCD-SUZUKI method identified a potential cause for non-conformities, which was considered to be the presence of forming compounds in the liquid melt due to the lack of a bench instruction. Subsequent research will concern the implications of the proposed methodology for the pro-quality analysis of other products offered by the company to ensure an appropriate level of product quality.

Applying quality management methods in the presented methodology of analyzing types and weights of nonconformities in aluminum castings is an integral and effective supplement. The proposed sequence of activities may constitute components of methods supporting quality management processes.

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