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# ANALYSIS OF NON-COMPLIANCE OF INDUSTRIAL ROBOT ARM PARTS

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**Abstract:** Identifying inconsistencies and taking adequate actions to eliminate them is an effective way to improve the quality of products. Casting products are one of the items commonly manufactured in the foundry industry. Determining their quality becomes problematic due to a large number of factors affecting them during production which can generate various types of incompatibilities. The problem with a large number of incompatibilities of castings arose in a company in the southern part of Poland. The aim of the research was to diagnose the state of a batch of castings of industrial robot arm parts and to precisely determine the most important reasons for the occurrence of unworthiness, in relation to which appropriate preventive measures could significantly contribute to the reduction of the number of non-compliant castings and hence, waste. The analysis of incompatibilities occurring in the casting using the Pareto-Lorenz method and the ABC method allowed indication of the most important (in terms of frequency and severity) incompatibility of castings – gas porosity. Continuing the analysis of the problem by means of a brainstorming session and organizing ideas via the Ishikawa diagram made it possible to identify the key cause of the problem, which was the inadequately prepared (wet) core of the casting mold.

**Keywords:** quality, visual control, Pareto-Lorenza method, ABC method, Ishikawa diagram.

## 1. Introduction

Competition in the industrial economy make it necessary to ensure that items produced are of high quality. Therefore, enterprises undertake activity to make it is possible to identify potential unconformities in their products and also to prevent reoccurrence in the future (Chądzińska, Klimecka-Tatar, 2016; Antosz et al. 2013). Quality management must ensure that items produced meet the specifications of their clients (Siwiec, Czerwińska, 2018). In the case of the foundry industry, the castings must meet the appropriate standards. Such castings are often made with aluminum alloys (Łuszczak, Dańko, 2013; Poloczek, Kiełbus, 2016). These must be free of defects. Achieving this state of being, however, can be problematic in view of the large number of factors interacting on these products during production. In order to assess the quality of castings, non-destructive tests (NDT) can be applied. NDT makes it possible to identify potential unconformities without significant impact on structural and surface properties (Zentek, 2016). However, sometimes the number of unconformities of castings is so large, that it is difficult to identify the reasons for their emerging. To do so, it is useful to use the right quality management instruments. Pareto-Lorenz diagraming and the ABC method are employed to indicate the group of factors generating a given problem (Pacana et al. 2018). However, after specifying the most important factors leading to the nonconformity, it is necessary to make further analysis in order to precisely identify the causes of the problem. In this case, enabling tools such as Ishikawa diagraming are applied (Sęp et al., 2006).

A problem wherein a large number of unconformities of castings from aluminum were created arose in an enterprise in the southern part of Poland. During inter-operational visual control, a lot of castings of parts of the arm of industrial robots were considered as incompatible and separated from products intended for further processing. The extent of wastage needed to be addressed. Therefore, a decision was made to analyze and identify the cause of the situation. Hence, the standard tools and methods of quality management were applied.

## 2. Method

### 2.1. Non-destructive tests

Non-destructive tests (NDT) are a group of methods that makes possible identification of unconformities without affecting structural and surface properties. The main aim of applying non-destructive tests is to identify unconformities and faults within material (Zentek, 2016; Poloczek, Kiełbus, 2016). Several types of NDTs can be used. These include visual, penetrant, magnetic-powder or ultrasonic.

Visual testing (VT) or 'Naked eye testing' involves unconformity testing without additional tools or with the use of simple optical and measuring tools. This method is applied in the case of unconformities on the surface of the material, such as concaves, cracks, flooding and in the case of non-conformities regarding the shape of the product, e.g. porosity, voids or cavities. These tests are treated as preliminary research, where after visual control of product, further analysis takes place with other non-destructive tests (Zentek, 2016; Borowiecka-Wilczyńska, 2007).

Other non-destructive testing methods are applied for detecting nonconformities that cannot be seen. For example, penetrant tests are made with colored or fluorescent liquid penetrants that flow into metal nonconformities. The last requires UV radiation to render visible cracks or pitting (Pacana et al., 2019). In magnetic-powder tests, the influence of magnetic flux forces is used. This is applied to ferromagnetic materials. In turn, in ultrasonic testing, the identification of nonconformities is made possible by ultrasonic wave reflections (Zentek, 2016; Łuszczak, Dańko, 2014).

In this study, due to the fact that the aim of non-destructive testing is to diagnose in the inter-operational quality control of the casting condition, the quality of the casting of an industrial robot arm, a visual method was selected for the research, and was carried out on an discard, destructively, by first sawing and then applying microscope analysis. After identifying the nonconformities on the surface of part of the industrial robot arm (gas porosity), the next analysis was carried out by way of brainstorming, then applying the ABC method, Pareto-Lorenz diagramming and Ishikawa diagramming.

## 2.2. Pareto-Lorenz diagram and ABC method

The ABC method was first applied. The assumption behind the ABC method is that the percentage of both relevant and less significant factors in the total number of all factors is the same. In this method, three groups are specified, i.e. A, B and C. Accordingly, factors are selected wherein A factors are the most significant, B are factors that are significant and C are factors that are less significant (Miller, 2011; Słowiński, 2011). The way of assigning factors to these groups conditions the percentage share of the values characterizing the given factor. In the case of A group, the value of factors is 65%, for the B group, this is 20%, and for C group, this is 15%.

The Pareto-Lorenza chart, or the Pareto-Lorenza diagram, or the 80/20 method is used to identify the areas in which attention should be focused and which of the casting nonconformities are the most important, and which are least important (Cosin, 2000). In reference to the large of the number of nonconformities on the product, by applying the 80/20 dependence of what was categorized as 'A' in the ABC method, it was possible to show which of the 20% of the possible causes of nonconformities generate 80% of the problem (Blike, 2017). The proportion can be different, depending on the analysis, but the essence of this method is to show that a relatively small number of causes generate a large number of problems (Szczepańska, 2009).

Both the Pareto-Lorenza diagram and the ABC method allow the specification of the most important factors, and also the appropriate actions to undertake to remediate a problem. These methods have been applied to test and analyze nonconformities of product in foundry operations (Pacana et. al. 2018). The sequences of undertaken actions are:

- collecting and ranking types and number of nonconformities,
- calculating the percentage share of values in the overall number of nonconformities,
- calculating cumulative values of the share of the number of non-compliances,
- analyzing the data by applying the ABC method (Pacana et. al. 2018; Miller, 2011; Słowiński, 2011).

In the studied situation, after analyzing the number of nonconformities by way of applying ABC method and Pareto-Lorenz diagramming, the 20% category of identified nonconformities consisted of gas porosity, near-surface sand inclusions, contraction cavities. It was concluded that gas porosity is the most serious disagreement and this is the reason why further analysis was focused using the Ishikawa diagram.

### 2.3. Ishikawa diagram

A Ishikawa diagram is also called a 'cause-effect' diagram or 'fishbone' diagram and is applied to identify the potential causes of the problem. This diagram allows graphically the showing of dependencies between the possible influences upon the problem. Hence, Ishikawa diagramming:

- identifies the problem,
- shows categories adequate to the problem (for example 5M+E),
- enables analysis of the problem and identification of potential causes,
- allows a revelation of the main cause or main causes (Pacana, 2017).

The main categories of Ishikawa diagrams follow the 5M+E rule. These are man, machine, material, method, management and environment. The choice of categories for analysis depends on the subjective assessment of people who make the analysis using this tool, as well as on the identified problem (Łuszak, Matuszak-Flejszman, 2007). This diagram has been applied to a variety of problems, but particularly to quality problems. In the studied case it was used to identify the causes of nonconformities (gas porosity). In order to conduct an in-depth analysis of the problem, brainstorming was carried out in the team whose aim was to analyze the problem. The research team included the quality manager, foundry manager and a senior foundry worker. The problem was written into the main part of diagram, i.e. gas porosity. The categories that were selected (i.e. 5M+E) were: man, measure, method, material, environment and management. It was considered that the category 'machine' did not refer to the problem of gas porosity, so this category was not included. To each category, the potential causes were written, and among them, the main reason was chosen which was inappropriate preparation of the core.

## 3. Analysis

### 3.1. Characteristics of AlSi7Mg0,3 alloy

For casting of the produced item, AlSi7Mg0,3 alloy (EN AC 42100 according to PN-EN 1706:2011) was used. This was heat treated through immersion and then artificially aged (T6) according to standard and special technical conditions.

Casting alloy AlSi7Mg0,3 is used in the automotive industry (chassis components, truck and passenger car wheels) (Vicen, et. al. 2017; Panušková, 2006), for components in the aerospace industry, for hydraulic components, for parts in mechanical engineering, in shipbuilding, for fittings and apparatus, as well as in the food industry and for fire extinguisher components (https://aluminium-giesserei.com). The chemical composition of AlSi7Mg0,3 alloy is presented in Table 1.

**Table 1.**
*The chemical composition of AlSi7Mg0,3 alloy (%)*

| Fe | Si | Mn | Ti | Cu | Mg | Zn | Others | - |
|---|---|---|---|---|---|---|---|---|
| max 0,19 | 6,5–7,5 | Max 0,1 | Max 0,25 | Max 0,05 | 0,25–0,45 | Max 0,07 | each 0.03; total 0.1 | Al – remainder |

Source: Fracchia et. al. 2018.

Mechanical properties of AlSi7Mg0,3 alloy are presented in Table 2.

**Table 2.**
*Mechanical properties of AlSi7Mg0,3 alloy*

| Parameter | Value |
|---|---|
| Rm - Tensile strength (MPa) | 290 |
| Rp0.2 0.2% proof strength (MPa) | 210 |
| A - Min. elongation at fracture (%) | 4 |
| Brinell hardness (HBW) | 90 |

Source: http://www.steelnumber.com.

### 3.2. Purpose, scope and subject matter of the study

The aim of the research was to diagnose in between operations, the quality control of the state of castings of parts of the arm of an industrial robot and to precisely determine the reasons why appropriate preventive actions could significantly contribute to the reduction of the number of non-compliant castings.

The survey concerned a batch of products manufactured in the 4th quarter of 2018 in one in the southern part of Poland. The scope of the casting inspection included visual verification of the casting surface and verification of the correctness of the casting marking. The 3D model of the industrial robot arm assembly is shown in Figure 1.

Quality control was performed in accordance with the internal procedure of the company according to each production order.

**Figure 1.** Subject of the study – 3D model of a part of an industrial robot arm.

## 4. Identification of the causes of negative control results

Currently, each casting of a part of an industrial robot arm is subject to a visual quality control carried out after the completion of each production operation. An analysis of the reasons for discards has been undertaken to reduce the number of negative verifications. In order to identify the causes of non-compliance in castings, it was decided to use a combination of traditional quality management tools, i.e. Pareto-Lorenza analysis and Ishikawa diagram. In the first step, the structure of the causes of negative control results was analyzed using the ABC method. Table 3 shows a list of all non-compliances recorded in the castings, together with the number of occurrences with regard to the group (A, B, C) to which they were qualified.

**Table 3.**
*ABC analysis of the causes of negative control results of castings of parts of the arm of an industrial robot*

| | Reason for negative control results | Value | | Group of quantities | Group of values |
|---|---|---|---|---|---|
| | | Per cent [%] | Accumulated per cent [%] | | |
| 1. | Gas porosity | 33,99% | 33,99% | A | A |
| 2. | Surface inclusions of sand | 25,50% | 59,49% | A | A |
| 3. | Intercrystalline shrinkage | 10,20% | 69,69% | A | A |
| 4. | Segregation of eutectic | 7,08% | 76,77% | B | A |
| 5. | Internal stress cracking | 6,52% | 83,29% | B | B |
| 6. | Sprue | 4,25% | 87,54% | B | B |
| 7. | Shrinkage porosity | 3,40% | 90,93% | B | B |
| 8. | Misrun | 3,12% | 94,05% | B | B |
| 9. | Exfoliation | 2,55% | 96,60% | C | C |
| 10. | Cold casting cracking | 2,27% | 98,87% | C | C |
| 11. | Incorporation of foreign material | 1,13% | 100,00% | C | C |

The Pareto-Lorenza graph of the ABC analysis of the causes of castings rejection is presented in Figure 2. Assuming that the causes that constitute up to 20% of the causes that should be assigned to category A, the following were included in this category: gas porosity, near-surface sand inclusions, contraction cavity. In accordance with the assumption that this category should include reasons that generate up to 80% of all rejected products, the collection should be extended to include the reason for the segregation of eutectic. Considering the structure of the number of causes of discards, gas porosity is the most serious inconsistency and it is on this cause that further analysis has been focused.

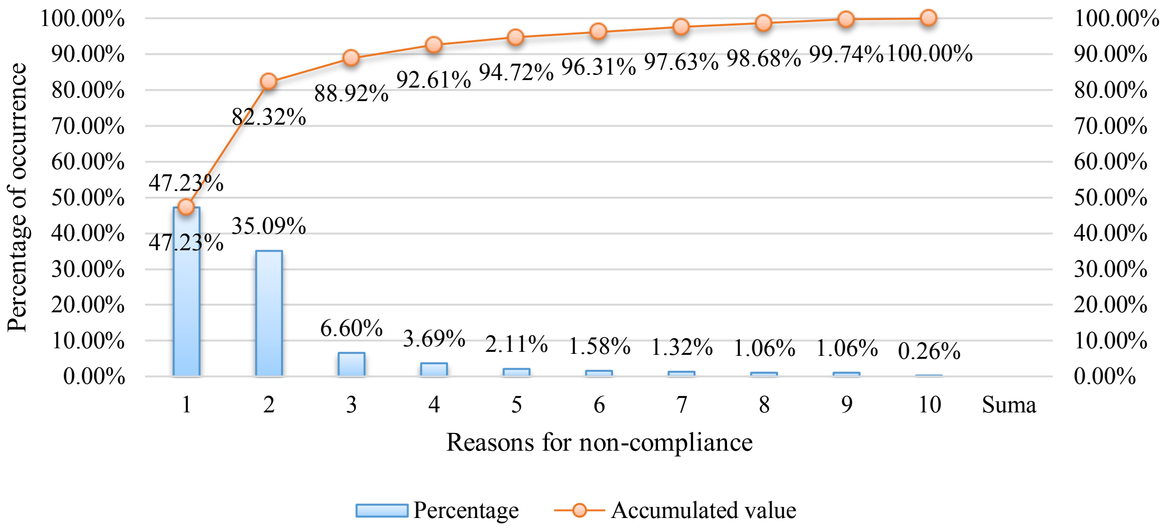


**Figure 2.** Pareto-Lorenzo Diagram showing the reasons for rejecting castings of industrial robot arm parts

Castings with identified gas porosities were analyzed. An example of a casting with an incompatibility found (gas porosity) is shown in Figure 3.

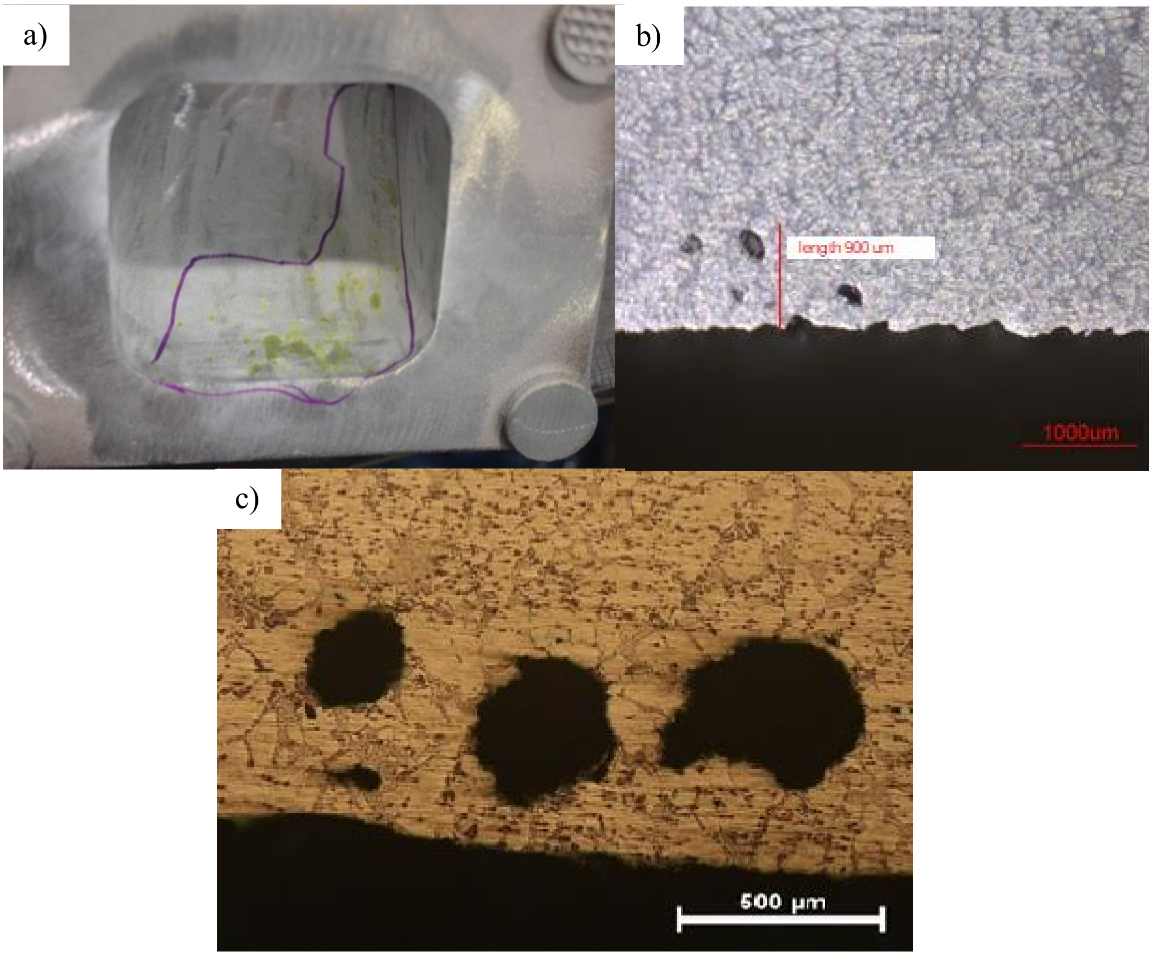


**Figure 3.** Example of non-compliance a) identified during visual inspection, b) identified after cutting the casting in the area of non-compliance, c) identified during microscopic observation.

For the most significant non-conformity (gas porosity), dredged surveys were carried out. During the brainstorming session supporting the Ishikawa diagram, detailed causes of non-compliance were searched for. The identified cause has been qualified to the area of "method";. The main reason for the occurrence of gas porosity in castings were wet cores. The result of an in-depth analysis of the reasons for non-compliance is shown in the Ishikawa diagram (Figure 4).

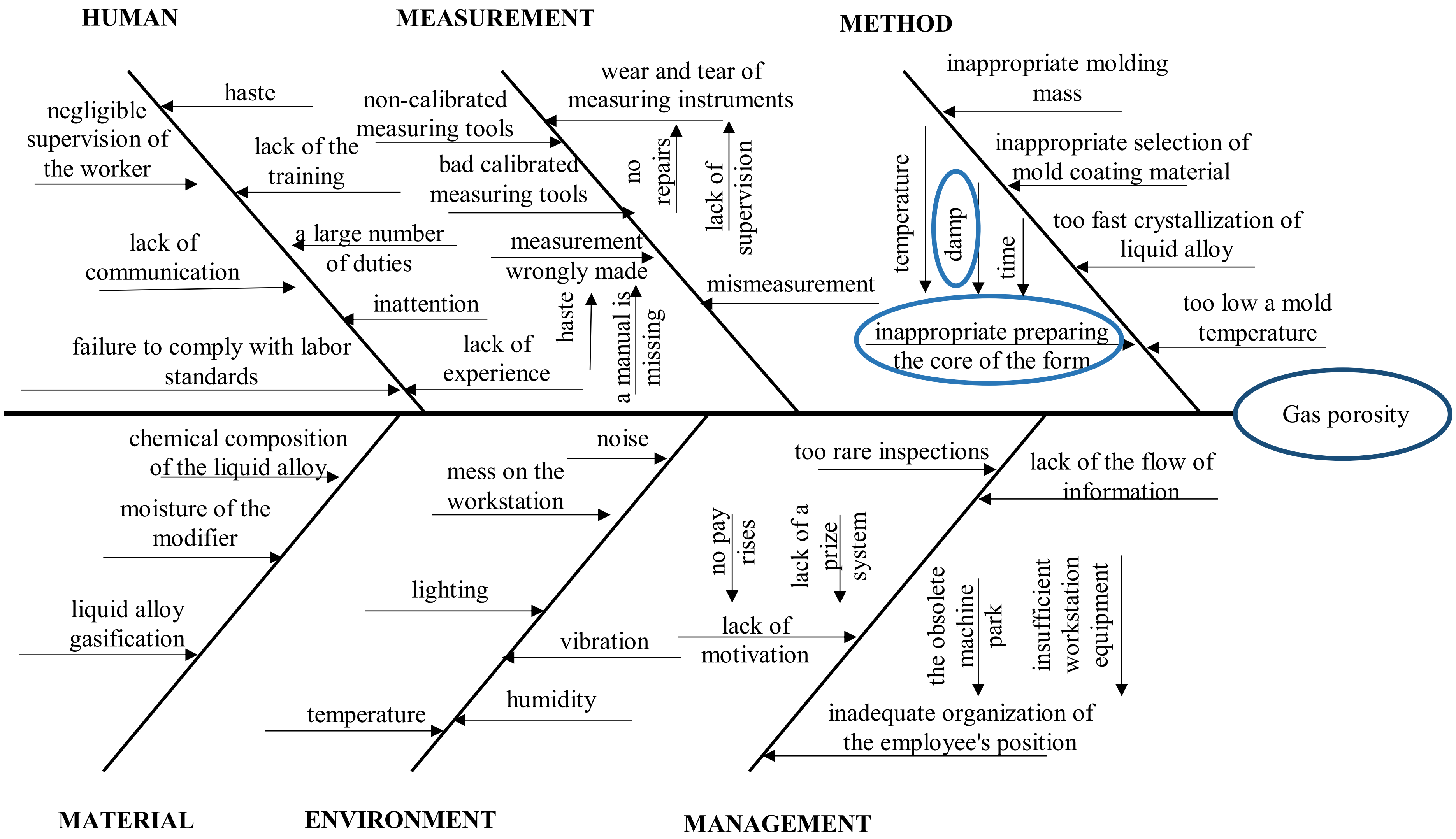


**Figure 4.** Ishikawa diagram for the problem of gas porosity in a casting of an industrial robot arm.

## Conclusion

The Pareto-Lorenza Diagram, together with the ABC analysis, is a traditional, broadly applicable quality management tool that includes both analysis and improvement of products and processes. The basic aim of the Pareto-Lorenzo analysis is to identify the key factors causing a certain effect – within the framework of the analysis carried out in the study, the most important cause responsible for the occurrence of the identified quality problem – the presence of gas porosity in the casting of a part of the arm of an industrial robot. The results of the analysis were subjected to in-depth analysis using a brainstorming session during which the potential, detailed causes of the non-compliance were collected. In order to systematize the ideas, they were grouped together and placed in a diagram of Ishikawa. The identified cause has been qualified to the area of "method";. The main reason for the occurrence of gas porosity in castings were wet cores.

The presented sequence of conducting research on the existing quality problem using traditional methods of quality management is a universal and effective way of analyzing production problems, which can be practiced in companies from various industries.

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