Improving the Quality of Products from Cast Alloy with the use of Grey Relational Analysis (GRA)

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Abstract. As part of the quality of products, corrective actions are necessary. In this context, organizations should use different methods to skillfully analyze product incompatibilities and their causes. The aim of a study is to propose the method for determining the degree of impact of causes on the occurrence of incompatibilities. This method is a new combination of Grey Relational Analysis (GRA) with known methods: brainstorm, causes and effects diagram, and important technique. The method was tested for an example of a cast alloy product.

Introduction

In the context of effective improvement of the quality of products, determining the sequence of corrective actions is legitimate, e.g. by using the incompatibilities catalog or Rule 20/80 (Pareto-Lorenz) [1-4]. However, it still happens that organizations do not note the number of incompatibilities and causes of its occurrence. Therefore, it is problematic to indicate the main incompatibility of mentioned techniques. For this purpose, other techniques are used.

The literature review of the subject has shown that these techniques are, e.g. the Ishikawa diagram [2, 4, 5] and brainstorm [3, 6]. In these techniques, the mentioned main incompatibility mentioned was not mostly specified, but only the causes of incompatibility were specified [2, 6]. Despite that, it is necessary to use other techniques, mainly effective to solve the problems in the so-called fuzzy (uncertain) environment [7, 8]. One of these not complicated methods is, e.g. grey relational analysis (GRA) [9,10], which has not been used yet in combination with the mentioned techniques. For this reason, the proposal of a new combination of quality management techniques with the GRA method was adequate [11-15].

It was assumed that if it is impossible to clearly indicate the main incompatibility of the product (e.g., based on the number of incompatibilities), it is possible to indicate it based on the degree of impact of the causes of the incompatibility. It is possible by the integration of the techniques, i.e., GRA method, brainstorm, cause and effect diagram, and importance technique.

Problem of Research

In a production company located in south-eastern Poland, the problem of quality alloy products was identified. The problem was four types of incompatibilities that were often repeated, i.e.: porosity, nonmetallic inclusions, cracks, and brick. The incompatibilities were identified by NDT, i.e. the fluorescent method (FPI) and the magnetic-powder method (MT). The mentioned incompatibilities with different types of products were identified, e.g., mechanical seal or bearing housing. However, in the company, the catalog of the number of incompatibilities was not made. Therefore, the problem was to unambiguous determine, which incompatibility is the most common. It made it difficult to accession effective corrective actions for incompatibility which generates the most source of waste. Despite it, methods that allow for a precise determine the causes of these incompatibilities were not used. It was claimed that the causes of these incompatibilities are, e.g. pollution and defective materials from the supplier. However, the main incompatibility was not yet clearly determined yet. To this aim, the integrated technique supported by grey relational analysis (GRA) was proposed.

Method

The integrated method is Grey Relational Analysis (GRA), which was combined with: a brainstorm, cause and effect diagram, and importance technique on the Likert scale. The choice of these methods was conditioned by their application to solving decision problems [5, 6, 9]. In turn, the choice of the GRA method was conditioned by its applications for a small number of criteria (that is, even 4 data) [9, 10, 12, 14]. The integrated method algorithm is shown in Figure 1.

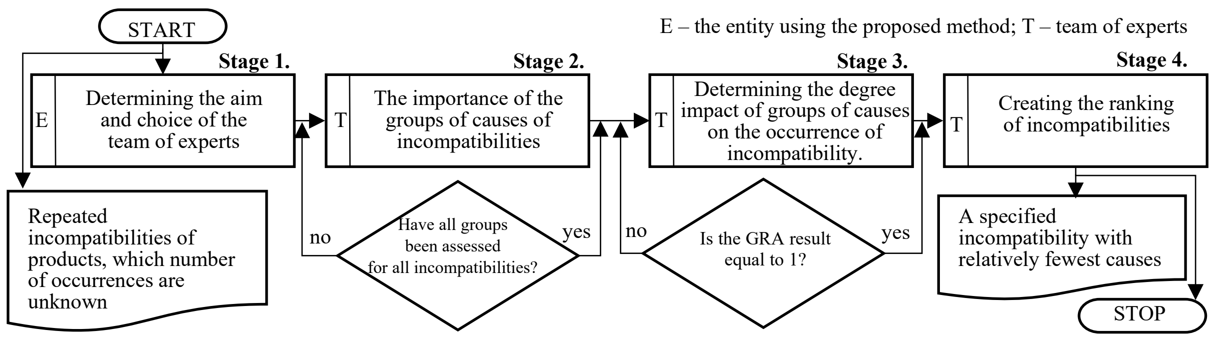

Fig. 1. *The algorithm of an integrated method of improving the product quality supports by GRA. Own study.*

Stage 1. Determining the purpose and choice of the team of experts. The aim of the proposed method should apply to the need to identify the incompatibility on which the relatively fewest causes are influenced. The number of selected incompatibilities to analyze is at least 4 [9, 10]. The SMART method can be used to define the aim [15]. Members of the selected team of experts should have experience and knowledge in the area of product incompatibilities of products [16, 17].

Stage 2. The importance of groups of causes of incompatibility. This stage is realized by the team of experts using in a combined way: brainstorming (BM), cause and effects diagram, and importance technique. Initially, the team of experts reports the causes of incompatibility using the first of two stages of BM, as, e.g. [6]. It is recommended that the same team conducts the BM separately for each type of incompatibility. Then, the team of experts groups the causes of individual incompatibilities into groups of thematic (categories). In this aim, the members of a team determine any number and type of group, that is, 5M + E, man, machines, method, material, environment, and management [2]. Then, the team notes for each cause the name of its category. Next, the team of experts makes the cause and effect diagram according to the method shown, e.g. in [2, 4, 5]. This diagram should be made separately for each incompatibility and shown in a place visible to the team. Then, the team of experts validated the thematic (category) groups, in which the causes of incompatibility were noted. It consists of assessments in the Likert scale the causes of incompatibilities in the causes group [18]. By voting, the team assesses the importance (from 1 to 5) of the group of causes in a given category for the emergence of this type of incompatibility. Assessment 1 - It is the smallest influence (weight) of the group of causes on occurrence of the incompatibility, in turn, the assessment 5 - It is the greatest impact (weight) of the group of causes on occurrence of the incompatibility. Assessments should be noted, for example, in causes and effect diagrams [19-22]. At this stage, the grouped and visualized groups of causes and the weights of groups, which determine the impact the causes of occurrence the incompatibility, are achieved.

Stage 3. Determining the degree of impact of groups of causes on the occurrence of incompatibility. This stage is performed by the team of experts as part of using the Grey Relational Analysis (GRA) [9, 10, 12, 14]. Initially, the matrix M is created, i.e., M $= m \times n$, where m – alternative (that is, incompatibility), n is the criterion (i.e. group of causes). This matrix should be supplemented with the weights from stage 2. Subsequently, the ratings (weights) of the cause groups should be transformed (normalized) so that the rating values are between 0 and 1. It is accepted that $x_0^{(O)}(k)$ and $x_i^{(O)}(k)$ are, respectively sequence original and comparison; $i = 1, 2, \ldots, m;\ k = 1, 2, \ldots, n$; and m – alternative (i.e., incompatibility), n – criterion (i.e., group of causes) [9]. For causes of „lower assessment is better" the formula (1) is used [9, 12]:

$$x_i^*(k) = \frac{\max x_i^{(O)}(k) - x_i^{(O)}(k)}{\max x_i^{(O)}(k) - \min x_i^{(O)}(k)} \tag{1}$$

In this context, it is accepted that the better is when fewer causes have influence on incompatibility. Then, based on normalized sequences, the grey relational coefficient is calculated (2) [9, 10, 14]:

$$\gamma[x_0^*(k), x_i^*(k)] = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}} \qquad 0 < \gamma[x_0^*(k), x_i^*(k)] \leq 1 \tag{2}$$

where: $\Delta_{0i}(k)$ the sequence of deviations between the original sequence $x_0^*(k)$ and comparison sequence $x_i^*(k)$, which is calculated from formula (3) [9]:

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)| \tag{3}$$

Similarly, the largest (4) and smallest (5) deviations are calculated [9]:

$$\Delta_{max} = \max_{\forall j \in i} \max_{\forall k} \left| x_0^*(k) - x_j^*(k) \right| \tag{4}$$

$$\Delta_{min} = \min_{\forall j \in i} \min_{\forall k} \left| x_0^*(k) - x_j^*(k) \right| \tag{5}$$

In turn, the coefficient $\boldsymbol{\xi}$ in formula (2) has value [0, 1]. Most often, it is assumed that $\boldsymbol{\xi}$ = 0.5 [9, 10]. The relational grey score is the weighted sum of the Grey coefficients as shown in formula (6) [9, 14]:

$$\gamma(x_0^*, x_i^*) = \sum_{k=i}^{n} \beta_k \gamma[x_0^*(k), x_i^*(k)] \tag{6}$$

where $\gamma(x_0^*, x_i^*)$, i.e. gray relational score, which is the level of correlation between the sequence of originally and the comparison, as if it were identical. The grey relational score should be equal to 1, that is, (7) [9]:

$$\sum_{k=1}^{n} \beta_k = 1 \tag{7}$$

Consequently, based on the results from GRA, it is possible to determine the degree of impact of groups of causes of occurrence and the incompatibilities.

Step 4. Creating the ranking of incompatibilities. It consists of ordering the values obtained from the GRA from minimum to maximum. The minimum value (first position in the ranking) is incompatibility, which according to the team of experts is characterized by the lowest degree of impact of the group of causes on its occurrence. It is proposed that first corrective actions were taken for this incompatibility. Then, the corrective actions would be a concern for fewer causes. After the implementation of the corrective actions for this incompatibility, it is possible to make corrective actions for the incompatibility on the next position in the ranking.

Results

The aim was to identify the incompatibility of the product from which corrective actions are necessary. So, the incompatibility was affected by a relatively small number of causes. The four types of incompatibilities of alloy products were analyzed: porosity on the mechanical seal of the 410 alloy, non-metallic inclusions on the mechanical seal of the CPW 407 alloy, cracks in the outer casing from CPW-S 5616 alloy, and prick on the lever made of the CPW-S 5613 alloy.

An example after BM performed, grouped according to 5M + E, causes and their assessment on the Likert scale is shown in Fig. 2.

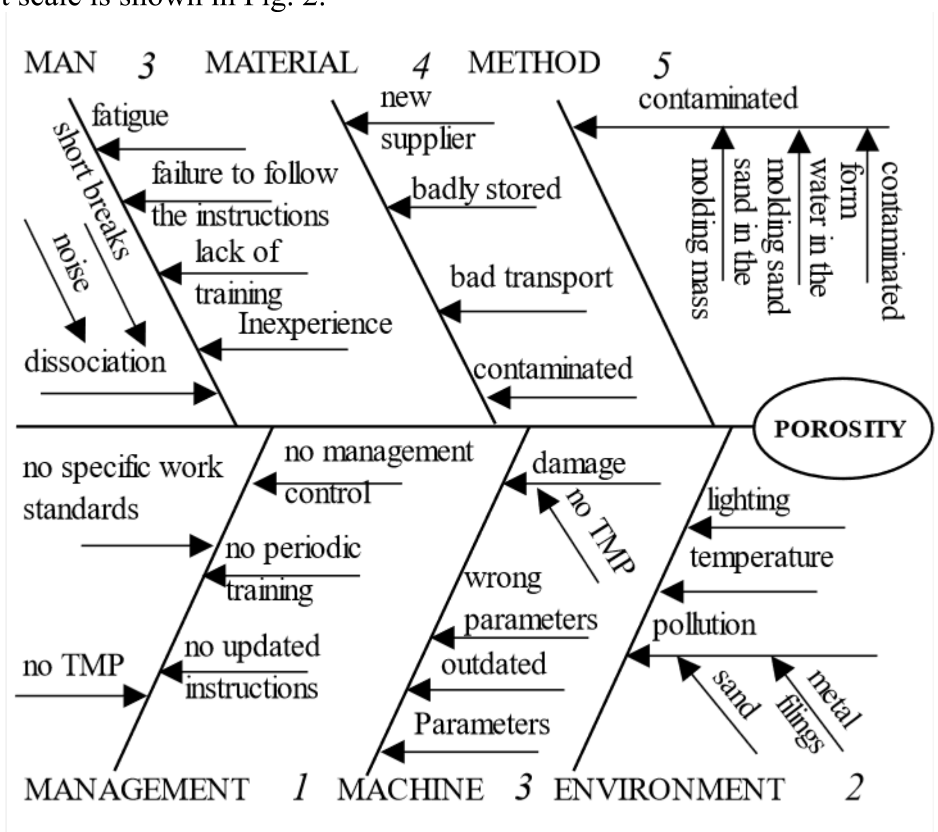

Fig. 2. *Example of a cause and effects diagram for the problem of porosity in the mechanical seal (own study).*

The matrix M with evaluations (weights) of groups of causes (M1-E) for selected incompatibilities (I1-I4) is shown in Table 1. The results obtained from the GRA method are shown in Table 2.

Table 1. *Assessment of groups of causes of the incompatibilities analyzed (own study).*

M	M1	M2	M3	M4	M5	E
I1	3	4	5	1	3	2
I2	2	5	5	2	3	1
I3	1	3	2	2	5	3
I4	5	2	4	1	2	1

Table 2. *The results of the GRA method (own study).*

G	M1	M2	M3	M4	M5	E	Rank	
I1	0,5	0,4	0,3	1,0	0,6	0,5	0,6	2
I2	0,7	0,3	0,3	0,3	0,6	1,0	0,5	3
I3	1,0	0,6	1,0	0,3	0,3	0,3	0,6	2
I4	0,3	1,0	0,4	1,0	1,0	1,0	0,8	1

It was shown that due to the I4 incompatibility (prick) it is necessary to make corrective actions are necessary.

Conclusion

The aim was to propose an integrated method to determine the degree of impact of causes of occurrence of incompatibilities. The incompatibilities analyzed in the company were: porosity on the mechanical seal of 410 alloy, non-metallic inclusions on the mechanical seal of CPW 407 alloy, cracks on the outer casing from CPW-S 5616 alloy, and prick on the lever made of CPW-S 5613 alloy. After using the proposed method, it was shown that the incompatibility of a prick on the lever of the CPW-S 5613 alloy was affected by the fewest causes. Therefore, corrective actions were proposed for this incompatibility were proposed. The analysis conducted confirmed that with the proposed method, it is possible to relatively precisely indicate the main incompatibility according to a certain degree of influence of the causes on their occurrence. Therefore, this method is an effective instrument to solve problems in an uncertain environment and to determine the main incompatibility of products.

The analysis presented in this paper may be useful in many areas of research (special alloys [23], implants [24], tribological tests [25], welding [26] and biotechnology [29]) and industrial production (special coatings [30, 31], laser surface treatment [32, 33], machine regeneration [34], power hydraulics [35], steel industry [36]), where failures and improper actions may appear, and should be repaired by corrective activities. Regardless, it is a development impulse both for the methods of experimental data analysis [37-39] and for the analysis of possible failure scenarios [40, 41].

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