Method for Analysing Quality Problems of Automotive Castings

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Abstract. The use of multifaceted quality analyses contributes to increasing the efficiency of production processes and quality control as part of maintaining competitiveness. The aim of this research was to develop an integrally configured method for the analysis of quality problems in automotive aluminium castings based on the methodological triangulation of NDT tests and quality management tools. The verification of the model was performed in one of the foundry companies against an engine block casting used in the automotive industry. The detection results obtained (VT and X-ray examination) allowed for the identification of a critical nonconformity - the presence of gas porosity, the description of the problem (5W2H method) and the identification of the root cause of the problem (5WHY method), which was the lack of up-to-date work instructions and a low level of employee competence. Corrective actions were proposed. The measures taken in the implementation of the quality problem analysis method were a new solution for the company – until now, in-depth analyses using a sequence of diagnostic methods and quality management technique tools had not been performed.

Introduction

When implementing a new technology or product, a manufacturing company should consider the quality level of the manufactured product, as it will have a significant impact on the organisation's market position and competitiveness. The quality strategy plays an important role here and should be taken into account when creating plans and objectives for the enterprise within the following areas: economy, organisation, finance or law [1,2]. Effective management of a manufacturing enterprise should be a well-thought-out and well-chosen group of activities enabling the organisation to overcome threats and unexpected events as well as obstacles and limitations, and to formulate original methods, solutions based on the desire to develop technologies that create and justify the necessary changes towards Industry 4.0 [3-5]. It should reinforce the company's focus on four correlative activities: quality, market, modernity and future.

The quality of a product starts already in the design phase. Even a correctly implemented technological process will not guarantee an exemplary level of quality if adequate quality is not ensured within the first phase of product creation. A significant number of non-conformities identified during the manufacturing process or operation of the product are initiated in the design phase [6,7]. However, design is not the only phase within the product quality life cycle. This cycle can be represented as a closed circle, which includes: the birth time of the product design, the stages of product development, the manufacturing and use of the product, and the decommissioning time [8,9].

Within the framework of improving the quality of the offered products, comprehensive methods of quality assurance by detecting inconsistencies and preventing their occurrence by detecting the sources of their origin and implementing corrective actions are constantly sought for. Methods enabling the implementation of the indicated activities are detection methods from the group of non-destructive methods [10] and quality management methods, which, skilfully applied, allow to increase the quality level of the offered products [11].

The aim of the research was to develop an integrally configured method for the analysis of quality problems of automotive aluminium castings based on the methodological triangulation of NDT tests and quality management tools. A clearly defined sequence of actions allows the problem to be specified, the cause of the drop in quality level to be identified and adequate improvement actions to be proposed.

The proposed method for addressing quality issues falls within the realm of organizational methods [12-14]. By enabling competence development, it modifies management frameworks [15,16] and influences changes in potential failure scenarios and their consequences [17-19]. Remedial actions are associated not only with purely organizational changes but also with interventions in material selection [20-22], the creation of special coatings [23-25], the methods employed for their application [26-28], and the execution of structural welds [29,30]. Improving the level of quality, which results in extended equipment lifespan and reduced failure occurrences, is also linked to a decrease in environmental pressure [31]. Furthermore, these changes may have implications in meeting the increased demand for military-grade production [32-34]. Given the complexity of production processes and the multidimensional interplay of significant process factors, the application of specialized analytical methods [35] and formal statistical techniques, such as Design of Experiments (DOE) methodology [36,37], including nonparametric variants [38,39], becomes essential.

Method for Analysing Qualitative Problems

In order to carry out a qualitative analysis of the castings, a study was carried out, in which the integration of detection methods and quality management tools was configured. Detection methods enable the identification of non-conformities and the determination of the basic characteristics of the non-conformity (type of non-conformity, and its size: depth, width and length of the non-conformity), while quality management tools will allow for the effective processing of the data on non-conformities and will make it possible to perform an analysis of potential causes of the occurrence of non-conformities. The execution of the indicated actions will enable the identification of the root cause of the decrease in the quality level of castings and the suggestion of adequate improvement actions. A diagram of the quality problem analysis method is shown in Fig.1.

The method for analysing quality problems is divided into three main areas (definition of research objectives, detection research and analysis of critical nonconformity) and into eight phases.

Phase 1. Selection of a test subject characterised by a decline in quality level

Due to the specific nature of the pro-quality analysis method developed (use of non-destructive methods - NDT), the selection of the test object should take into account the detection capabilities of the methods. The selection should concern a product characterised by a decrease in quality level and, at the same time, a product for which the detection of discontinuities of approximately (0.5% - 2.0%) of the object thickness represents a satisfactory result.

Phase 2: Selection of the expert team

The members of the expert team should have knowledge of the test object under analysis, the manufacturing process within which the product is manufactured and should have experience in the use of NDT methods used in the method to achieve the objective of the model realisation. The selection of the members of the expert team should be done according to the methods presented in the study, e.g. [40,41].

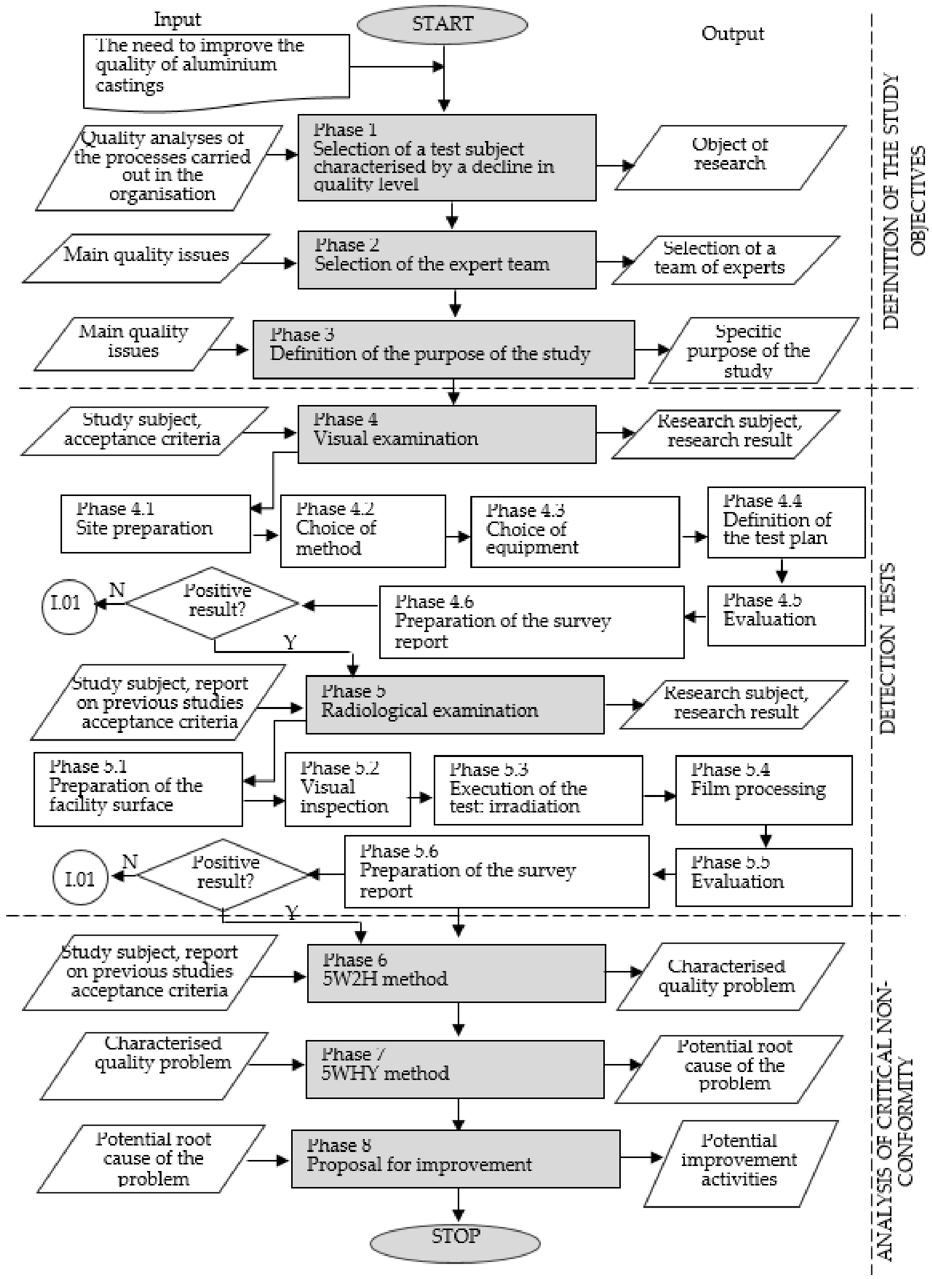

Fig.1. *Concept of a method for analysing qualitative problems*

Phase 3. Defining the research objective

The aim of the quality problem analysis method should be to identify the critical nonconformity and analyse its causes in order to identify its root causes and, ultimately, to propose appropriate corrective actions. In addition, the objective should take into account the customer's requirements for the subject of the study.

Phase 4: Visual examination

Visual examination of the test object is carried out as a preliminary visual inspection prior to X-ray examination. This examination includes preparation of the product surface and familiarisation with the specimen and specifications.

Depending on the accessibility of the surface to be inspected and the lighting conditions, the visual examination should be carried out using: endoscopes, videoscopes, periscopes and sets of mirrors, magnifying glasses and microscopes. The development of the test plan concerns the determination of the detection route. This survey allows the detection of any surface discontinuities, such as cracks. Discontinuities are classified and their number, type, severity and dimensions are determined. The results of the survey must be plotted on appropriate documentation [42,43].

Phase 5. Radiographic examination

Radiographic examination makes it possible to detect: spatial discontinuities, blisters, residual shrinkage cavities, planar discontinuities, shrinkage cracks, inclusions. With this test, it is also possible to detect and ocean changes in object thickness and coating thickness [44]. When preparing the surface for testing, residues of the gating system, moulding compound, reinforcement and cores must be removed. For the inspection of castings, the literature recommends that a visual inspection is carried out before the X-ray examination [45]. For this examination, a sending transducer is placed on one side, generating X-rays. The article being inspected absorbs radiation (gamma and X-rays), which is supplied from an external source. A detector (e.g. silver film) is placed on the other side of the device. The homogeneous beam of radiation passing through the device is partially absorbed, which depends on the variation of the internal structure and is noticeable in the final image. Radiographs show two-dimensional shadow images of three-dimensional discontinuities. The object's discrepancies take the form of darker areas, most often irregularly shaped located against a lighter object background. The evaluation and determination of dimensions is done by direct measurement on the radiographs. The test report should include key product information and identification of material discontinuities [46,47].

Phase 6. 5W2H method

The 5W2H method provides a detailed analysis of the problem. It is recognised that a correct and insightful description of the problem is a guarantee of reaching a correct conclusion, which is the basis for problem solving, so the 5W2H method is often used not only as a way of making a preliminary analysis, but also as a tool for characterising the identified problem. Answers to the seven questions should be gleaned from insightful interviews with employees [48,49].

Phase 7. The 5WHY method

The 5WHY method makes it possible to find the causes of the problem under analysis. The method addresses two aspects. The first relates to the causes of the problem and explaining why the problem arose, while the second aspect relates to the detectability of the problem and obtaining information on why the current quality control system did not detect the problem when it arose. The method is based on the assumption that each subsequent finding is determined by asking the question "why?" [50,51].

Phase 8. Suggesting improvement actions.

Once the main root causes of the quality problem have been identified, it is necessary to define adequate improvement actions, i.e. actions that, when properly implemented, will contribute to the elimination or significant reduction of the nonconformities that occur. These actions are determined by a team of experts.

The use of methodological triangulation in the model including sequential control (diagnostic-analytical) contributes to the validity of the collected data by including more sources and reducing measurement error.

Verification and Test of the Method

The test of the universal method for the analysis of the quality problem was carried out in a foundry company located in the south-eastern part of Poland. The test covered production data from 6 months of the year 2021.

Stage 1 – Defining the research assumptions (selection of the research subject, team of experts and definition of the research objective)

The method test was performed on an engine block casting that had lost quality stability. The loss of quality stability of the product was noticed after the implementation of design changes to the casting according to customer requirements. The product is used within engine and car technology. Fig.2a shows a model of the tested product. A team of experts was appointed, taking into account their experience, skills and knowledge of the manufacturing process and detection testing. The team consisted of: chief technologist, quality control manager, NDT specialist, claims specialist. The aim of applying the method to the engine block casting was to propose a course of action for the detection of the casting, characterise the quality problem, identify the root causes of the problem and finally indicate appropriate corrective actions.

Stage 2 – Detection tests (visual examination (VT), radiographic examination (X-ray))

Quality control of the engine block production process is performed on the basis of a control plan, which takes into account the relevant product parameters defined by standards and customer requirements. The tests carried out identified gas porosity as a critical nonconformity. In order to characterise the discontinuity areas, metallographic scrap and microscopic observations were made. An image of an example of a discontinuity is shown in Fig.2b. The detection results of the indicated methods within the control points were the input data of stage 3 of the method.

Stage 3 – Analysis of a critical nonconformity (method 5W2H, method 5WHY, proposal for improvement measures)

Based on the microstructure analysis of the non-conformity, gas porosities were identified in the engine block casting, which disqualified the product. In the next step, a group of experts, performed a gemba walk within the production process and then performed a 5W2H analysis to characterise the problem in detail (Table 1). After characterizing the quality problem in the subsequent step of the analysis, the 5WHY method was employed to identify the cause of the material discontinuity. Fig.4 displays the outcome of the analysis.

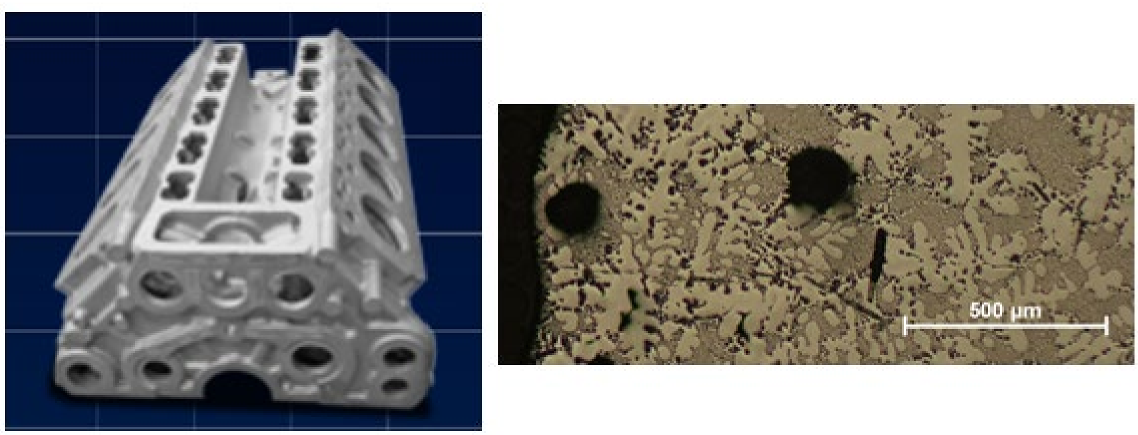

Fig.2. *Left: model engine block, Right: Engine block area where material discontinuity has been identified*

Table 1. *5W2H method for the engine block casting discontinuity problem*

Question		Answer
Who?	Who has detected the problem?	The employee who performed the X-ray inspection
What?	What is the problem?	Gaseous porosity clusters in the engine block casting
Why?	Why is this a problem?	Failure to meet standards and customer requirements - disqualification of the product
Where?	Where was the problem detected?	In the area of engine block base
When?	When was the problem detected?	During X-ray inspection and nicroscopic observation
How?	How was the problem detected?	Observation of radiographic films, observation of computerised registration (in real-time radiography systems), observation of metallographic scans
How much?	How big is the problem?	9% of products manufactured within 6 months 2021

Based on the analysis conducted (as shown in Fig. 3), it was concluded that the root cause of gas porosity in the engine block castings was attributed to inadequate employee qualifications resulting from a lack of instructional training provided in the workplace. The observed situation may have resulted from insufficient employee training following the design modifications made to the product, and the root cause was identified in the human/management aspect.

As improvement measures, it was proposed to carry out a series of training courses for employees within the scope of which the introduced changes to the product are significant, as well as to conduct constant supervision over the performance of their duties and to develop adequate position instructions. The diagnostic and analytical activities carried out indicate the effectiveness of the developed method for analysing quality problems of automotive castings. The method is characterised by efficiency, universality, a broad approach to quality problems and a relatively fast implementation time.

Summary

In modern times, companies must prioritize meeting the demands of customers who expect high-quality products delivered promptly at the most competitive prices. Hence, companies are looking for solutions to increase the level of quality of the products offered. The aim of this research was to develop an integrally configured method for analysing the quality problems of automotive aluminium castings based on the methodological triangulation of NDT tests and quality management tools. A clearly defined sequence of actions allows the problem to be specified, the cause of the drop in quality level to be identified and adequate improvement actions to be proposed.

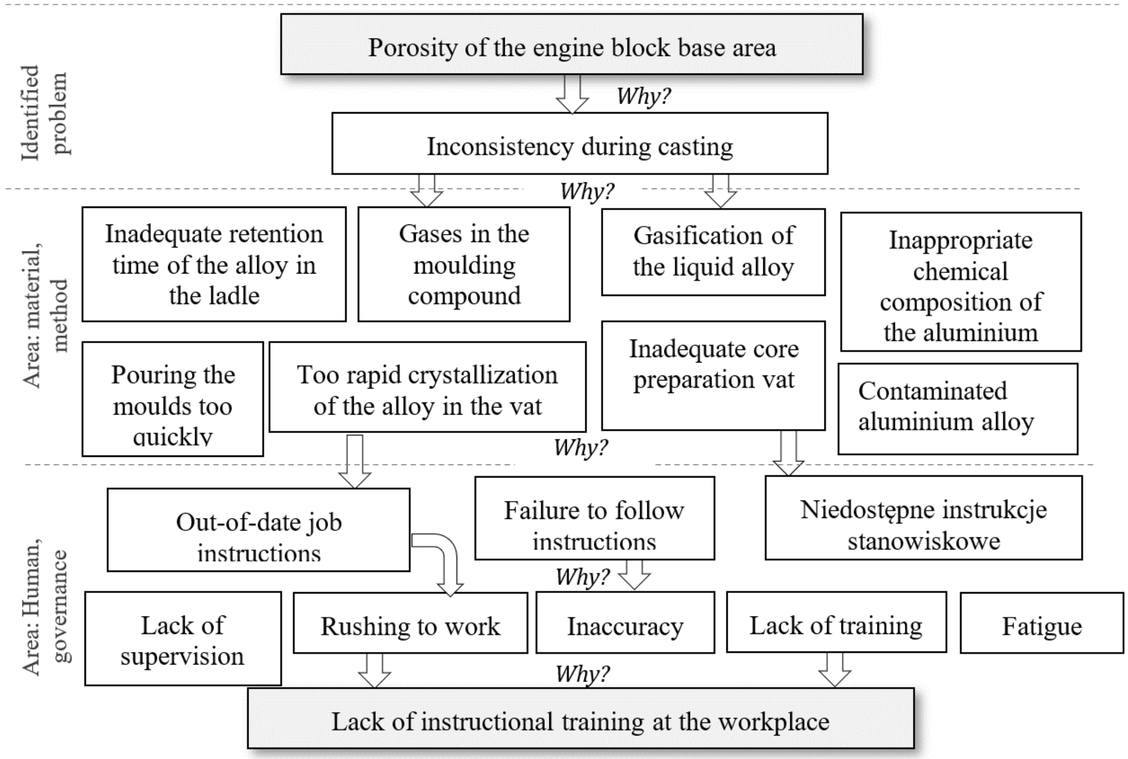

Fig.3 *5WHY method for the problem of the presence of clusters of porosity in the base area of an engine block.*

Visual and X-ray examinations detected the most serious type of non-conformity - the presence of gas porosity in the engine block casting. The presence of the indicated material discontinuity disqualifies the product. In order to recognise and characterise the problem, the expert team performed a 5W2H, while a 5WHY analysis was performed to identify the source of the problem. It was identified that the main cause of the casting quality deterioration was a worker's lack of relevant qualifications due to a lack of instructional training on the job. The implementation of training and the development of job instructions were proposed as corrective actions.

The application of the model does not require huge costs and its implication brings very accurate results. Further research directions will include the implication of the diagnostic-analytical method for the solution of possible quality problems within other casting processes in the company. This action is aimed at taking care of a high level of quality while optimising production costs.

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