ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20230128000283
Preliminary communication

Universal Model for the Quality Analysis of Aluminium Alloys Castings

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Abstract: The production of products in foundry technology is fraught with many problems, including the impossibility of controlling all parameters affecting casting quality. It is important to take effective improvement measures related to the implication of non-destructive testing (NDT), but these methods are rarely combined in the diagnostic cycle. As part of quality assurance, it is also important to identify the root causes of problems. In view of this, it is appropriate to develop a model that facilitates diagnosis and the search for the key causes of nonconformity, which would be a combination of NDT and quality management methods. The originality of the model presented in the study is reflected in the combination of NDT and quality management methods. The model presents a universal method that can be implemented in foundries to ensure the stability of production processes. The application of the model brings tangible benefits in the form of an increase in the speed of detection and a reduction in non-conformities in aluminium castings, which significantly increases the quality level of the products offered. Further research directions will address the application of the model within foundry processes characterised by loss of quality stability.

Keywords: casting; mechanical engineering; quality engineering; quality management

1 INTRODUCTION

The current increasing intensity of competition in the foundry industry, the risks associated with crisis events, as well as increasing globalization and a dynamically changing environment, requires the creation and subsequent implementation of innovative management systems. Achieving and maintaining a permanent competitive advantage means for manufacturers to orient the management system to increase the quality of products offered, efficiency and innovation in the implementation of manufacturing processes [1-3]. Various management strategies are widely described in the literature, as well as the actions taken in this area [4-8]. Economic progress has contributed to the fact that, in addition to the quality of products and services offered, ISO standardization has become an additional criterion determining the success of enterprises [9, 10]. These aspects support the achievement of energy, economic, social and environmental goals, and this in turn provides a convenient platform for the implication of the concept of sustainability and the development of Industry 4.0 [11].

Effective quality management determines the exercise of constant control of processes to identify existing problems and nonconformities and their improvement. This activity should lead to the reduction or complete elimination of the root causes of loss of quality stability of processes. In general, quality control is based on checking the conformity of the manufacture of a specific product in terms of meeting the requirements established for it [12]. Castings are an important part of any industry, while their quality is defined by technical conditions of acceptance [13, 14]. The realization of production using casting technology is associated with many difficulties. The considerable variety of nonconformities that can occur in castings is due to the specifics of the casting manufacturing technology itself, which consists of technological operations for the design and subsequent manufacture of the casting mold and the technology for melting the liquid metal [15, 16]. When nonconformities are identified in the manufactured product, it ceases to meet the requirements of buyers, which generates excessive costs and has an adverse effect on customer evaluations. Therefore, it is important to determine the root causes of the quality problem [17]. Incompatibilities in aluminum castings are a common problem affecting the decrease in the strong performance of the casting and the subsequent machining and operation of the casting [18]. Occurring quality problems have contributed to the fact that more and more attention has begun to be paid to models in optimizing the course of production processes using quality management methods [19, 20]. However, there is still a search for comprehensive and effective quality control implementation models that would support the implementation of in-depth causal analysis of manufacturing problems.

2 METHODS OF RESEARCH

The proposed model for the analysis of the quality level and improvement of aluminum castings was developed as a diagnostic-analytical control performed after a special process such as aluminum casting. The model takes into account the area of detection of nonconformities in aluminum castings and the area relating to the analysis of the causes of the quality problem. Correlations of selected diagnostic and analytical methods and their order of application are shown in Fig. 1.

According to the literature, a visual inspection should be implemented as the first - preliminary inspection [21], which was pointed out during the development of the model. The visual method is one of the key inspection methods despite the great automation of production processes and developed information technologies. The main purpose of the method is to separate details having defects visible to the unaided eye. Visual inspection is one of the economically viable activities, as it can be applied at any stage of production processes and anywhere in the company. In addition, its implementation does not require expensive equipment [22].

Radiographic examinations can be used in resectoscopes of a variety of objects made of almost any material. They make it possible to detect discontinuities with a depth (height) of about 0.5% of the thickness of the material under examination, in the direction in which the radiation propagates, and discontinuities with a width of dilation of about 0.1 mm or more [23]. The use of radiographic examination requires two-sided access to the object under examination. On one side a source of radiation (X-ray tubes or gamma-ray cameras) is placed, while on the other side of the examined object a radiation detector is placed. Detectors, in radiographic studies, are radiographic films. The intensity of the radiation (on the plane, on the other side of the examined object) in the plane of the detector, is mapped as, the so-called, image of the radiographic material of the examined object on the detector [24, 25].

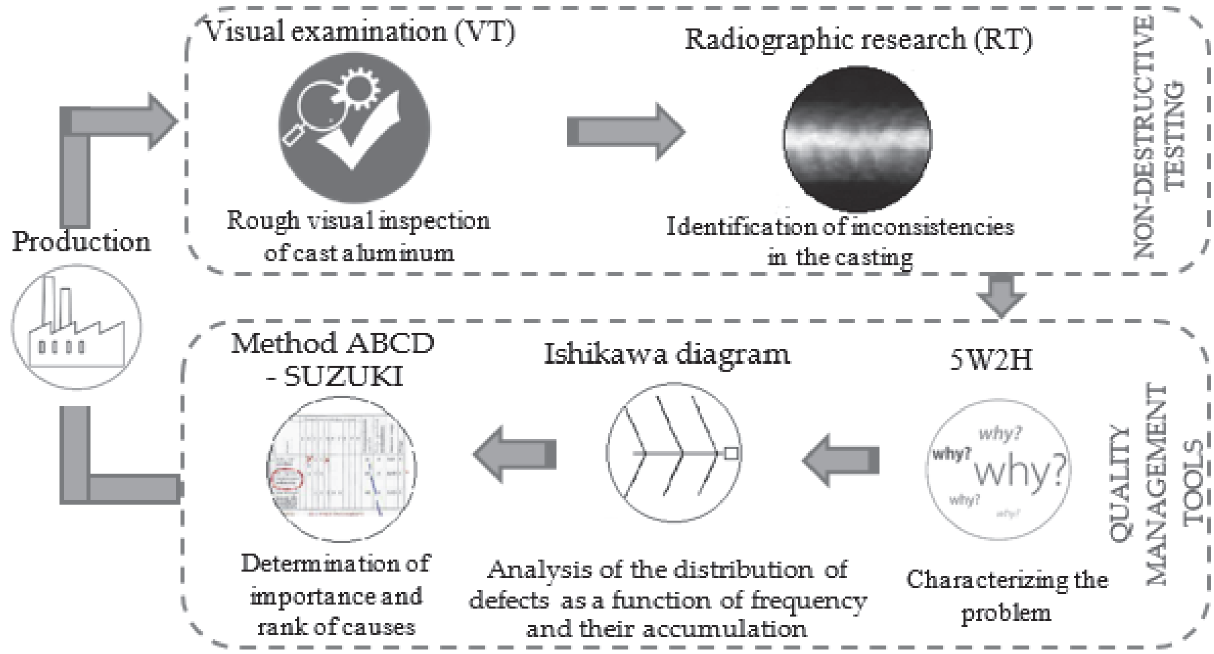

Figure 1 Diagram of the quality level analysis and improvement model for castings

The 5W2H method is an instrument through which it is possible to identify, define and perform problem characterization transparently. The 5W2H method involves asking seven questions that relate to the problem under analysis [26].

Ishikawa diagram, that is, categorizing the potential causes of nonconformity of the analyzed detail. In the implementation of the presented methodology, the potential causes are identified by a team of experts in - a brainstorming session (BM). How to implement the brainstorming session is described in detail in the literature, e.g. [27]. Group the identified causes according to the listed categories: man, method, machine, material, measurement, management, and environment [27].

The ABCD - Suzuki method facilitates the selection of the causes of major non-conformities. This selection is made by a team of experts, which is supported by a brainstorming session (BM). All causes placed on the Ishikawa diagram should be analysed [28]. The ABCD method is easy to use and to analyze the results, as the final result is obtained by simple mathematical operations. To determine the importance and rank of each potential cause, a team of experts indicates the appropriate number of points to a given cause [29].

3 MODEL VERIFICATION AND RESULTS

Verification of the proposed model for the analysis of the level of quality and improvement of aluminum castings realized in relation to nonconformities, is the main problem in the context of maintaining a stable level of quality of manufactured products in one of the enterprises located in the southern part of Poland.

Oil sump with dimensions of 600 × 600 × 3000, weighing 253 kilograms was tested (Fig. 2).

Figure 2 3D model of test object - oil sump

The product is used in automotive applications and was cast from AlSi10Mg. Gravity casting in permanent moulds was used, which is characterised by a relatively more stable filling stage in the mould cavity than high-pressure casting. The main advantages of gravity casting include high production rates, the ability to cast products with complex shapes and very good surface finish and accuracy.

The choice of the product was conditioned by a decline in the level of quality, as well as the lack of implementation of measures to analyze the problem. Thus, it was reasonable to verify the quality of the oil pan, identify the critical causes of loss of stability in the production process. Products manufactured in Q4 2021 were examined.

A visual inspection of the detail was performed, followed by radiographic testing. The choice of the method of product diagnostics was based on the specifics of the tested object (material, geometry) and the production process. After realization of the nondestructive examination, porosity surrounded by crud in the casting was identified. An example of the indication is shown in Fig. 3.

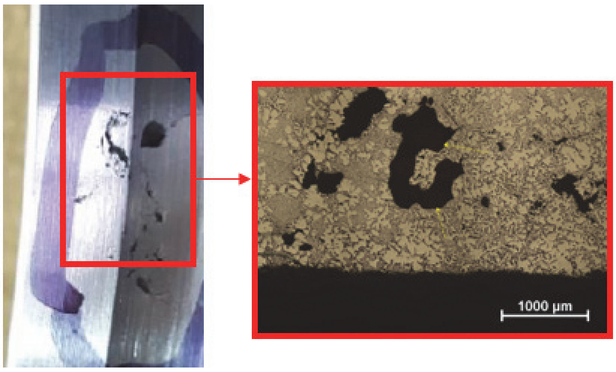

Figure 3 An example of the identified presence of porosity surrounded by rows in a casting

The identified nonconformities disqualify the products. In the next step, an appointed group of experts performed a Gemba walk and then conducted a 5W2H analysis to accurately characterize the problem (Tab. 1).

Table 1 5W2H method for casting discontinuity problem

Question		Answer
Who?	Who has detected the problem?	The employee who performed the radiographic inspection
What?	What is the problem?	Clusters of rows and porosity in the casting
Why?	Why is this a problem?	Failure to meet standards and customer requirements - disqualification of the product
Where?	Where was the problem detected?	The base of the oil pan and the outer area of the upper edges of the product
When?	When was the problem detected?	During radiographic inspection
How?	How was the problem detected?	During visual inspection, radiography and after observation of microstructure
How much?	How big is the problem?	17% of products produced in Q4 2021

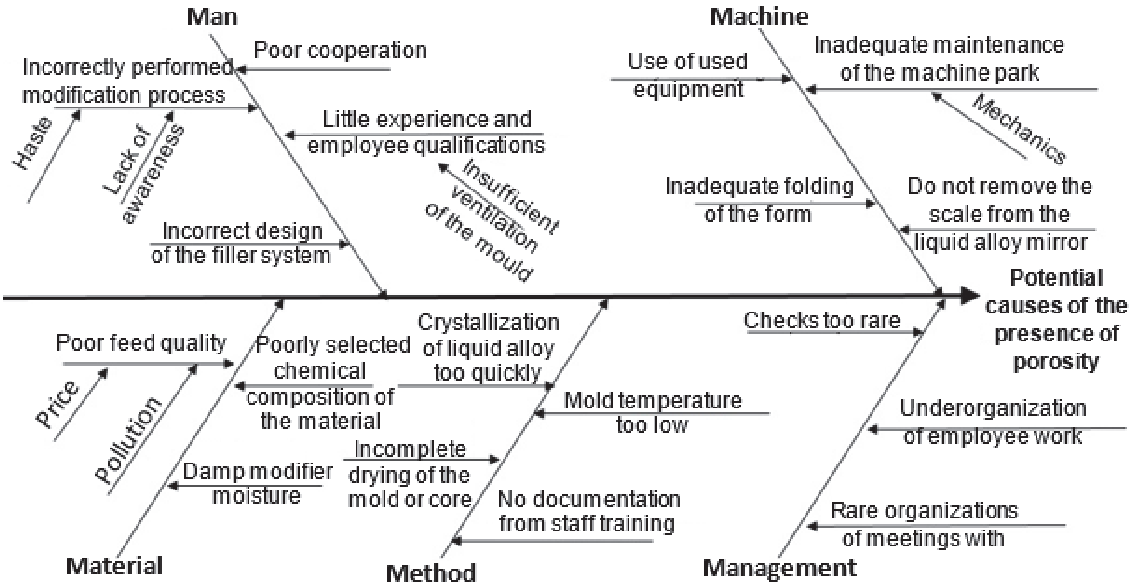

Figure 4 Ishikawa diagram for incompatibility - presence of porosity

In the next step of the research, an Ishikawa diagram was made to isolate the most likely causes of nonconformity and classify them into the following categories: man, machine, material, method, management (Fig. 4).

Based on the Ishikawa diagram of material nonconformities such as casting ripples located in critical areas of the workpiece, it can be seen that a significant number of potential causes of nonconformities were identified. As part of determining the importance, as well as the rank of individual causes, the ABCD-Suzuki method was used.

In the first step, a list of 15 causes of key non-conformity was created (Tab. 2). The expert team then ranked the importance of the listed causes on a scale of 1 - 10 (rating 1 - most important need, rating 10 - least important cause). The validity of the cause of a key product nonconformity was assessed in terms of the strength of the impact on the quality problem that occurred. Extreme responses (best and worst) were eliminated, bringing the number of unselected responses to 13. The adjusted sum of importance for each reason and the rank value were then calculated. The adjusted sum of meanings was calculated from the formula:

$$C = \sum_{i=1}^{k} \left(N_i \cdot R_1 \right) \tag{1}$$

where: C - adjusted sum of meanings, N - number of indications of a given cause, R - indication of the rank of a given cause.

The rank index was calculated from the formula:

$$R = \frac{C}{Nu} \tag{2}$$

where: R - the rank index, C - the adjusted sum of meanings, Nu - the number of uncompleted responses,

The next step is to rank the rank indicators from the smallest to the largest value. In this way, the ranked indicators were assigned consecutive ordinal numbers, starting with one and ending with 15. When repeated values of the ranking indicator occurred, successive integer values were assigned.

The sheet used in the method, along with the results of the analysis (the 10 most important causes of nonconformity), is presented in Tab. 2.

As a result of the analysis, it was noted that the three most important causes of material discontinuity (in order of importance) were: poor batch quality (impurities), incomplete drying of the mold, and too rapid crystallization of the liquid metal.

Table 2 Summary of the results of the ABCD-Suzuki method for the casting discontinuity problem

Symbol	Reason for non-compliance	Rank of criteria										Corrected sum of meaning	Number of responses not deleted	Rank indicattor	Rank
		1	2	3	4	5	6	7	8	9	10				
A	Poor quality of the charge (pollution)	5	5	1	1		1	0				28	13	$\frac{28}{13}=2.15$	1
B	Poorly chosen chemical composition of the charge	0	3	6	3	2	1					41		$\frac{41}{13}=3.15$	8
C	Moisture modifier	1	2	5	6	5						40		$\frac{40}{13}=3.08$	6
D	Liquid metal crystallization too fast	2	6	4	2	1						30		$\frac{30}{13}=2.31$	3
E	Incomplete drying out of form	4	4	3	3	2						29		$\frac{29}{13}=2.23$	2
F	Mould temperature too low	0	5	2	6	0						40		$\frac{40}{13}=3.08$	7
G	Do not remove the scale from the liquid alloy mirror	1	5	5	2		1	0				34		$\frac{34}{13}=2.62$	5
H	Inappropriate maintenance of the machinery	3	2	4	1		3	0				41		$\frac{41}{13}=3.15$	9
I	Incorrectly performed modification process	3	3	6	2	1						31		$\frac{31}{13}=2.28$	4
J	Inappropriate gating system design	0	4	4	4	2	1					41		$\frac{41}{13}=3.15$	10
K	No documentation from staff training	0	1	7	1	3	2		0			52		$\frac{52}{13}=4.00$	15
L	Use of used equipment	0	3	6	3		1			0		42		$\frac{42}{13}=3.23$	11
M	Inadequate folding of the casting form		3	6	2	1	1	0				43		$\frac{43}{13}=3.31$	13
N	Little experience and employee qualifications	0	2	5	4	2		0				45		$\frac{45}{13}=3.46$	14
O	Infrequent checks		3	6	2	1	1	0				43		$\frac{43}{13}=3.31$	12

4 CONCLUSION

Continuous monitoring of manufacturing processes together with quality control is the key to the success of manufacturing companies. The purpose of the study was to develop a model for analyzing the quality level and improvement of aluminum castings consisting of a combination of non-destructive testing (visual inspection, X-ray method) and occurring quality management tools (5W2H, Ishikawa diagram, ABCD-Suzuki method) possible for implication in inter-operational and receiving quality control. The implementation of the study was aimed at identifying non-conforming products, as well as verifying the usefulness of the presented inspection-diagnostic testing methodology in the production process.

Using non-destructive testing by the visual method, discontinuities were detected in the area of the base of the oil pan and the outer area of the upper edges of the product. Radiographic examination allowed the identification of discontinuities - ripples and porosity. The presence of these discontinuities disqualifies the product. As part of defining the problem of discontinuities in castings, Gemba walk and subsequent 5W2H analysis were performed. To identify the causes of material inconsistencies, an Ishikawa diagram was drawn up and ABCD - Suzuki was performed, according to which the key cause of inconsistencies was improper to charge quality (impurities).

The applied methods from the non-destructive testing group correlated with quality management methods are largely complementary. The proposed model can be a component of methods to support quality management processes and improvement activities.

The application of the cited improvement proposals can largely contribute to the development of the enterprise and avoid the occurrence of similar types of non-conformities.

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