MODEL OF EFFECTIVE QUALITY MANAGEMENT FOR THE IMPROVEMENT OF CASTING PROCESSES

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Abstract

The goal was to develop a model for effective quality management of cast products by integrally configuring quality management tools. Within the framework of the model, the output information from a given analysis step is the input for further research. Verification of the model made it possible to solve the quality problem - to identify the critical nonconformity (incorrect execution of the selection for valves in pistons) and its root causes (failure to provide adequate job documentation, inadequate management of the machine park, and human resources. Regarding the identified causes, it was proposed that corrective and improvement actions be implemented. These actions included the execution of documentation, implementation of a comprehensive approach to maintenance of the machinery park using the TPM method, and implementation of training for production employees. Practical verification of the model confirmed its effectiveness. Further research directions will concern the expansion of the model, which will allow multifaceted analyses to be carried out to ensure the quality stability of production processes of cast parts.

Keywords: mechanical engineering, quality engineering, foundry process, management and quality, quality management tools

1. INTRODUCTION

Manufacturing metal parts by casting is a relatively old process, but the principles of implementing this process are unchanged to date [1]. Thus, scientific research on improving and increasing casting efficiency is constantly developing [2]. Castings are used in every industry. Examples of castings can be found in engineering [5] and in metallurgy, construction, and household appliances [4]. Because of this, the casting industry has become diverse and often specialized in producing different types of casting parts. The process of casting production (while maintaining the quality of the final casting) is influenced by a significant number of factors (this includes the parameters of the casting system, the temperature of pouring the liquid alloy, the contact surface of the metal with the liquid alloy, the material of the model and its density, the skills of workers, the organization of work) [5]. A significant problem in ensuring an adequate and stable level of casting quality is the difficulty of controlling all factors at any given time [3, 6]. Developing a casting production process that eliminates nonconformities completely is virtually impossible. Regardless of the level of nonconforming products in a given process, runaway castings always generate additional costs [7]. Therefore, companies strive to reduce the number of nonconformities occurring in aluminum castings. It is necessary to effectively and appropriately manage changes, preserving in companies with the stability of the course of processes of a given organization. The development of a company depends largely on proper management, making difficult decisions, and the ability to solve problems that may arise at any stage of product manufacturing [8].

Foundry companies, to ensure a high and, at the same time, stable level of product quality, are constantly looking for comprehensive methods of detecting nonconformities to then effectively prevent them through effective identification of the root causes of defects and quality problems that have occurred [9]. Methods that allow the implementation of the indicated analyses are quality management methods [10]. These methods, skillfully applied, make it possible to increase the level of quality of manufactured products [11]. The literature on the subject indicates studies in the field of quality analysis, which are supported by individual quality management tools [7, 11] or models relating to optimizing the course of production processes [12]. Statistical methods [13, 14] and optimization and simulation models [15, 16] also optimize production systems in foundries. However, there is still a lack of models that will allow the realization of multi-level causal analyses of production nonconformities, making it possible to identify the root causes of quality problems. Hence, it was expedient to develop a model for effective quality management of cast products through integral configuration of quality management tools. It seems that the use of analyses related to fuzzy logic [17, 18] and associated fuzzy statistics [19] will be inevitable, as will data-driven machine learning [20].

2. METHOD OF RESEARCH

To analyze the quality level of piston castings, a study was performed using an effective quality management model based on integrally configured quality management tools. The next steps of the procedure are shown in Figure 1.

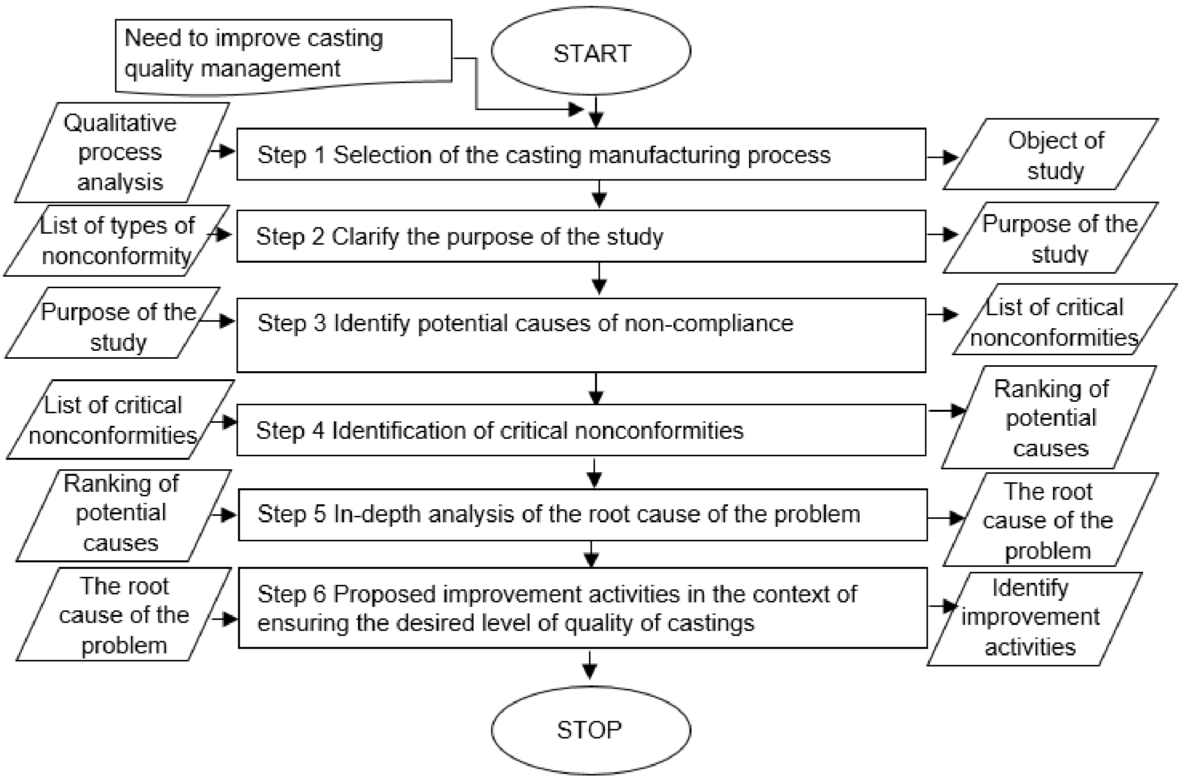

Figure 1 Concept of a model for effective quality management of cast products

Step 1. Selection of the production process of the cast product. According to the developed model, the selection of the subject of the study should concern the production process of the cast product, which should be diagnosed and improved in terms of identifying significant causes of loss of quality stability of the process. Implementing this step involves collecting the necessary information on the nonconformities in the product under study.

Step 2. Clarification of the research objective. The goal of the model's implication should be effective quality management within the selected casting production process. Identifying critical, in terms of quantity and severity, nonconformities of the analyzed casting should be considered as an additional objective.

Step 3. Identify potential causes of inconsistencies. Next, an unconventional way for the team to search for new ideas on methods of solving problems was used - a brainstorming session was conducted. The brainstorming session should be used by experts (selected employees of the company) to isolate potential causes of nonconformities.

Stage 4. Identification of critical nonconformities. The next stage consisted of identifying the most frequent nonconformity with an indication of its significance. Using a Pareto-Lorenz diagram as part of the analysis helped to itemize critical nonconformities regarding the number of occurrences and the severity of their impact.

Stage 5. In-depth analysis of the root cause of the problem. This stage allows you to perform a detailed analysis and identify the root cause of the problem. This step is carried out using the 5Why method, which involves asking questions to effectively identify the root cause of the problem and take countermeasures. This method involves asking at least five questions, allowing you to get to the root of the problem step by step, the so-called root cause of the problem.

Stage 6. Proposed improvement actions in the context of ensuring the desired quality of castings. The last stage of the study referred to the determination of temporary corrective actions and actions to prevent the occurrence of the problem in the future - improvement actions. The indicated solutions should eliminate the nonconformity under consideration or minimize the frequency of its occurrence. These actions are expected to contribute to stabilizing the quality of the production process.

3. METHOD VERIFICATION AND RESULTS

Today, the foundry industry faces many challenges related to sustainability and environmental protection. One of the biggest challenges is to reduce emissions of pollutants into the air and water, as well as to minimize the amount of waste produced. Efficient and responsible management of the quality of manufactured products is also a key issue. For this reason, improvement measures are being taken at foundry companies. The verification of the model was carried out in one of the foundries located in the southeastern part of Poland. The research was carried out in the third quarter of 2023.

Stage 1. In order to verify the developed model, the production process of aluminum pistons used in diesel engines of heavy-duty vehicles was selected. Data on the number of complaints and nonconformities occurring in the process prompted an in-depth analysis of the problem of loss of quality stability. Among the nonconformities, the most serious and most frequent was the nonconformity of the diameter, position, and depth of the valve pick-up in the pistons, and it was decided that the existing quality problem should be analyzed. Figure 2 illustrates a correctly made valve bump and a product with a discrepancy.

Figure 2 Comparison of correctly (left piston) and incorrectly (right piston) made valve selection in the piston

Valves located in the engine head control the supply of compressed air necessary for ignition, which sets the pistons in motion. The power of the engine mainly depends on the valves. There are intake valves (controlling the supply of air) and exhaust valves (discharge of exhaust gases). A slight inconsistency in the design of the valve bump is capable of jeopardizing the proper operation of a diesel engine.

Stage 2. The purpose of the activities undertaken with the developed model was to ensure effective quality management within the selected production process of castings by identifying critical nonconformities of castings, identifying the root cause of the occurrence of nonconformities, and developing adequate improvement activities within the production process of a specific type of pistons.

Step 3 During the brainstorming session, the team of experts determined the topic of the session: "Potential causes of nonconformity - improper selection for aluminum piston valves". The experts included the quality manager, chief technologist, foundry manager, and quality control specialist. The members of the working group analyzed the problem and presented potential reasons for the nonconformity. Among these, their task included: (1) poor positioning of the casting in the machine chuck, (2) worn workpiece stabilizing chuck, (3) poor mounting of the piston in the machine chuck, (4) worn workpiece stabilizing frame, (5) poor setting of machining parameters, (6) worn machining knives, (7) bad diameter of the piston bottom, (8) bad piston bottom, (9) bad oval of piston bottom, (10) low level of worker knowledge, (11) too infrequent inspections, (12) lack of job instructions, (13) crowded duties, (14) lack of supervision, (15) lack of motivation, (16) haste, (17) too infrequent training. The ideas submitted were subject to discussion. The evaluation resulted in solutions for further analysis.

Stage 4. The indicated stage of the analysis was concerned with specifying and clarifying the number of the most important potential causes of the analyzed nonconformity, which were identified in Stage 3. This was done using a Pareto-Lorenz diagram (Figure 3).

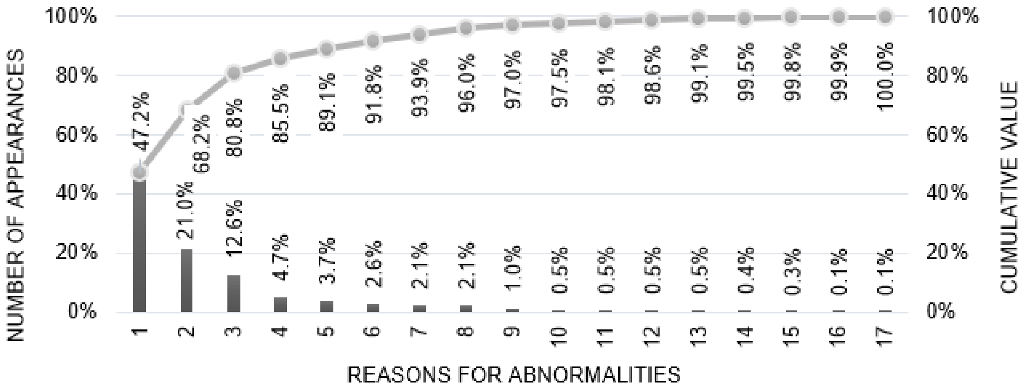

Figure 3 Pareto - Lorenz diagram indicating potential causes determining the formation of a piston defect

The result of the analysis indicates that three of all the listed potential causes cause 80.8% of the cases of defect (incorrect post-valve selection) in the aluminum piston. The causes are poor positioning of the casting in the machine chuck (47.2% of all causes), a worn workpiece stabilizing chuck (21.0% of all causes), and poor attachment of the piston in the machine chuck (12.6% of all causes). As part of the remedial measures, it was first decided to eliminate the most common cause - poor positioning of the workpiece in the machine chuck.

Step 5 A schematic representation of the use of the 5Why method to identify the root cause of poor positioning of the aluminum pestle casting in the machine chuck is shown in Figure 4.

An analysis of the causes of the quality problem (Figure 4) identified the root cause, which was the failure to provide adequate procedures and workstation instructions for the implementation of the process and inadequate management of the machinery park and human resources (not enough training directed at predictive workers). The workstation lacked a workstation manual, and its duties were performed by an employee who was not properly trained.

Step 6 With regard to documentation, it was recommended that job instructions for the workstations located within the analyzed process be developed and the production process updated. With regard to the inadequate condition of the machine, the working team recommended implementing, as a first step within the analyzed workstation and then in the production line area, a comprehensive machine maintenance approach - TPM (Total Productive Maintenance). In addition, it was recommended that a training schedule be created for employees involved in the production process of aluminum pistons and their implementation, culminating in a knowledge test.

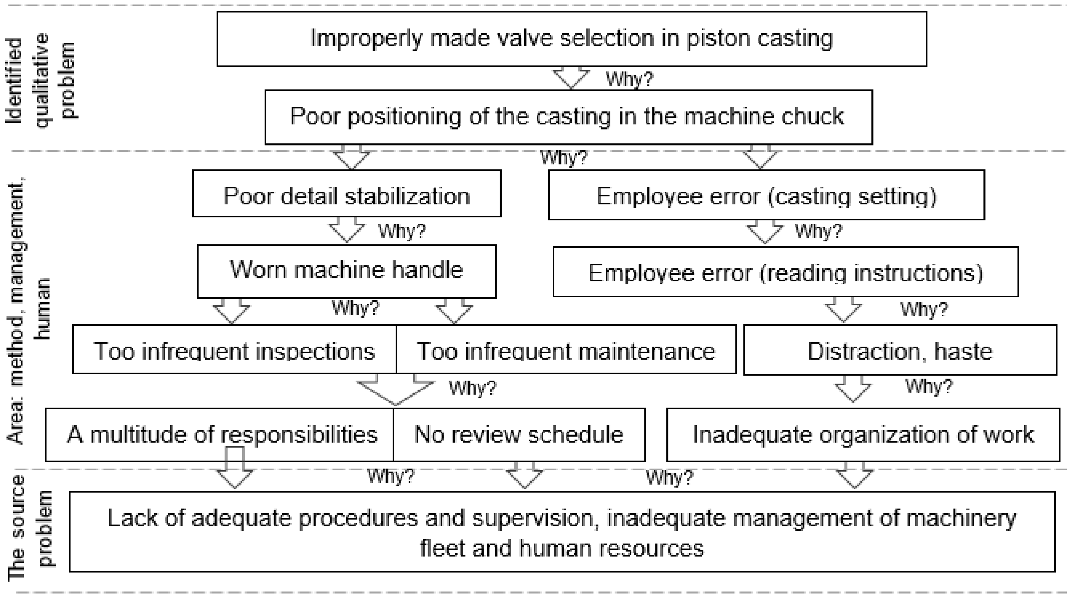

Figure 4 Graphical representation of the analysis using the 5Why method for the problem: incorrect execution of the valve selection in an aluminum piston casting

Verification of the developed model for effective quality management of cast products was confirmed through practical implications.

4. CONCLUSION

Given the automotive industry's requirements for cast products, which often determine the safe use of the final product, quality is a key aspect. Therefore, the overarching goal was to develop a model for effective quality management of cast products through the integral configuration of quality management tools. Within the framework of the model, the output information from a given analysis step is the input for further research.

Verification of the model made it possible to solve the quality problem - to identify the critical nonconformity (incorrect execution of the selection for valves in pistons) and, in relation to it, to determine the root causes of the loss of quality stability of the production process of aluminum pistons used in trucks. The following were identified as the root causes of the problem: failure to provide adequate documentation (production process procedure and job instructions) and inadequate management of the machinery fleet and human resources. As part of corrective and improvement measures, the expert team recommended the execution of documentation, implementation of a comprehensive approach to the maintenance of the machinery park using the TPM method, and implementation of training for production employees. Practical verification of the model confirmed its effectiveness.

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