Examination of engine cylinder-piston group damages

Yu Bazhenov, A Kirillov and M Bazhenov
Vladimir State University named after Alexander and Nikolay Stoletovs, 87 Gorky St., Vladimir, 600000, Russian Federation

Corresponding author: mikbazh@yandex.ru

Abstract. Results of investigations of engine cylinder-piston group (CPG) damages and causes of their occurrence are given. The object of the study is the KIA Ceed engine, which came for examination due to a significant decrease in power, increased consumption of motor oil, violation of the dynamics of the car. The analysis of the technical condition of the disassembled engine showed that the parts of the crank mechanism and the cylinder head have no operational damages. Serious damages were detected only in the cylinder-piston group of the engine: abrasive wear of the working surfaces of cylinders, pistons and compression rings, coking of oil removal rings, deposits on the surfaces of all pistons of the engine. According to the results of the studies, the cause of loss of efficiency by the engine is the destruction of the ceramic catalyst, the products of which in the form of ground powdered substance enter the cylinders together with the exhaust gases. This occurs at the moment of simultaneous opening of exhaust valves of two cylinders having different exhaust gas pressure. A small amount thereof, together with the catalyst breakage products, penetrates the lower pressure cylinder through the manifold. A study of the substance of deposits on the pistons of the engine and the destruction products of the elements of the ceramic catalyst (cordierite Al₄Mg₂O₃Si₅), carried out on the powder diffractometer BRUKER AXS, showed the identity of their diffraction composition. This indicates that damage to the parts of the CPG and loss of performance by the engine is caused by destruction of the ceramic catalyst.

1. Introduction
The internal combustion engine is the most complex and expensive vehicle unit, which accounts for up to 20% of all its failures resulting from various mechanical damages (wear, plastic deformation, aging, fatigue and corrosion damage, etc.) [1, 5]. Untimely detection and repair of these damages leads to failures in engine operation, complete or partial loss of its operable condition (failure) [2, 6].

Determination of actual causes of engine failures requires not only high professional qualification of researchers-experts, but also knowledge of physical essence and patterns of their occurrence. Due to nature and reasons of occurrence all failures of internal combustion engine during operation are the result of violations of technological processes of manufacturing of their structural elements, or violation of established rules and (or) operating conditions (non-compliance with maintenance intervals, use of poor quality operating materials, low qualification of production and technical personnel, etc.) [8, 12].

During the examination to determine the cause of failure, first of all, it is necessary to study the signs of initial damage of parts, as a result of which the engine lost its operability. Careful analysis of
such features makes it possible to determine which structural element damage was the most likely cause and primary source of engine failure [13, 14].

2. Methods
This article presents the results of research into the causes of serious malfunctions in the operation of the KIA Ceed gasoline engine. The engine came for examination due to significant reduction of power, increased consumption of engine oil and fuel, noisy operation, violation of car dynamics.

After disassembly it is established that parts of crank mechanism (crank inserts, crankshaft necks and other parts of crank mechanism) have no signs of wear or other damages. No operational damage was detected in the engine cylinder head.

During the performed tests, damages were detected only for parts of the cylinder-piston group of the engine, the most serious of which are:
1. Abrasive wear of working surfaces of cylinders over the whole working stroke of piston with complete loss of honing structure (Fig. 1). No deep burrs are found, which indicates absence of molecular-mechanical wear of contacting surfaces (cylinder mirror – piston rings) [7, 12].
2. Increased wear of piston skirts (0.07 to 0.09 mm) and compression rings in all engine cylinders without exception, which is well correlated with wear of their working surfaces.
3. Coking of oil removing piston rings due to lacquer deposits on their surfaces.
4. Significant deposits of coke and engine oil oxidation products on the surfaces of all four pistons of the engine are mainly in the zone of piston rings (Fig. 2).

Figure 1. Wear of engine cylinders working surfaces  
Figure 2. Condition of engine pistons and rings surfaces  

Lacquer deposits are products of oxidation of thin layers of lubricant on surfaces of pistons and piston rings heated to high temperatures. Lacquer deposits include carbon (up to 80%), hydrogen, oxygen and solid non-combustible compounds. Lacquer deposits have the greatest harm on piston rings, causing their coking, and pistons, causing their overheating due to reduced thermal conductivity [10, 13].

The formation of deposits usually begins with the appearance on the piston surfaces of lacquer films on which the oxidation products of hydrocarbons included in the oil base of motor oils (asphaltenes, resins, carbenes, carboids) and various mechanical impurities are deposited and retained. Under the influence of high temperatures, the formed films are charred, turning into coke [10].

The deposits have a significant effect on the durability of the engine due to the disruption of the working process and the deterioration of the thermal conductivity of the parts, as a result of which the total temperature of the engine increases. In particular, formation of deposits in the combustion chamber causes abnormal ignition of the working mixture (coking ignition, detonation) [7, 13].
Processes of oxidation and formation of deposit are intensified at occurrence of abrasive wear of cylinder-piston group of engine, causing power drop, increase of fuel and engine oil consumption. Thus, abrasive wear is taken as the main sign of serious malfunctions of the testing engine.

Abrasive wear of the cylinder-piston group parts is mainly a consequence of abrasive particles ingress with air, engine oil, fuel (owing to insufficient filtration) into engine cylinders. Therefore, in the first stage, the technical condition of the intake duct, air and oil filters of the engine was examined. During check of visible damages and depressurization of air branch pipes, inlet manifold, air and oil filters were not found. This indicates that external air and oil contaminants are unlikely to enter the engine due to insufficient filtration.

As shown in the literature [10, 15], the source of increased wear of the parts of the cylinder-piston group may be a violation of the lubrication conditions of these parts. The amount of fuel supplied to the cylinders and the completeness of its combustion have a significant influence, for example, on the lubrication of the parts of the cylinder-piston group. Excess fuel input causes on the one hand condensation of this fuel on cylinder walls, and on the other hand combustion disorder, which causes unburned part of fuel to enter exhaust system. As a result, the fuel washes the oil from the cylinder walls, causing increased wear of the mating parts, as well as burning of the unburned fuel in the catalyst, resulting in overheating and destruction of the catalyst.

Since the tested engine is equipped with a ceramic catalytic converter of exhaust gases, there is a possibility of particles of its possible destruction entering the cylinders of the engine. This is indicated by the symptoms with which the engine came for examination (violation of car dynamics, reduction of power, increase of fuel consumption, etc.) [8, 18]. In order to test this hypothesis, it was decided that it was necessary to cut out a fragment of the catalytic converter (cat-collector) in the front (input) part of its housing (Fig. 3).

In the opened cavity, the products of destruction of ceramic elements of the catalytic converter in the form of a grey powder were found (Fig. 4). Ceramic cells are rather brittle material and upon mechanical impact the cells move away from the catalyst walls, begin to move inside the housing and break down, spreading over the whole exhaust system. Approximately 50% of the ceramic insert was destroyed on the test engine, resulting in a portion of the catalyst cells being clogged with destruction products.

The catalytic converter could fail not only as a result of mechanical action (impact), but also for other reasons: due to overheating, ingress of motor oil together with exhaust gases into it, temperature difference during immersion of the operating catalyst into the water medium, failure of the oxygen sensor, etc.

Under normal conditions of engine operation, the temperature of the neutralizer must not exceed 800-900 °C. At temperature increase to 950-1000 °C occurs mechanical destruction of its active catalytic layer and cellular channels for pass of exhaust gases. The possibility of thermal damage to the neutralizer is particularly increased when ignition in one of the cylinders is stopped, for example, when the spark plug fails. In this case, the fuel-air mixture unburned in the engine begins to burn in the neutralizer, heating it intensively. This leads to destruction and melting of ceramic cells, which leads to deterioration of exhaust gas passability [14].
3. Results and discussion

In order to establish the identity of the deposition material on the pistons of the engine and the destruction products of the catalyst elements, their diffraction composition on the powder diffractometer BRUKER AXS (Germany) was investigated. The results of the study are presented in Fig. 5 as a combined diffractogram.

![Diffractogram of deposition material from piston surface (black graph) and catalyst destruction products (red graph)](image)

From a diffractogram it is visible that products of destruction of the catalyst represent mix of cordierite (Al₄Mg₂O₁₆Si₅) with addition of zirconium (Zr) (active agent of the catalyst).

Material of deposits on piston is based on non-crystalline (amorphous) substance (sintered motor oil) and inclusion of fine particles of cordierite. The blue vertical lines on the diffractogram correspond to peaks of graphs, both catalyst material and deposits on the piston surface.

Thus, it can be stated that together with the exhaust gases, a powdered substance (ceramic dust) of the broken catalyst enters the cylinders of the engine.
The ingress of ceramic dust of the breaking catalyst into the combustion chambers is explained by the peculiarities of gas distribution of modern engines [7]. The catalyst, which is a system of cells that pass exhaust gases, creates additional resistance to their exit. In the course of operation, periodically, there are moments of simultaneous opening of exhaust valves of two cylinders having different gas pressure, accordingly, part of exhaust gases can be thrown through the manifold into the cylinder with lower pressure. The small amount of exhaust gas trapped in the engine cylinders does not significantly affect its operation. However, if neutralizer cartridge breakage products representing an abrasive substance are introduced into the cylinders together with exhaust gases, they cause intense wear of friction pairs of the cylinder-piston group, which happened in the engine presented for examination.

In the present case, the catalyst is built into the outlet collector as close as possible to the engine (cat-collector). Such design solution contributes to faster heating of catalytic elements after engine start-up and maximum efficient cleaning of exhaust gases from harmful substances (carbon monoxide – CO, nitrogen oxides – NOx, etc.). At the outlet of a serviceable catalyst, the exhaust gases have a relatively environmentally friendly concentration of carbon dioxide (CO2), water (H2O) and nitrogen (N2) with impurities. However, with this arrangement of the catalyst, it is more likely to break down due to the systematic overheating.

4. Conclusions

1. The results of the study showed that the KIA Ceed engine lost its performance due to the destruction of the ceramic insert of the catalyst, the products of which in the form of ground powdered substance enter the cylinders together with the exhaust gases. This caused abrasive wear of the mirror of the cylinders, pistons and compression rings of the engine.

2. Due to the intensive wear of the parts of the cylinder-piston group and the increase in the gap "cylinder mirror - piston rings" engine oil and "ceramic dust" enter the combustion chamber of the engine. At high temperatures, such a mixture causes the formation of deposit on the pistons and the coking of the oil removal rings.

3. The destruction of the ceramic catalyst insert had no effect on the damage to the parts of crank mechanism, even at 50% of the catalyst failure there were no signs of wear or other deterioration of crank mechanism.

References
[1] Bazhenov Y and Bazhenov M 2019 Prediction of a residual operating life of engines JOP Conf. Ser.: Mater. Sci. Eng. 695 012010 https://doi.org/10.1088/1757-899X/695/1/012010
[2] Bazhenov Yu V and Bazhenov M Yu 2018 Research of operational dependability of automotive engines Dependability 18(4) 22–27 https://doi.org/10.21683/1729-2646-2018-18-4-22-27
[3] Bazhenov Yu V and Bazhenov M Yu 2015 Forecasting of residual life of structural elements of cars in operation conditions Fundamental Research 4 16–21
[4] Belov N A and Avksentieva N N 2005 Analysis of five-component state diagrams in the field of compositions of piston silumins Izvestiya Vysshikh Uchebnykh Zavedeniy. Tsvetnaya Metallurgiya 4 47–56
[5] Gurvich I B and Syrkin P E 1984 Operational reliability of automobile engines (Moscow: Transport)
[6] Denisov A S 2007 Ensuring dependability of autotractor engines (Saratov: Publishing house SGTU)
[7] Kawtaradze R Z 2016 Piston engine theory. Special chapters (Moscow: MGTU)
[8] Pronikov A S 1978 Reliability of Machines (Moscow: Mechanical Engineering)
[9] Prudnikov A N 2009 Structure and properties of heat-resistant silumin piston with high content of silicon Izvestiya Vysshikh Uchebnykh Zavedeniy. Chernaya Metallurgiya 8 28–30
[10] Oil consumption and oil loss. Service, recommendations and information No. 50 003 605-09 (Motor Service International GmbH, Germany)
[11] Smirnov K A 2005 Development of the system of formation of technical influence systems
during repair of engines according to the state: Abstract of the thesis candidate of engineering sciences (Vladimir: Vladimir State University)

[12] Shashkin V V and Karzova G P 1992 Reference book. Reliability in mechanical engineering (Saint-Petersburg: Polytechnic)

[13] Khrulev A E 2000 Why knocking the connecting rod? Car and Service 12 14–16

[14] Shestopalov L P and Likhachev I E 2017 Methods of research of materials and parts of machines during auto-technical examination (Moscow: MADI)

[15] Waldhauer B 2006 Damage to pistons - how to detect and eliminate them (Neckarsulm: Motor Service International GmbH)

[16] Engine Bearing: Failure Analysis and Correction 2014 (MAHLE Aftermarket Inc. 23030 MAHLE Drive, Farm. Hills, M1 United States)

[17] Engine Failure and Tips Job Aid. Guide to Preventing Repeat Engine Failures. Version 1.0 2013 (Ford Motor Company)

[18] Greuter E and Zima S 2012 Engine Failure Analysis (Warrendale: SAE International)

[19] Mohammed M N, Omar M Z and Sajuri Z 2011 Failure analysis of a fractured connecting rod Journal of Asian Scientific Research 2 737–741

[20] Raghuvanshi N K, Pandey A and Mandloi R K 2012 Failure Analysis of Internal Combustion Engine Valves: A Review International Journal of Innovative Research in Science, Engineering and Technology 1(2) 173–181