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Analysis of the Diagnostic Process of Castings used in Automotive

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Abstract. The durability of aluminum pistons determines the resistance of the combustion chamber of a piston (bottom) to pressure and temperature. For this reason, the condition of a combustion chamber surface must be monitored scrupulously and any incompatibilities corrected if necessary. The paper uses the eddy current method and the penetration test method for surface quality control of the combustion chamber of diesel engine pistons used in light vehicles. The aim of the study was to determine the sources of the most acute non-compliance detected by the study, using traditional quality management methods. Ultimately, the aim of the analysis was to reduce the number of non-compliant products or to eliminate them completely.

Introduction

Internal combustion engines are the primary source of vehicle drive. Despite intensive work related to the improvement of alternative sources (electric motors, fuel cells), none of them is at a level of development that would enable them to compete with combustion engines (referring to aspects of their operation such as versatility, ease of use taking into account the universality of fuel/energy, traction characteristics, operating costs, spare parts, service network or vehicle users, habits) [1, 2]. Piston with piston ring package and cylinder is one of the most important kinematic nodes of combustion engine. The piston-crankshaft system of a combustion engine is a unit that is exposed to extreme heat and mechanical loads. It is estimated that the resistance, as a result of friction of pistons and piston rings against cylinder smoothness, reaches from 50÷65% of all mechanical losses occurring in the engine [3, 4]. Aspects such as reduction of operating and production costs, requirement for reliability, constant improvement of travel standards, as well as care for the environment affect the need to work on new solutions in the area of construction, production and operation of combustion engines [5, 6]. Both the cooperation of various components of the piston-cylinder group are key to the operation of the engine efficiency and its durability [7, 8], quality of engine components, which determines the need to eliminate non-compliance products subsurface and surface [9, 10]. As part of the diagnostic process in foundry engineering, a trend can be observed in the implementation of comprehensive testing methods [11, 12], in which castings are controlled using several non-destructive testing methods. Quality control with the use of eddy current, penetration, ultrasonic, radiographic or magnetic methods is applied at various stages of the production process.

Continuous progress in the development of research facilities enables high-precision measurements to be made with more information at the same time [13, 14] to determine the

technical condition of equipment and, on this basis, to enable action to be taken to improve its durability, reliability and operational efficiency [14].

The approach described below may be applied in analogous issues of quality control and failures detection e.g. logistics in SMES [15], flow elements in biotechnological installations [16, 17] or heavy-duty actuators [18, 19]. It may also be interesting in the case of corrosion protection [20] and the application of protective coatings [21-23] and their laser modification [24], where the physicochemical processes are highly unstable. Also in the analysis of microstructures, carried out with the use of image analysis techniques [25, 26], such an approach can be very useful.

Methodology of research

In order to diagnose the condition of the casting surface, two non-destructive testing methods were used, i. e. the eddy current and penetration method. Both methods used are non-destructive tests - a group of test methods that provide information on the properties of the material of an object without affecting its surface or structural properties [27]. The priority objective of non-destructive testing is to detect and assess non-conformity supremacy of material. The use of non-destructive studies mainly justifies safety considerations and the economic aspect of the occurrence of unforeseen failures [28, 29].

The centrifugal current method is a surface method. Electromagnetic induction consisting of inducing current in a closed electrical circuit as a result of the action of a variable magnetic field is a fundamental phenomenon that is used in wirocurrent studies. Inducted in the test material, centrifugal currents produce their own magnetic field, which is directed in accordance with Lenz rule, to the opposite to the inciting field of [30]. The intensity of the magnetic field produced by the operation of centrifugal currents depends on the electromagnetic properties of the product area checked (magnetic permeability relative and electrical conductivity appropriate). All changes in the analysed material, such as e. g: change of structure, change of hardness, discontinuity, affect the value of electromagnetic parameters, and thus the value of eddy current intensity and induced magnetic field. Diagnostics of the values of electromagnetic field changes and amplitude as well as phase shift of voltage and intensity create the possibility to assess the condition of the examined product area [31, 32].

Peetric studies use the phenomenon of capillary, that is, penetration of liquids into capillaries. An important role here is played by the moisture of the material, the surface voltage of the liquid and the width of the slot (the continuity of the material). When the penetrant penetrates the slot, its excess is removed on the surface of the object and the residue of the penetrant which is located in the slot is pulled to the surface by means of a developer. Most often, colour (red) or fluorescent penetrants are used for penetration tests [33]. Penetration tests enable detection of incompatibilities emerging to the surface such as narrow-slit cracks, open surface defects, flat and other surface defects, no melt, through defects (leaks), non-metallic surface inclusions, folds, pores, porosity and rolling. By means of this method it is possible to detect differently-oriented open surface discontinuities, i. e. discontinuities not drawn and not filled with contaminants [34-36].

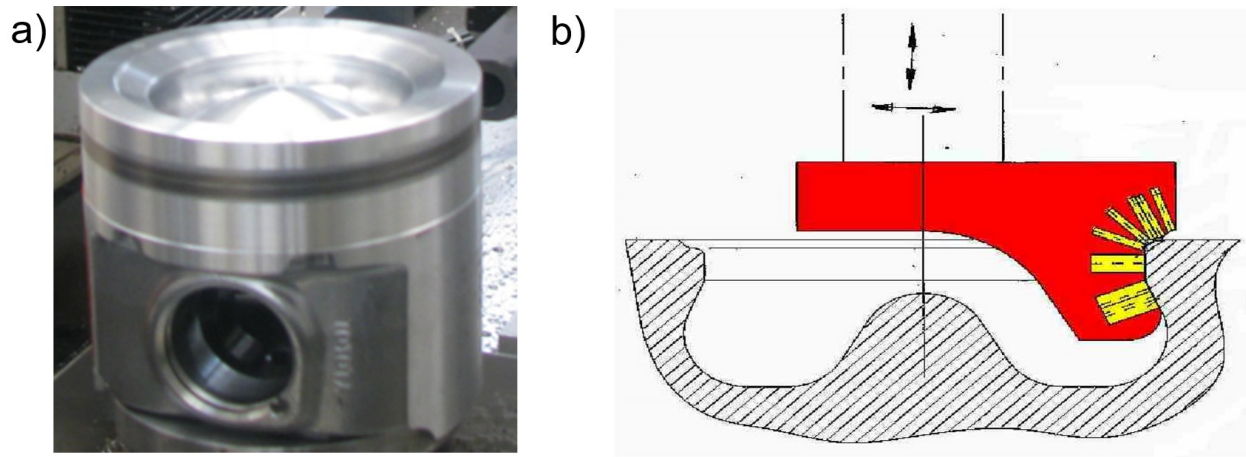

Figure 1. *Subject of research - (a) model of piston used in diesel passenger cars, (b) area subject to research – combustion chamber*

Analysis

The aim of the research was to diagnose the condition of a combustion chamber surface in a piston used in a diesel engine in between-operational quality control, by means of eddy current and penetration tests. The research was to determine the reasons for the occurrence of incompatibility of castings and to propose remedial actions that could ultimately contribute to the reduction of the number of non-compliant castings in the combustion chamber surface in the piston used in the diesel engine.

The conducted research concerned batches of products made in the 2nd and 3rd quarter of 2019 in one of the production companies located in the southern part of Poland. Quality control was performed in accordance with the internal procedure of the company according to each production order.

In order to assess the possibility of detecting internal inconsistencies in the material of the product, experimental tests were conducted. A piston (Fig.1a.) designed for a Toyota diesel engine for use in passenger cars was the subject of the study. The piston combustion chamber (Fig.1b).

Pistons are cast from B2 alloy (designation functioning in the company), which is a eutectic aluminum and silicon alloy designed for the production of petrol and diesel pistons used in light vehicles. B2 alloy has no international or national equivalents.

Results

The obtained results of tests carried out with the use of eddy current method in the combustion chamber of the diesel engine piston are presented in Figure 2.

The result of the tests showed the presence of an unacceptable material discontinuity in the combustion chamber of the piston. As a result of the in-depth inspection and confirmation of the presence of non-compliances, a penetration survey of the pig bottom in the area was carried out to determine whether any non-compliances existed. The result of the penetration test is shown in Fig. 3.

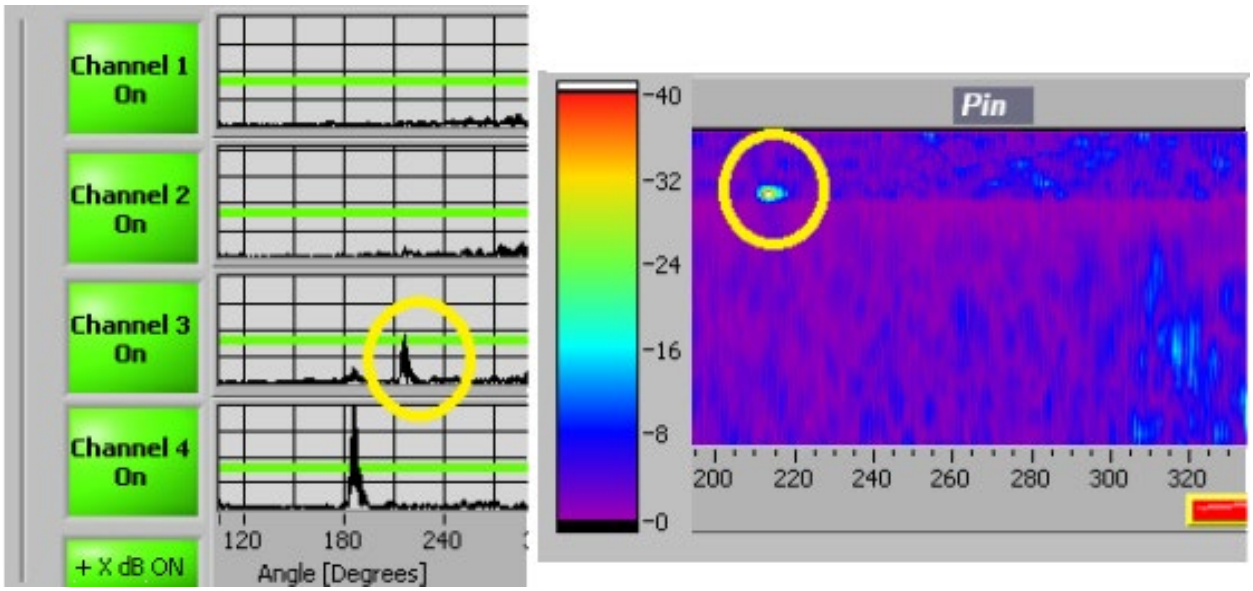

Figure 2. *The result of the eddy current testing of the combustion chamber of the piston with the indication of the detected, unacceptable surface discontinuity*

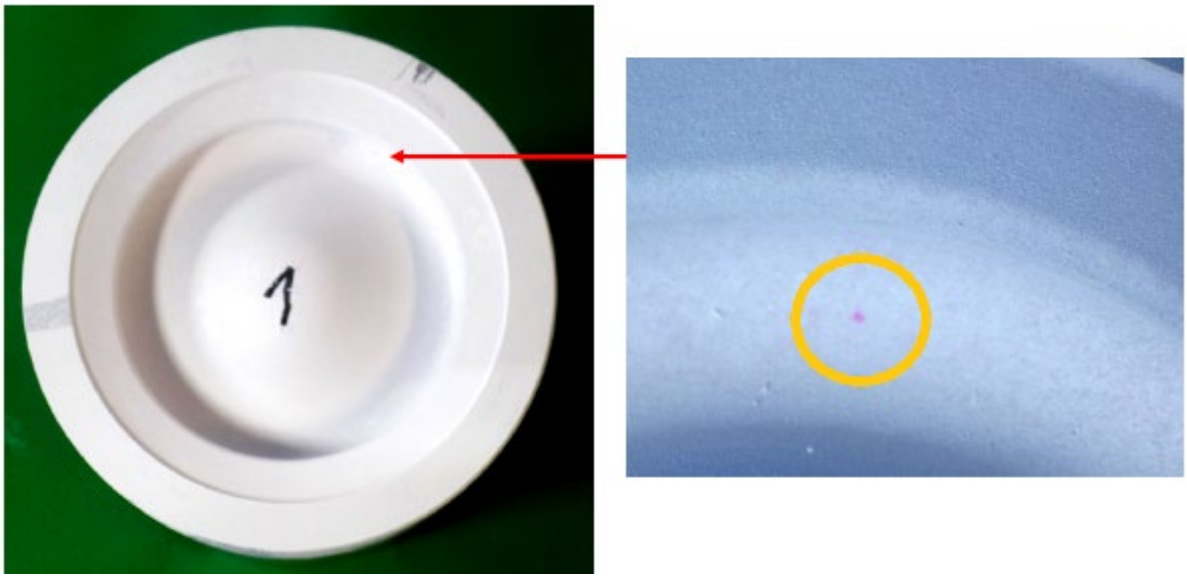

Figure 3. *Piston combustion chamber research result - view after color luminescence*

Penetration tests confirmed the presence of incompatibilities in the combustion chamber. Metallographic surveys were carried out to deepen the analysis from the area of non-compliance (Fig. 4).

The occurrence of observed discontinuity - near-surface material discontinuity (fracture) of the chamber base results in a qualitative disqualification of the piston. A brainstorming session and an Ishikawa diagram were the methods used in order to identify the root cause of the discrepancy. The working group consisted of the following employees: quality control manager, quality control employee and non-destructive testing specialist. The brainstorming session was used to analyze the cause of non-compliance in the product. Potential causes of the analyzed

(most severe for the company) non-compliance were identified on the Ishikawa diagram in the 6M system (Fig. 5).

Figure 4. *The result of metallographic research - a near-surface material*

Figure 5 presents factors which influence the occurrence of one of the most important piston inconsistencies for the company – a near-surface material discontinuity in the combustion chamber. The most important factor influencing the occurrence of incompatibilities in the discussed series of products was distinguished in the scope of the method. In this group, the inadequate removal of castings from the mould was the most important.

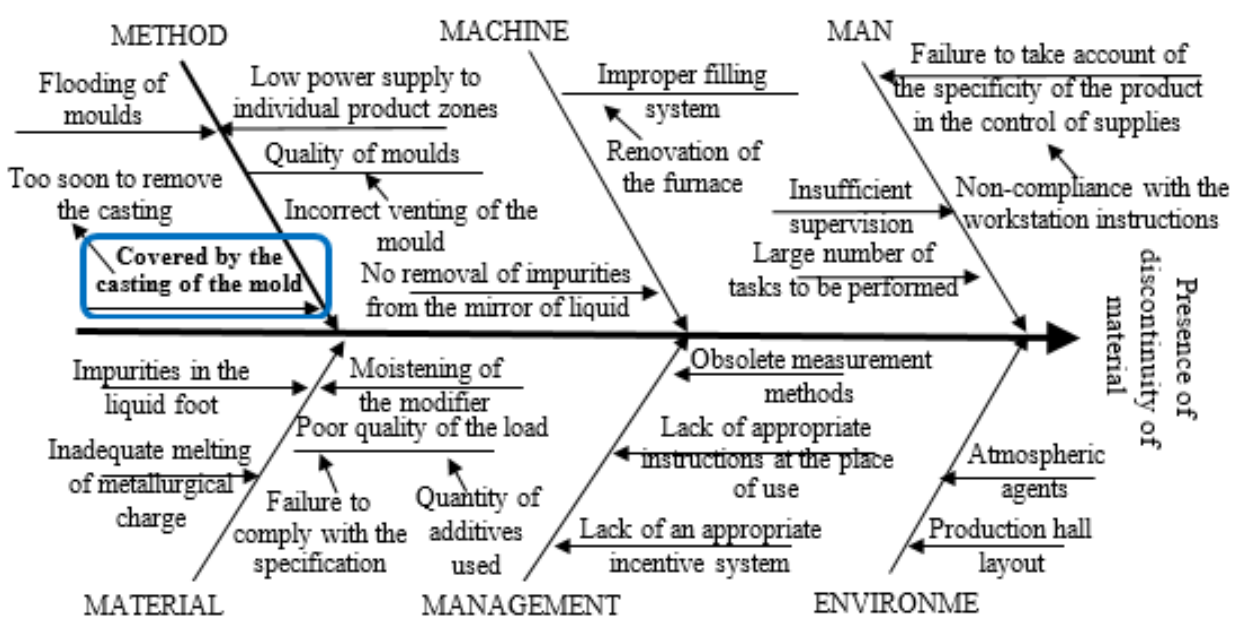

Figure 5. *Ishikawa Diagram of Causes of Surface Material Discontinuity in the Piston Combustion Chamber*

Conclusion

In this work, diagnostic tests of the surface of the combustion chamber of a diesel engine piston were carried out using the eddy current method and penetration test. The aim of the test was to control the quality of a batch of products, check the usefulness of the control and diagnostic test in the production process and analyze the identified inconsistencies.

The non-destructive eddy current method was used to locate the discontinuity in the area of the combustion chamber – a near-surface material discontinuity, and then, in order to verify the indication, a luminescent test was performed, which confirmed the presence of discontinuities. Due to the fact that the discontinuity indication eliminates the piston, metallographic surveys were carried out on the area where the discrepancy occurred. During the brainstorming session and the Ishikawa diagram, it was diagnosed that the key cause of the discrepancy was inadequate (too fast) removal of castings from the mould.

The applied non-destructive testing methods combined with the quality management method largely complement each other. The proposed combination may be a component of methods supporting quality management processes.

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