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## Improving the quality level in the automotive industry

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### Abstract

Currently, effective quality management of manufactured products is a factor determining the development of manufacturing companies. However, the identification of the source of non-compliance and the analysis of its causes are sometimes underestimated and are not followed by appropriate methodologies. The study aimed to streamline and improve the production process of aluminium pistons for passenger cars by solving the problem related to a significant number of non-compliant products. The analysis of types of nonconformities identified through penetration testing was performed. The use of histogram, brainstorming session and Pareto-Lorenz diagram was proposed, which allowed identifying the causes of the problem. The presented solution shows the practical effectiveness of a sequence of selected instruments to solve production problems. The proposed sequence of methods can be implied in other qualitative analyses in different companies.

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## 1. Introduction

Concerning companies in the automotive industry, the level of product quality is a particularly important issue as it is additionally linked to safety and human life. The quality of a vehicle's finished product largely depends on the quality of its components, i. e. car parts manufactured in different companies. Therefore, the quality of each of the components making up the finished product, which goes directly to the buyer, is important (Czerwińska et al., 2018; Zima, 2005).

The selection of materials, including metal alloys, should be based not only on technical design assumptions (determined by its technological, physicochemical and operational properties) but also on economic grounds (Górny, 2002; Kozaczewski 2004; Sygut and Krynke, 2017). The need for technical and economic choices also applies to cast aluminium alloys, which are intended for the production of diesel engine pistons (Pacana, 2018; Pacana, 2019).

In the scope of quality control, the use of appropriate control and measurement equipment and the use of quality management instruments affecting the quality of production processes and products at all stages in their life cycle leads to ensuring an appropriate quality level of the offered products (Pająk, 2013; Krzak et al., 2015). Once a casting is found to be free of defects, it is considered to be of good quality (Poloczek, et al., 2016, Nowicka-Skowron, et al. 2013). Therefore, it is reasonable and necessary to select not only technological parameters

aimed at stabilizing the process, but also to select appropriate quality management instruments contributing to the achievement of the desired quality level and at the same time measurable benefits (Pawlowski et al., 2018; Ulewicz, 2014; Urban et al. 2017).

## 2. Piston silumines

Silumines designed for internal combustion engine pistons are among the most complex in terms of chemical composition, cast alloys. These are metal materials of the Al-Si-Cu-Mg-(Ni)-(Mn)-(Fe)-(Zn) system, often supplemented by alloying additives (Mo, Cr, Co, W or V), silicon eutectic modifiers (K, Na, Sr), as well as Al- solid solution grain choppers (Sc, Ti, V, Zr, B) and primary silicon crystal modifiers (P, S) (Lezhnev et al., 2018; Szymczak et al., 2018). In specialist publications, there are also views on the appropriateness of introducing other alloyed additives into piston silos, which are grain shredders or modifiers. Among the elements of the periodic table are for example Ce or La (Anantha, et al. 2012; Akopyan et al., 2019).

Until recently in Poland, most of the pistons, in a wide range of sizes and type ranges, were manufactured from AlSi13Mg1CuNi (AK12) alloy compliant with PN-EN 1706:2001 and marked as EN AC-48000 (EN AC-AlSi12CuNiMg). This alloy has about 1% nickel, copper and magnesium each. AK12 alloy is equivalent to A-S12UNG

(France), Mahle 124 and KS 1275 (Germany), AJ130 (Russia), ZL108 (China) and AC 8A (Japan). After mastering the technology enabling modification of over-eutectic silo, pistons for two-stroke and highly loaded engines, both in Poland and abroad, were made of over-eutectic silo mines [according to PN-76/H-88027 grade AK20 (AlSi21CuNi)]. However, at present, there is a conviction among the piston manufacturers and researchers that more technological alloys in the form of periodic silo should be used for such products as far as possible. (Bing, et al., 2005; Delcourt, 2003; Lee, et al. 2002).

## 2. Objective and subject matter

The tests aimed to diagnose, utilizing penetration tests, the condition of the surface of the combustion chamber in the piston and to determine, utilizing traditional quality management tools, the sources of occurrence of non-conformity in piston castings identified employing non-destructive testing and ultimately to reduce the occurrence of non-conforming products or to eliminate them. The tests were conducted in 2019 on a test batch of products.

The subject of the tests was the piston used in the internal combustion engines of passenger cars. A model of a compression-ignition engine piston is shown in Fig. 1.



Fig. 1. Subject of tests - Diesel engine piston model

The pistons are cast in eutectic aluminium-silicon alloy. The range of chemical composition of the alloy is given in Table 1.

Table 1. Alloy chemical composition range

Elements	Min [%]	Max [%]
Si	12.0	14.5
Cu	3.7	5.2
Mg	0.5	1.5
Ni	1.7	3.2
Fe	-	0.7
Mn	-	0.2
Zn	-	0.1
Pb	-	0.08
Sn	-	0.1
Ti	-	0.2
Zr	-	0.2
V	-	0.2

The durability of the combustion chamber located at the bottom of a diesel engine piston often determines maximum temperatures and safe pressures. There is a risk of fatigue cracking of the edges and base of the chamber, starting with free silicon particles in aluminium (Jiang et al., 1991; Perini et al., 2018). Therefore, the physical and mechanical properties of the alloy used are important (Table 2).

Table 2. Physical and mechanical properties of the alloy used

Physical properties	
Density	2.78 g/cm <sup>3</sup>
Coefficient of linear expansion (200°C)	21 · 10 <sup>-6</sup> K <sup>-1</sup>
Heat conductivity coefficient (200°C)	128 W (mK) <sup>-1</sup>
Mechanical properties	
Tensile strength (20°C)	min 240 MPa
Contractual yield strength (20°C)	200 MPa
Brinell hardness HB10/1000 lub HB5/250	110 – 150 HB

The properties indicated in Table 2 apply to actual piston castings. The hardness of the pistons is measured on the upper outer surface of the crown (bottom) of the piston. Strength tests were carried out following EN10002 Part 1 using non-proportional samples taken from the thickest section of the piston.

## 2. Methodology of testing

To effectively perform a qualitative analysis of the condition of piston castings, tests were performed with non-destructive testing and integrally configured quality management tools.

The first step of the methodology included collecting the necessary information on the nonconformities present in the tested product and selecting the most frequent defect. At this stage, Gemba-walk was performed, employees were interviewed and internal documentation of quality control results was analysed. The identification of the non-conformity was made utilizing penetration tests in a specially adapted room. These tests are performed after mechanical treatment of the pistons.

Samples for metallographic testing were cut out of the defective areas of the piston casting on a metallographic cutter and then encapsulated in resin. The next step was to grind and polish the samples on the Saphir 530. The metallographic specimens were etched with a 5% aqueous solution of HF acid. The microstructure was observed on the Zeiss Neophot 2 metallographic microscope.

Then, an unconventional way of searching for new ideas for problem-solving methods was applied in a team brainstorming session. The brainstorming session was used by experts to identify potential causes of non-compliance.

The use in the analysis of the Pareto-Lorenzo diagram of graphical representation of the data in the diagram, in a decreasing way taking into account the Lorenzo line indicating the sum of the percentage of causes, contributed to the specification of the most significant nonconformities in terms of their number and severity of effects.

### 3. Results and discussion

The results of the piston combustion chamber penetration test are shown in Figure 2. The results obtained indicate the occurrence of surface discontinuities in the highly stressed zone.

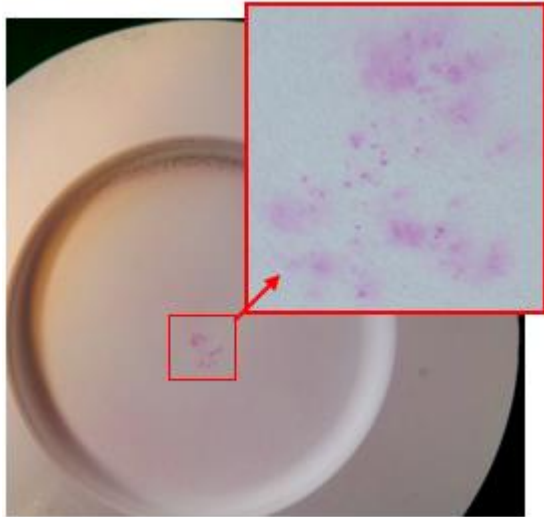


Fig. 2. The result of the penetration test – the most common non-incompatibility in the area with the combustion chamber

Metallographic surveys were carried out in the area of occurrence of discrepancies in order to observe and qualify the size of the discrepancy (Fig. 3).

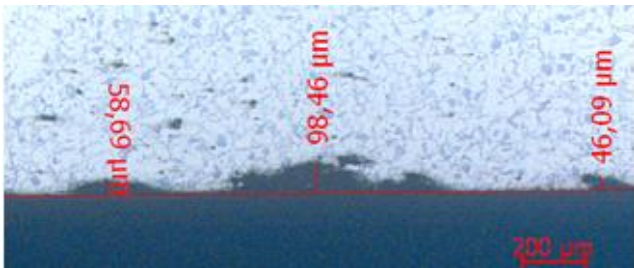


Fig. 3. The result of the penetration test - the most common incompatibilities in the combustion chamber area

There are surface defects on the bottom surface of the combustion chamber, reaching a depth of 0.1 mm.

As part of further statistical analysis, the porosity values located in the area of the combustion chamber of the castings under investigation were considered. A histogram showing the distribution of defects as a function of incidence and its accumulation was developed (Fig. 4).

The largest number of internal inconsistencies identified in the area of the combustion chamber occurs in the size of about 90 μm and combined with defects in the range from 1 to 90 μm represents 77.3% of all analysed discontinuities of the material. Due to the large number of porosities not within the tolerance limits, action has been taken to identify the causes of the problem. For this purpose, a brainstorming session was held, which was attended by a team of experts composed of: the Head of the European Commission and the Director of the

European Commission. The quality manager, chief technologist, foundry manager and specialist in the field of quality assurance, quality control. The result of the session is presented in Table 3.

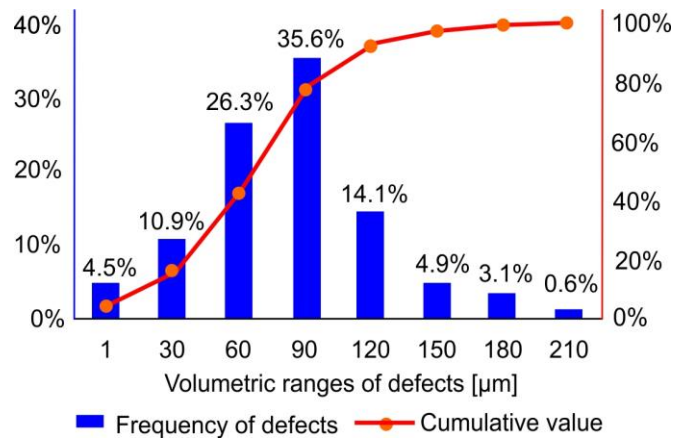


Fig. 4. The result of the penetration test – the most common incompatibilities in the area of the combustion chamber

Table 3. Diagram of the brainstorming session

Potential causes of non-compliance in the form of discontinuity of the material in the area of the aluminium piston combustion chamber	
Problem definition	Submitted proposals
1. What are the most common inconsistencies?	1. Worn-out tool for the finishing of the combustion chamber,
2. Why do incompatibilities arise?	2. Piston not properly set,
3. Whose fault are the discrepancies?	3. Incorrectly set up machine,
4. At what stage of the production process do you think non-compliances arise?	4. Worn-out piston positioning handle,
5. What are the activities during this stage?	5. Worn-out tool for roughing the combustion chamber,
6. How to eliminate arising inconsistencies?	6. The release of gases from the moulding compound,
7. How serious is the problem?	7. Too fast flooding of forms,
	8. Liquid alloy crystallization too fast,
	9. Liquid alloy gasification,
	10. Too long to keep the alloy in the vat,
	11. Contamination in aluminium alloy,
	12. Failure to follow the instructions.

The next stage of the analysis was to specify and clarify the number of the most important, potential causes of a qualitative problem, which were detailed during the brainstorming session. This was done using the Pareto-Lorenz diagram (Figure 5). The potential actions that could cause a defect in the aluminium piston combustion chamber in Figure 5 are marked as indicated in Table 3.

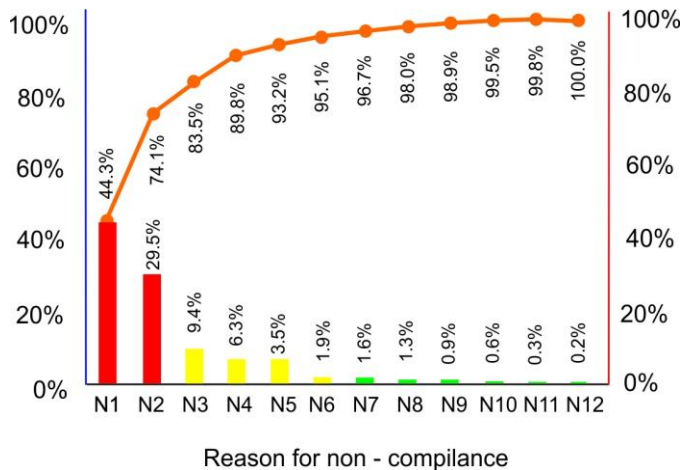


Fig. 5. Potential causes determining the occurrence of a piston combustion chamber defect - Pareto-Lorenzo diagram

The analysis presented using the Pareto-Lorenz diagram shows that the highest percentage share was recorded concerning the use of a worn-out finishing tool for the combustion chamber and the reason for the incorrectly set piston in the machine holder. The non-compliance identified reached 44.3% and 29.5% of all non-compliances respectively. As a first step, it was decided to eliminate the inappropriate positioning of the workpiece in the machine mount. Yellow indicates the reasons for non-compliance, which should be further eliminated by a misaligned machining machine, the use of a worn piston positioning tool and a worn roughing tool for the combustion chamber and excessive gas release from the moulding sand.

#### 4. Summary and conclusion

Monitoring of the production process together with quality control is the key to maintaining a stable position in a dynamically changing market. The proposal for a non-conformity analysis concerning the identification of the causes of defects in products combined with the use of configured integration of quality management instruments has contributed to the identification of the causes of non-conformity.

The key reason for the non-compliance in terms of reducing the appropriate level of quality was the use of an unused finishing tool for the combustion chamber (too infrequent replacement of the machining machine accessories) and the inadequate positioning of the workpiece in the machine holder. These incompatibilities have contributed to a significant amount of discontinuity in the area of the combustion chamber of the aluminium piston intended for passenger cars. As part of the remedial measures, it is recommended to carry out continuous inspections of machines and equipment on the production line and to provide additional training for technical staff.

Future directions of research will be related to the analysis of other production processes functioning in the examined company.

The proposed sequence of methods is a useful and effective way of analysing production processes, which can be practised in different production companies.

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## 提高汽车行业的质量水平

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### 關鍵詞

质量工程 机械工业 活塞  
式硅胶 渗透测试

### 摘要

当前，对制造产品的有效质量管理是决定制造公司发展的因素。但是，有时会低估发现违规根源的原因并分析其原因，而没有采用适当的方法论。该研究旨在通过解决与大量不合格产品有关的问题来简化和改善乘用车铝活塞的生产工艺。对通过渗透测试确定的不合格类型进行了分析。提出了使用直方图，集思广益会议和 Pareto Lorenz 图的方法，从而可以确定问题的原因。提出的解决方案显示了一系列选定的仪器解决生产问题的实际效果。建议的方法顺序可以隐含在不同公司的其他定性分析中。

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