Development of a Hybrid Method for Identifying the Causes of Product Incompatibility in Metallurgical Manufacturing

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Abstract. For the analysis of the quality of metallurgical products, it is important to use techniques that identify the internal and external unconformity of the product without destroying it. These techniques are non-destructive testing (NDT). Although these techniques identify the unconformity of the product, they do not indicate the source of their creation. The purpose of the study was to develop a hybrid method to make decisions about the causes of product incompatibility. This hybrid method was created as a combination of NDT and quality management techniques, i.e.: 5W2H method, Ishikawa diagram, 5Why method. The subject of the study was an unconformity detected in the tube made of the magnesium alloy AMS 4439. Research was carried out using the FPI method. In the analyzed case, its application allowed the detection of a linear indication in the product. To identify the root of the linear indication, the 5W2H method, the Ishikawa diagram, and the 5Why method were used sequentially. The main causes were bad casting and pollution. The root cause was defective supplier material. Integration of the FPI method, the 5W2H method, the Ishikawa diagram, and the 5Why method in the performance of a comprehensive qualitative analyze of products, after which it is possible to identify the unconformity and the root of its occurrence. The integration of FPI and quality management techniques can be practiced to analyze the quality of products (including metallurgical products) in manufacturing and service enterprises.

Introduction

Quality control of the product is a necessary stage of creation of the product. For the production industry, and aviation industry extremely useful are the non-destructive test (NDT), because it allows pointing out the non-conformity without damaging the product [1]. For non-destructive methods, the fluorescent method (i.e., penetrant method) is counted, which was used to quality test a selected subject of the study (tube). Fluorescent penetrant inspection (FPI) is the most commonly used method for the analysis of aviation components that has been applied, for example, in production and also in service inspection [2]. A review of selected elements of the literature indicates that the fluorescent method was used for example in quality analysis of product surface [3-5], detection and further processing of the unconformity by other methods to identify unconformity [1,4,6]. The FPI was improved or its effectiveness was assessed by, among others: the use of other substances or devices for penetration [7,8], the FPI performance rating [9]. A review of the literature shows that an important step for the qualitative analysis of products way shown that an effective is to integrate quality management techniques with the FPI method to identify the root of unconformity [10]. It is essential for enterprises, in which it is necessary not only to identify the unconformity but first of all point out the source of their occurrence.

The proposed hybrid method for identifying the causes of product nonconformities falls into the group of methods aimed at improving quality through organizational and technological changes [11-13]. In the organizational domain, these methods involve modifying management schemes [14-15] and pre-prepared scenarios of potential failures and their consequences [16-18]. In the technological domain, this influences the selection of materials with better technological properties [19], modification of already used materials through the production of special coatings [20-22], application of techniques such as electrospark deposition [23-25], or modification of the morphological characteristics of the surface layer [26]. This brings numerous benefits, including increased reliability of produced machine parts [27-29] and the expansion of the customer base to include demanding military recipients [30,31]. The implementation of such multidimensional technological changes inevitably involves the use of special computational [32,33] and statistical techniques [34-36], including non-parametric methods [37-39] and dimensionality reduction [40].

Method and Material

An attempt was made to solve the problem with linear indications on the AMS 4439 magnesium alloy cast tube in a selected production and service company located in south-eastern Poland, by extension of the fluorescent method about the quality management techniques. In the selected company, product analysis was carried out using NDT methods (i.e., magnetic powder and fluorescence methods). So far, after the unconformity because of their episodic character, no additional analyzes were not made, due to which it could be possible to identify the source of the unconformity. The fact that analysis of unconformity with use of quality management techniques could be made, for example, due to types of product and types of unconformity has been omitted. In turn, the types of unconformity were often repeated (for example, linear indication). Therefore, it was an order to implement the quality management techniques after the product analysis process by using NDT for types of identified unconformity. The analysis was carried out to show that it is effective to use NDT methods (based on the example of the FPI method) together with quality techniques to analyze product quality and identify the source of possible non-conformity. The purpose of the study was to develop a hybrid method to make decisions about the causes of product incompatibility. This hybrid method was created as a combination of NDT and quality management techniques, i.e.: 5W2H method, Ishikawa diagram, 5Why method. The subject of research was the so-called tube, applicable in the aviation industry. The choice of this product for analysis was determined by the type of unconformity identified on it (linear indication). The product was made of magnesium alloy AMS 4439 (SAE AMS 4439: 2012). AMS 4439 is a magnesium alloy, sand-cast 4.2 Zn - 1.2 rare earths - 0, 7 Zr. This material is used, among others, for products requiring uniform, medium strength up to 160 ° C, pressure tightness, good fatigue, and creep characteristics. Moreover, applicable to products that require welding during production.

The method was developed as a hybrid method to make decisions about the causes of product incompatibility. This hybrid method was created as a combination of NDT and quality management techniques, i.e.: 5W2H method, Ishikawa diagram, 5Why method. An analysis of the product quality used integrated one of method NDT, i.e. fluorescent method (FPI - fluorescent penetrant inspection) with these selected quality management techniques. The choice of the NDT method was conditioned by the type of material (magnesium alloy) from which the tube was made and also by the requirements of the customer ordering product quality control. The fluorescent method has applied to identify discontinuities on the surface free from pollution. However, it can be difficult to research the porous surface [41]. The way of conducting research using the fluorescent method has been characterized in the literature on the subject [42]. To identify the root of unconformity were implemented in sequential way methods, i.e. 5W2H, Ishikawa diagram, and 5Why. These techniques were selected because they were used sequentially to allow to analyze and define the problem (unconformity) (5W2H method), identifying the potential and main causes (Ishikawa diagram) and next to identify the root of the unconformity (5Why method) [43]. The choice of these techniques is an expert choice and, in other cases, it can be duplicated or the composition and order of the techniques used can be modified depending on the nature of the problem. The 5W2H has an application to analyze and characterize the problem by seven questions in a practical way (often in the form of a table). These questions relate to the most important information about the problem (in this case, it was a linear indication) [43]. The Ishikawa diagram, called causes and effects diagram, allows pointing the potential causes of problem. It was developed during a brainstorming with 7 employees [44]. To develop the diagram, from basic Ishikawa, categories (5M+E) were selected: man, method, machine, material, management, and environment [44,45]. For these categories, the potential causes of linear indication on the tube were noted. Of the indicated potential causes, three main causes were selected, which were further analyzed using the 5Why method. The 5Why method (that is, the Why-Why diagram) is used to identify the source of the problem [42,46]. The analysis of the linear indication on the tube was started from pointed main causes. Next, to each of the causes, the „Why?" question was asked. The method was completed when the source cause was indicated, that is, one after which improvement measures can be taken [43,47-49]. In the last stage, actions were proposed that could minimize or eliminate the formation of a linear indication r on the product.

Results

After analyzing the fluorescence cast tube of AMS 4439 magnesium alloy, unconformity was found, which was a linear indication, it is shown in Figure 1.

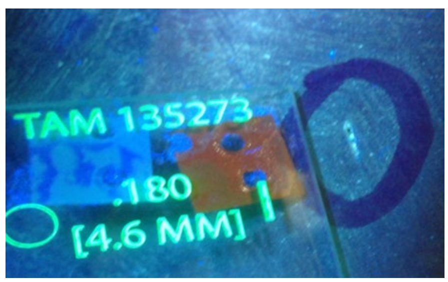

Figure 1. *Linear indication identified on the tube from magnesium alloy AMS 4439.*

Next, the analysis of the linear indications was performed using the 5W2H method (Table 1).

Table 1. *The 5W2H method to linear indication problem on the product.*

Question		Answer
Who?	Who has detected the problem?	An employee who checks the product using the FPI method
What?	What is the problem?	unconformity – linear indication
Why?	Why is this problem?	product disqualification
Where?	Where was the problem?	on the product surface
When?	When was the problem?	during quality control by FPI method
How?	How was the problem identified?	FPI method
How much?	What is the scale of this problem?	1 piece of the product

The analysis using the Ishikawa diagram shown in Figure 2. Potential causes of unconformity (linear indications) on the tube were analyzed according to selected Ishikawa categories, i.e., man, method, machine, material, management, and environment.

The identified source cause of the linear indication on the tube was a destructive material from the supplier. The supplier of the material was informed about the source of the cause of the irregularities. This action was taken in order to minimize or eliminate the cause of porosity cluster.

Conclusion

The product quality analysis for the aviation industry is one of the most demanding analyzes, and the fluorescent method (FPI) is one of the most practiced. Although its use allows one to assess the quality of products and indicate unconformity, it does not identify the source of their creation. This has consequences in the future, because according to the philosophy of continuous improvement, the cause of the unconformity must be resolved at the source, so that it does not occur in the future. Therefore, it was important to improve NDT analysis using qualitative techniques. The purpose of the study was to develop a hybrid method to make decisions about the causes of product incompatibility. This hybrid method was created as a combination of NDT and quality management techniques, i.e.: 5W2H method, Ishikawa diagram, 5Why method. This was done in a selected leading production and service company located in south-east Poland. The subject of the study was a tube made of the magnesium alloy AMS 4439.

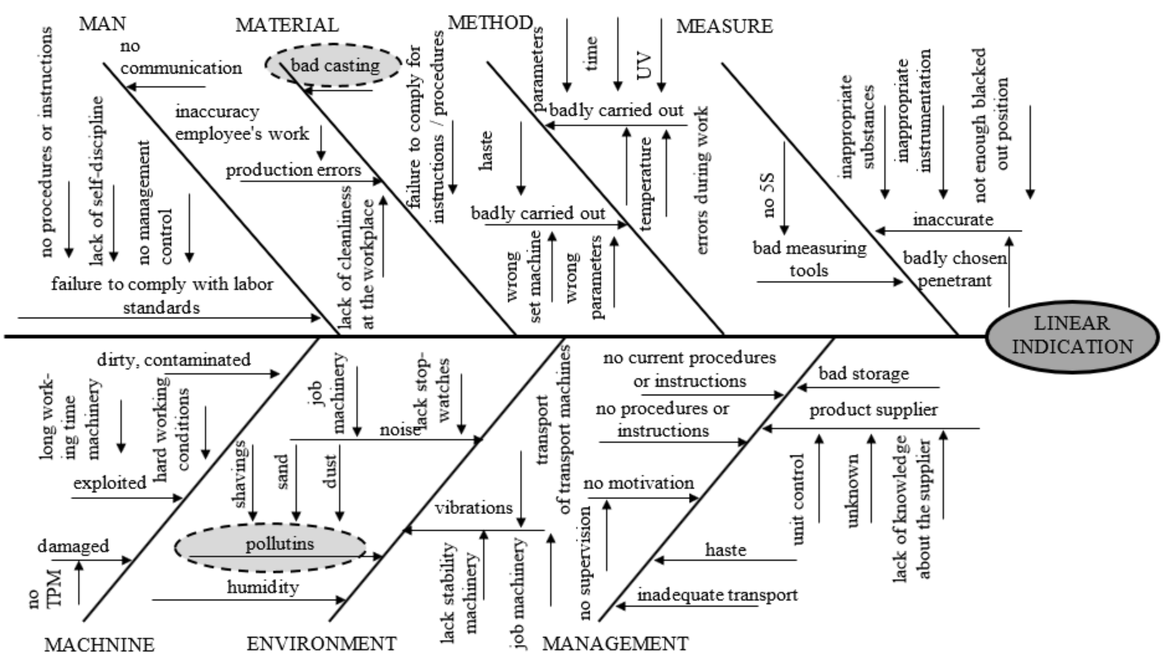

Fig.2. *The Ishikawa diagram for the problem with linear indication identified on the tube.*

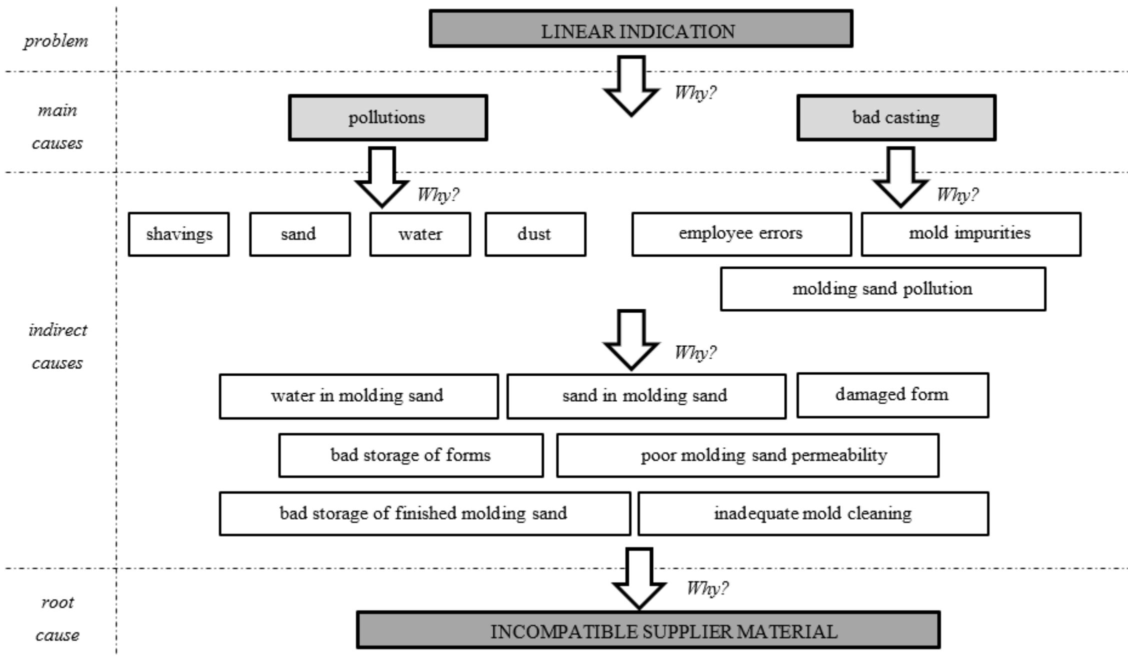

Fig.3. *The 5Why method for the problem with linear indication identified on the tube.*

Then, three main causes of the problem were selected. The main reasons were bad casting and pollutions. To identify the source of cause the 5Why method was performed, whose course is shown in Fig.3.

The analysis of the product was carried out using the FPI method by which the unconformity – linear identification - was detected. In the FPI method, the selected quality management techniques (5W2H method, Ishikawa diagram, and 5Why method) were implemented. These techniques were chosen because they are used sequentially to indicate the source of the problem, which was intended to improve the process of NDT tests (for example, using the FPI method). Using the 5W2H method, the linear indication on the tube was analyzed and characterized. Using the Ishikawa diagram, the main causes of the problem of the linear indication on the tube were identified, i.e., bad casting and pollutions. Next, the 5Why method was used, by which: the source of the cause of linear indication on the tube was identified, i.e., destructive material from supplier. Integrated NDT method with quality management techniques (5W2H method, Ishikawa diagram, and 5Why method) turned out to be effective in the analysis of the unconformity product (casting of magnesium alloy), so can be effective in the analysis of other types of unconformity or metallurgical products.

References

[1] J. Zheng et al. Design of an advanced automatic inspection system for aircraft parts based on fluorescent penetrant inspection analysis, Insight: Non-Destr. Test. Cond. Monit. 57 (2015) 18-34. https://doi.org/10.1784/insi.2014.57.1.18

[2] L.J.H. Brasche et al. Characterization of developer application methods used in fluorescent penetrant inspection, AIP Conf. Proc. 820 (2006) 598-605. https://doi.org/10.1063/1.2184582

[3] H. Fischer et al. Detection of microscopic cracks in dental ceramic materials by fluorescent penetrant method, J. Biomed. Mater. Res. 61(1) (2002) 153-158. https://doi.org/10.1002/jbm.10148

[4] N. J. Shipway et al. Performance Based Modifications of Random Forest to Perform Automated Defect Detection for Fluorescent Penetrant Inspection, J. Nondestructive Evaluation 38 (2019) art. 37. https://doi.org/10.1007/s10921-019-0574-9

[5] R. Wong, K. Cunningham. Mechanical processing of aluminum alloy components and its effect on fluorescent penetrant indications. Mater. Eval. 64 (2006) 1180-1186.

[6] N. J. Shipway et al. Automated defect detection for Fluorescent Penetrant Inspection using Random Forest, NDT & E International 101 (2019) 113-123. https://doi.org/10.1016/j.ndteint.2018.10.008

[7] K. Daneshvar, B. Dogan. Application of quantum dots as a fluorescent-penetrant for weld crack detection, Mater. at High Temp. 27 (2010) 179-182. https://doi.org/10.3184/096034010X12813744660988

[8] A.S. Bakunov et al. Increasing the reliability of magnetic-particle testing by means of a YMJIK-10 automated unit for magnetic fluorescent-penetrant inspection of pipe end faces, Russian J. Nondestruct. Test. 40 (2004) 311-316. https://doi.org/10.1023/B:RUNT.0000045935.55674.d3

[9] L. Brasche et al. Engineering studies for fluorescent penetrant inspection with a focus on developer application methods, Insight: Non-Destr. Test. Cond. Monit. 51 (2009) 88-91. https://doi.org/10.1784/insi.2009.51.2.88

[10] P. Ewert P., C.T. Kowalski. Detection of the damage of the submerged pump aggregates with induction motors. Prace Naukowe Instytutu Maszyn, Napędów i Pomiarów Elektrycznych Politechniki Wrocławskiej. Studia i Materiały 69 (2013) 181-193.

[11] S. Borkowski, R. Ulewicz, J. Selejdak, M. Konstanciak, D. Klimecka-Tatar. The use of 3x3 matrix to evaluation of ribbed wire manufacturing technology, METAL 2012 - 21st Int. Conf. Metallurgy and Materials (2012), Ostrava, Tanger 1722-1728.

[12] R. Ulewicz, F. Nový. Quality management systems in special processes, Transp. Res. Procedia 40 (2019) 113-118. https://doi.org/10.1016/j.trpro.2019.07.019

[13] T. Lipiński, R. Ulewicz. The effect of the impurities spaces on the quality of structural steel working at variable loads, Open Eng. 11 (2021) 233-238. https://doi.org/10.1515/eng-2021-0024

[14] R. Ulewicz, J. Selejdak, S. Borkowski, M. Jagusiak-Kocik. Process management in the cast iron foundry, METAL 2013 - 22nd Int. Conf. Metallurgy and Materials (2013), Ostrava, Tanger 1926-1931.

[15] R. Ulewicz, D. Jelonek, M. Mazur. Implementation of logic flow in planning and production control, Management and Production Engineering Review 7 (2016) 89-94. https://doi.org/10.1515/mper-2016-0010

[16] J. Fabiś-Domagała, G. Filo, H. Momeni, M. Domagała. Instruments of identification of hydraulic components potential failures, MATEC Web of Conf. 183 (2018) art.03008. https://doi.org/10.1051/matecconf/201818303008

[17] K. Knop et al. Evaluating and Improving the Effectiveness of Visual Inspection of Products from the Automotive Industry, Lecture Notes in Mechanical Engineering (2019) 231-243. https://doi.org/10.1007/978-3-030-17269-5_17

[18] P. Lempa, G. Filo. Analysis of Neural Network Training Algorithms for Implementation of the Prescriptive Maintenance Strategy, Mater. Res. Proc. 24 (2022) 281-287. https://doi.org/10.21741/9781644902059-41

[19] P. Jonšta et al. The effect of rare earth metals alloying on the internal quality of industrially produced heavy steel forgings, Materials 14 (2021) art.5160. https://doi.org/10.3390/ma14185160

[20] N. Radek et al. Technology and application of anti-graffiti coating systems for rolling stock, METAL 2019 28th Int. Conf. Metall. Mater. (2019) 1127-1132. ISBN 978-8087294925

[21] N. Radek et al. Influence of laser texturing on tribological properties of DLC coatings, Prod. Eng. Arch. 27 (2021) 119-123. https://doi.org/10.30657/pea.2021.27.15

[22] N. Radek et al. Formation of coatings with technologies using concentrated energy stream, Prod. Eng. Arch. 28 (2022) 117-122. https://doi.org/10.30657/pea.2022.28.13

[23] N. Radek, J. Pietraszek, A. Gadek-Moszczak, Ł.J. Orman, A. Szczotok. The morphology and mechanical properties of ESD coatings before and after laser beam machining, Materials 13 (2020) art. 2331. https://doi.org/10.3390/ma13102331

[24] N. Radek et al. The effect of laser treatment on operational properties of ESD coatings, METAL 2021 30th Ann. Int. Conf. Metall. Mater. (2021) 876-882. https://doi.org/10.37904/metal.2021.4212

[25] N. Radek et al. The impact of laser processing on the performance properties of electro-spark coatings, 14th World Congress in Computational Mechanics and ECCOMAS Congress 1000 (2021) 1-10. https://doi.org/10.23967/wccm-eccomas.2020.336

[26] N. Radek et al. The influence of plasma cutting parameters on the geometric structure of cut surfaces, Mater. Res. Proc. 17 (2020) 132-137. https://doi.org/10.21741/9781644901038-20

[27] A. Goroshko et al. Construction and practical application of hybrid statistically-determined models of multistage mechanical systems, Mechanika 20 (2014) 489-493. https://doi.org/10.5755/j01.mech.20.5.8221

[28] R. Ulewicz, M. Mazur. Economic aspects of robotization of production processes by example of a car semi-trailers manufacturer, Manufacturing Technology 19 (2019) 1054-1059. https://doi.org/10.21062/ujep/408.2019/a/1213-2489/MT/19/6/1054

[29] I. Drach et al. Design Principles of Horizontal Drum Machines with Low Vibration, Adv. Sci. Technol. Res. J. 15 (2021) 258-268. https://doi.org/10.12913/22998624/136441

[30] N. Radek et al. Operational tests of coating systems in military technology applications, Eksploat. i Niezawodn. 25 (2023) art.12. https://doi.org/10.17531/ein.2023.1.12

[31] W. Przybył et al. Microwave absorption properties of carbonyl iron-based paint coatings for military applications, Def. Technol. 22 (2023) 1-9. https://doi.org/10.1016/j.dt.2022.06.013

[32] S. Borkowski, R. Ulewicz, J. Selejdak, M. Konstanciak, D. Klimecka-Tatar. The use of 3x3 matrix to evaluation of ribbed wire manufacturing technology, METAL 2012 - 21st Int. Conf. Metallurgy and Materials (2012), Ostrava, Tanger 1722-1728.

[33] L. Cedro Model parameter on-line identification with nonlinear parametrization – manipulator model, Technical Transactions 119 (2022) art. e2022007. https://doi.org/10.37705/TechTrans/e2022007

[34] J. Pietraszek, A. Szczotok, N. Radek. The fixed-effects analysis of the relation between SDAS and carbides for the airfoil blade traces. Archives of Metallurgy and Materials 62 (2017) 235-239. https://doi.org/10.1515/amm-2017-0035

[35] J. Pietraszek, N. Radek, A.V. Goroshko. Challenges for the DOE methodology related to the introduction of Industry 4.0. Production Engineering Archives 26 (2020) 190-194. https://doi.org/10.30657/pea.2020.26.33

[36] B. Jasiewicz et al. Inter-observer and intra-observer reliability in the radiographic measurements of paediatric forefoot alignment, Foot Ankle Surg. 27 (2021) 371-376. https://doi.org/10.1016/j.fas.2020.04.015

[37] J. Pietraszek. The modified sequential-binary approach for fuzzy operations on correlated assessments, LNAI 7894 (2013) 353-364. https://doi.org/10.1007/978-3-642-38658-9_32

[38] J. Pietraszek et al. Non-parametric assessment of the uncertainty in the analysis of the airfoil blade traces, METAL 2017 26th Int. Conf. Metall. Mater. (2017) 1412-1418. ISBN 978-8087294796

[39] J. Pietraszek et al. The non-parametric approach to the quantification of the uncertainty in the design of experiments modelling, UNCECOMP 2017 Proc. 2nd Int. Conf. Uncert. Quant. Comput. Sci. Eng. (2017) 598-604. https://doi.org/10.7712/120217.5395.17225

[40] J. Pietraszek, E. Skrzypczak-Pietraszek. The uncertainty and robustness of the principal component analysis as a tool for the dimensionality reduction. Solid State Phenom. 235 (2015) 1-8. https://doi.org/10.4028/www.scientific.net/SSP.235.1

[41] A. Pacana, D. Siwiec. Universal Model to Support the Quality Improvement of Industrial Products, Materials 14 (2021) art. 7872. https://doi.org/10.3390/ma14247872

[42] A. Pacana et al. Analysis of the incompatibility of the product with fluorescent method, Metalurgija 58(3-4) (2019) 337-340.

[43] A. Pacana et al. Comprehensive improvement of the surface quality of the diesel engine piston, Metalurgija, 58(3-4) (2019), 329-332.

[44] D. Siwiec, A. Pacana. A New Model Supporting Stability Quality of Materials and Industrial Products, Materials 15 (2022) art. 4440. https://doi.org/10.3390/ma15134440

[45] M. Korzyński, A. Pacana. Centreless burnishing and influence of its parameters on machining effects, J. Mater. Process. Technol. 210 (2010) 1217-1223. https://doi.org/10.1016/j.jmatprotec.2010.03.008

[46] A. Pacana et al. Study on improving the quality of stretch film by Shainin method, Przemysl Chemiczny 93 (2014), 243-245. https://doi.org/10.12916/przemchem.2014.243

[47] D. Siwiec, A. Pacana. A Pro-Environmental Method of Sample Size Determination to Predict the Quality Level of Products Considering Current Customers' Expectations, Sustainability 13 (2021) art.5542. https://doi.org/10.3390/su13105542

[48] A. Gazda et al., Study on improving the quality of stretch film by Taguchi method, Przemysl Chemiczny, 92 6(2013), 980-982.

[49] R. Wolniak. Application methods for analysis car accident in industry on the example of power, Support Systems in Production Engineering 6 (2017) 34-40.