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The Model for Analyzing and Improving Aluminum Castings

CZERWIŃSKA Karolina[1,a *], DWORNICKA Renata [2,b] and PACANA Andrzej[3,c]

[1] Rzeszow University of Technology, The Faculty of Mechanical Engineering and Aeronautics al. Powstańców Warszawy 8, 35-959 Rzeszów,Poland, ORCID: 000-0003-2150-0963

[2] Cracow University of Technology, Faculty of Mechanical Engineering al. Jana Pawła II 37, 31-864, Kraków, Poland, ORCID: 0000-0002-2979-1614

[3] Rzeszow University of Technology, The Faculty of Mechanical Engineering and Aeronautics al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland, ORCID: 0000-0003-1121-6352

[a] k.czerwinska@prz.edu.pl, [b] renata.dwornicka@pk.edu.pl *, [c] app@prz.edu.pl

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Abstract. The purpose of this study is to develop a model for the analysis and improvement of aluminum castings and to perform its test in the framework of verifying the quality of industrial robot arm parts, and then, determine the causes of potential and root causes of nonconformities, including proposing improvement actions in the production area. Aluminum castings have become the focus of research due to significant problems in maintaining their expected level of quality. The use of the model (consisting of eddy current testing and consecutive brainstorming sessions, Ishikawa diagram, and ABCD - Suzuki method) would contribute to the detection of the causes of nonconformities and consequently to the elimination of non-conforming products. The study demonstrates the desirability of using an integrated approach to solving quality problems. The actions taken were a new solution for the company, as no in-depth analysis of quality problems using a sequence of quality management techniques had been carried out before.

Introduction

The economic progress of recent years has caused both the quality of offered products and services, and ISO standardization have become a priority criterion that determines the success of manufacturing companies [1, 2]. These aspects can support the achievement of key economic, environmental, and social objectives, which in turn helps to facilitate the implications of the concept of sustainability [3]. Equally important is the knowledge and experience of the management regarding the possibilities of increasing the efficiency of work and implemented processes [4].

Quality management in manufacturing enterprises requires control of processes to identify non-conformities appearing in these processes, and their effective improvement, so as to completely eliminate the occurrence of both non-conformities and their causes. In general, quality control consists of checking the conformity of the manufacture of a specific product in terms of meeting the requirements intended for it [5]. The manufacturing process represents the cost of production that is borne by the organization. A key aspect of business operations is controlling these costs. At the moment when there are inconsistencies in the manufactured product, it ceases to meet the requirements of buyers, which generates excessive costs and affects negatively the evaluation of the customer. In such a situation, it is crucial to identify the causes of the quality problem [6]. To this end, the subject literature recommends the use of quality management tools as an effective way to improve quality. Increasing attention has begun to be paid to the use of more quality management instruments in the in-depth analysis of quality problems, thus indicating their

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universal nature [7, 8]. However, comprehensive and effective quality control methods are still being sought to realize the in-depth causal analysis of production problems.

The objective of this research was to develop an integrally configured model for the analysis and improvement of aluminum castings consisting of the integration of nondestructive testing (eddy current method) and consecutive quality management tools (brainstorming, Ishikawa diagram, ABCD-Suzuki method) for use in post-implementation control of the casting process or inter-operational quality control. The proposed model makes it possible to perform an in-depth analysis of a manufacturing problem and to propose effective improvement actions.

Model for Analyzing and Improving Aluminum Castings

The proposed analysis and improvement model consisted of a sequence of appropriately selected quality management tools that are used to sequentially determine the cause of a problem identified using nondestructive testing (NDT). The tools were brainstorming (BM), Ishikawa diagram, and ABCD - Suzuki method. On the other hand, eddy current (ET) testing was used to diagnose the castings.

When a casting nonconformity is detected and the root cause of the nonconformity is identified, appropriate improvement actions can be taken. Eliminating the cause of the problem will eliminate or reduce product nonconformance. A schematic of the model is shown in Fig. 1.

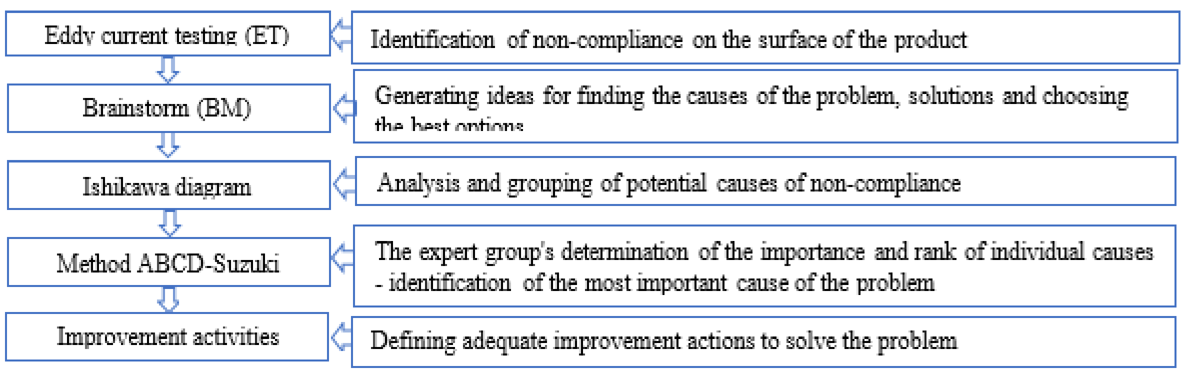

Fig. 1. *Schematic of a model for analysis and diagnosis of aluminum castings including quality management tools and NDT testing*

Limitations of the model include the subjective approach of the combined techniques. This is a result of the specificity of the techniques used, which are based on the knowledge and experience of the experts appointed to solve the qualitative problem [9]. The issue of the applicability of the eddy current method may also be a limitation. The main limitations of the method include [10, 11]:

- difficulty in testing castings with rough surfaces, non-uniform and irregular shapes,
- difficulty in testing ferromagnetic components due to the so-called skin effect (concentration of eddy current field near the surface),
- limiting the depth of verification of material within the audit,
- difficulty in detecting discontinuities lying parallel to the probe winding course and test direction. (for example, material delamination, cracks),
- vibrations and impacts make it difficult to find defects.

A brief description of the proposed model was developed in six main steps, as presented in the following section.

Step 1. Research subject selection. Considering the applicability of the selected NDT method in the model, the diagnosed test object should have axisymmetric elements or be an axisymmetric product made of conductive material [12]. The object of study may be an aluminum casting, which should be diagnosed for the presence of the most dangerous discontinuities: flat, narrow-slot, and other object discontinuities.

Step 2. Eddy current testing - product quality control. Eddy current defectoscopy was used to inspect the castings for the presence of surface flat discontinuities, narrow-slit discontinuities, and relatively large near-surface surface discontinuities. It is possible to detect cracks with a depth of about 0. 1 mm, a width of about 0. 0005 mm and a length of about 0. 4 mm [13]. Once a product nonconformity has been detected, a characterization of that nonconformity must be made, such as identifying the type (type) of nonconformity and the product material on which the nonconformity occurred.

Step 3. Brainstorm - identify potential causes of non-compliance and step 4. Ishikawa diagram - categorize potential causes of non-compliance. In the study, causes are identified by a panel of experts in a brainstorming (BM) session. A detailed implementation of brainstorming is presented in the literature e. g. [14]. You need to group all the generated causes according to appropriately selected categories, thus taking into account the next step of the method - the Ishikawa diagram. It is effective to use a participatory factor system Ishikawa diagram, which includes the following range of causal categories, i. e. , human, method, machine, material, measurement, management, and environment [15].

Step 4. ABCD method - Suzuki - selection of causes of major inconsistencies. The selection of root causes is done by a panel of experts in a brainstorming (BM) session. All causes placed on the Ishikawa diagram (step 4) are considered. The root causes should be considered those that are as likely as possible to result in noncompliance. The expert team uses the ABCD-Suzuki method [16] to determine the importance and rank of each potential cause. The ABCD method is easy to use and analyze the results because the final result is obtained from simple mathematical operations.

Stage 6. Suggest improvement activities. Once the root causes of a quality problem have been identified, appropriate improvement actions should be determined. That is actions that, when properly implemented, will contribute to the elimination or significant reduction of existing nonconformities. These activities are determined by a panel of experts.

After implementation of the proposed improvement actions, the obtained results should be analyzed and, if necessary, the proposed model should be applied to further nonconformities.

Model Verification and Results

Verification of the proposed model for the analysis and improvement of aluminum castings was carried out against a nonconformity that is relatively often identified in one of the enterprises located in the southern part of Poland.

A part of an industrial robot arm weighing 92 kilograms, gravity cast from AlSi7Mg0. 3 alloy, was tested. It is a product whose specificity depends on the type of purpose of the industrial robot. The selection of the product was due to the declining quality level and the lack of clearly defined reasons for critical nonconformities. Therefore, the purpose of the study was to verify the quality of the industrial robot arm part, and then, identify the causes of potential and root causes of nonconformities, including proposing improvement actions.

In the next step, quality control of the axially symmetric part of the industrial robot arm was performed. The inspection was performed using non-destructive testing - eddy current testing. The choice of the method of product diagnostics resulted from the specifics of the tested object (material, geometry) and the production process. The presence of oxides in the casting was identified after non-destructive testing was realized. An example of the indications is shown in Fig. 2.

As part of the implementation of the following research steps, potential causes for the presence of oxides in the castings of the robot arm component were determined. To this end, a team of experts conducted brainstorming sessions. The generated potential causes were grouped and visualized in an Ishikawa diagram. The result of the analyses is shown in Fig. 3.

According to the fifth step of the analysis, the expert team applied the ABCD-Suzuki method to determine the importance and rank of each potential cause. All causes placed on the Ishikawa diagram are considered. The analysis result sheet is shown in Table 1.

As a result of the conducted analyses it turned out that the three most significant reasons for the occurrence of nonconformities (the presence of oxides) in the casting (in order of importance) were: inappropriate temperature of pouring the mold (too low temperature), impurities in the liquid melt and improper ventilation of the mold.

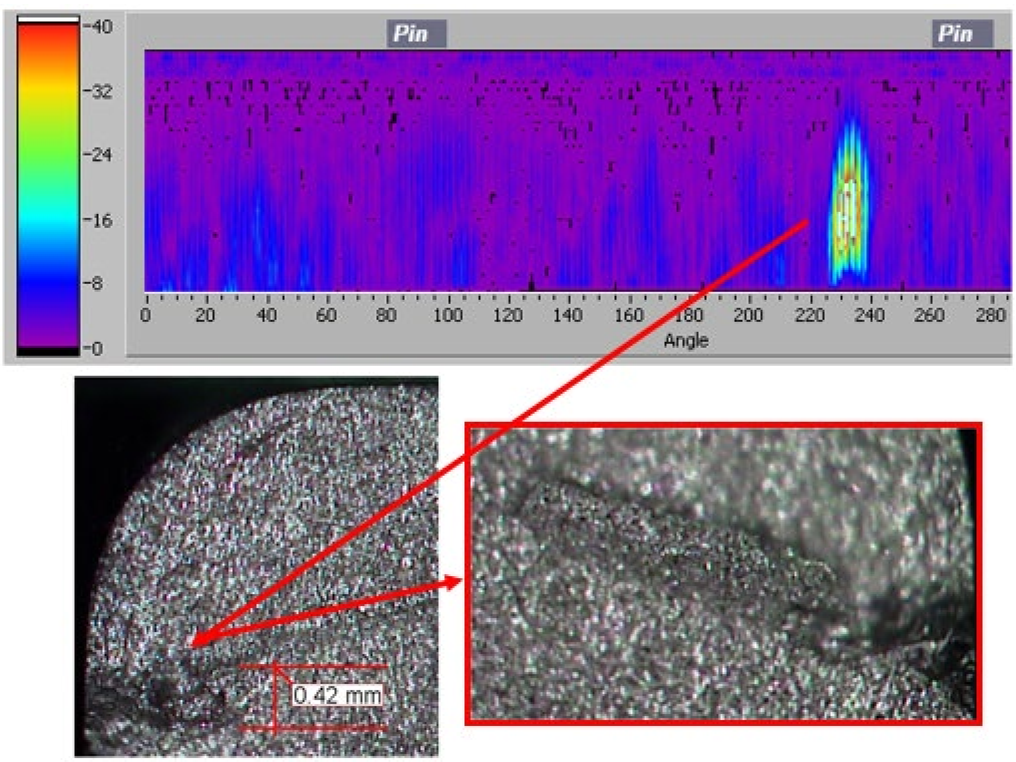

Fig. 2. *Example of oxide presence in a casting*

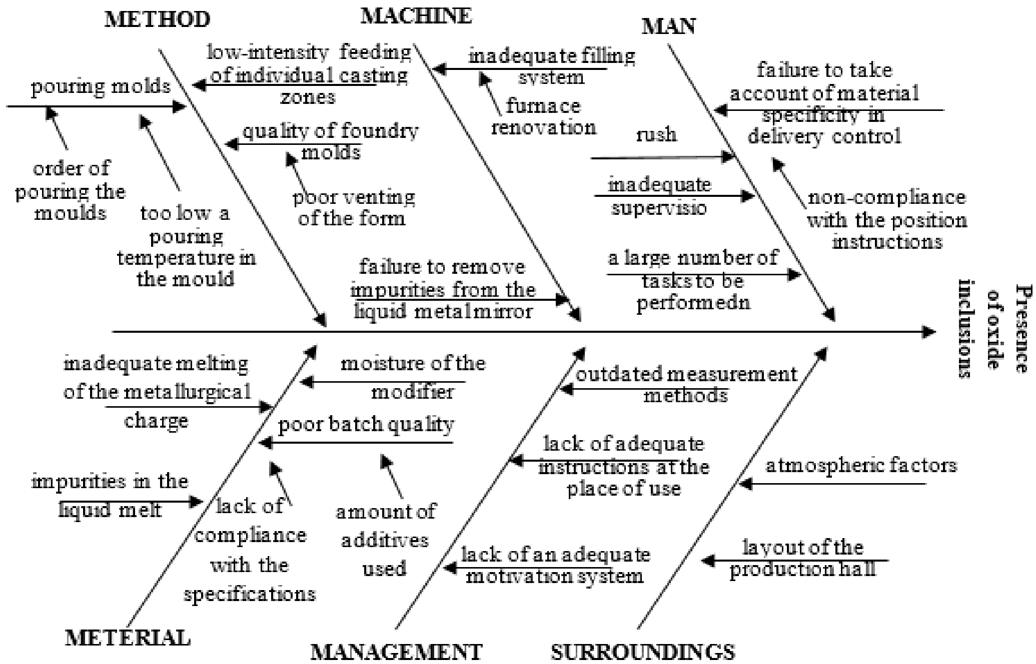

Fig. 3. *Ishikawa diagram for the problem of the presence of oxides in a casting*

Table 1. *Summary of the results of the ABCD-Suzuki method for the problem of the presence of oxides in a casting*

Cause of non-compliance	**The rank of the criteria**										**The adjusted sum of meanings**	**The number of undeleted answers**	**Rank indicator**	**Rank**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**				
Bad feed quality	3	3	6	2	1						31	13	2.38	4
Low-intensity supply of individual zones of the casting	1	5	5	2		1	0				34		2.62	5
Bad mold bleeding	0	5	2	6	0						40		3.08	6
The temperature of pouring the mold is too low	5	5	1	1		1	0				28		2.15	1
Impurities in the liquid melt	4	4	3	3	2						29		2.23	2
Moisture in the modifier	3	2	4	1		3	0				41		3.15	8
Inadequate melt of the metallurgical charge	0	4	4	4	2	1					41		3.15	10
Bad mold bleeding	2	6	4	2	1						30		2,31	3
Not removing the scum from the liquid metal mirror	1	2	5	6	5						40		3,08	7
Failure to comply with the workplace instructions	0	3	6	3	2	1					41		3,15	9
Inadequate supervision	0	1	7	1	3	2		0			52		4,0	14
Obsolete measurement methods		3	6	2	1	1	0				43		3,31	11
Lack of proper instructions at the place of use	0	3	6	3		1			0		42		3,32	12
Lack of an adequate motivation system	0	2	5	4	2		0				45		3,46	13

According to step six, improvement actions were proposed according to the indicated root cause of the verified problem. It was concluded that up-to-date and adequate job instructions should be developed and that additional training directed at foundry department employees is recommended. Additionally, it is recommended that the effectiveness of these actions be periodically reviewed. Subsequently, improvement actions can be taken for further nonconformities.

Conclusion

In this paper, a model for casting analysis and refinement is proposed and its test is performed. The purpose of the study was to verify the quality of the industrial robot arm parts, and then, to identify the causes of potential and root causes of nonconformities, including proposing improvement actions in the manufacturing area.

Using eddy current testing, the most serious type of nonconformity – the presence of oxides in the casting – was detected. The presence of an identified nonconformity disqualifies the product. To characterize the problem, the expert team completed a brainstorming session to isolate potential causes of noncompliance. An Ishikawa diagram was drawn to classify the potential causes of nonconformance. To indicate the importance and rank of each potential cause, the ABCD – Suzuki method was used, according to which the main cause of nonconformity was the inadequate temperature of pouring the mold (too low temperature), impurities in the liquid melt, and improper venting of the mold.

The applied model for the analysis and improvement of aluminum castings combines the diagnostic testing method in combination with quality management methods, which are largely complementary. The model presented can be useful in terms of methods to support quality management processes.

The model presented in this paper may be useful in many areas of research (tribological tests [17], biotechnology [18], waste treatment [19-21]) and industrial production (special coatings [22], laser surface treatment [23, 24], machine regeneration [25], power hydraulics [26]), where castings may appear as part of devices. Regardless, it is a development impulse both for the methods of experimental data analysis [27-29] and for the analysis of possible failure scenarios [40, 41].

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