Peculiarities of choice of materials for pistons of heat engines

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Abstract. In the modern automotive industry, heat engine pistons must have sufficient strength characteristics to ensure the necessary reliability and durability under high dynamic, mechanical and thermal loads. Currently, aluminum alloys, cast iron, steel and composite materials are used in domestic and international practice for the production of pistons. The use of cheap reinforcing elements made of carbon materials instead of expensive ceramic and boron fibers, silicon carbide particles will significantly reduce the cost of pistons and make them more affordable for mass production.

1. Introduction
Improving the performance of automotive diesels in the face of increasing demand in the automotive industry is one of the most urgent tasks. This task is solved both by improving the working process of the engine, and by optimizing the main components and parts.

The possibility of improving the working process of a piston engine by increasing the gas pressure and thermal loads on the parts is largely related to the design of the piston, the technologies and materials used in its production. This is especially true when using alternative fuels, in particular natural gas, when the temperature in the combustion chamber increases significantly [1].

When the engine is running, especially in conditions of high temperatures and pressures, special attention is paid to the design of the piston, on which the main indicators of the engine depend [2-5].

The piston must have sufficient strength characteristics to ensure the necessary reliability and durability under high dynamic, mechanical and thermal loads. At the same time, it must have a low mass, high wear resistance of the contact surfaces, low friction losses with minimal mounting gaps in the cylinder, optimal thermal conductivity and a low coefficient of thermal expansion.

2. Design features of modern pistons
A special place is given to working out the design of the piston using the latest computational optimization methods, which will allow you to choose the best material, type of hardening and geometric configuration for a specific type of engine, ensuring compliance with environmental standards and high fuel efficiency.

For the production of pistons, aluminum alloys, cast iron and steel are used in domestic and international practice. In the past two decades, the development of pistons made of composites has been carried out abroad.

The main dimensions of the piston are determined based on the properties of materials, static data on the ratio of structural elements of the piston, calculations of its stress-strain state, verified by experimental studies. In this case, special attention is paid to determining the height of the head and the piston itself, the thickness of the bottom and the height of the heat belt. These parameters of the design...
of the piston depend on its mass, the location of the center of gravity and, consequently, the condition of the shift in the cylinder, noise and vibration, the temperature in the groove area of the first piston ring, which is the reason for reducing its hardness and wear resistance and intensive coking of oil, which leads to the occurrence of the ring in the groove. The height of the heat belt also determines the "dead" volume of the engine combustion chamber and the emissions of unburned hydrocarbons with exhaust gases [4].

Until recently, reducing the thermal expansion of the piston guide was achieved by using steel temperature-regulating inserts, but the desire to reduce the weight of the piston led to a decrease in the output of such pistons. Currently, the main way to compensate for and account for the significant expansion of the piston guide is to optimize its geometric shape-an oval-barrel profile [6-8]. This problem is particularly acute when designing pistons of gasoline engines operating in a cylinder with minimal gaps in conditions when the thermal expansion of the skirt exceeds the thermal expansion of the cylinder and the mounting gap between them, that is, when elastic deformations of the skirt occur [9-11]. This problem is further compounded at present by the use of "hard" short pistons with a reduced friction surface. An error in selecting the profile can lead to a bully of the cylinder-piston group.

Pistons made of aluminum alloys doped with silicon, with a content of the latter 11...13 % (eutectic alloys) and 17...23 % (non-eutectic alloys), are widely used. The main advantages of aluminum alloys over other metals are: low material density, high thermal conductivity and satisfactory tribological characteristics. At the same time, the obvious disadvantages of pistons made from aluminum alloys developed by the industry, such as a significant reduction in strength characteristics at high temperatures, a high coefficient of thermal expansion and low wear resistance, are overcome by structural and technological measures. These include the development of special alloys with the addition of components that improve strength characteristics at high temperatures and reduce thermal expansion, as well as the use of special technologies for manufacturing piston blanks: injection molding, isothermal stamping for eutectic alloys and isothermal stamping for non-eutectic alloys, including granular.

3. Ways to improve the reliability and durability of pistons

It should be noted that the capabilities of traditional piston alloys no longer satisfy the manufacturers of internal combustion engines, who have focused their efforts on increasing wear resistance, thermal and mechanical strength, reducing friction losses, and reducing the weight of the piston [12-14].

Thus, to reduce the wear of the first compression ring groove, special inserts made of cast iron and other materials are used that reduce wear in the friction pair: the piston - compression ring.

Much attention is paid to the use of various coatings. The guide part of the piston is covered with a thin layer of lead, tin or zinc, several microns in order to protect the piston surface from being bullied in conditions of deterioration of the lubricant in certain operating modes. Graphite coatings with a special filler that provides a strong grip on the wall of the guide part are widely used. This coating significantly increases the wear resistance of the piston.

To strengthen the upper groove under the compression ring, wear-resistant coating is increasingly used instead of inserts. Usually this coating is made on the firing surface of the bottom of the piston, covers the heat belt and the first groove around the perimeter. The coating has a thickness of 40 ... 120 microns, formed as a result of solid anodizing, i.e. thermochemical conversion of the upper layer of aluminum alloy into solid ceramics (aluminum oxide Al₂O₃). In supercharged gasoline engines, this coating protects the piston from destruction when detonation combustion occurs [15-17].

The concentration of engine manufacturers ’ efforts on increasing the thermal and mechanical strength of pistons and thereby achieving a reduction in their mass, reducing friction surfaces and, consequently, mechanical losses has led to the development of composite materials in which the matrix - aluminum alloy - is strengthened with Al₂O₃ or Al₂O₃+SO₂ oxide ceramic fibers, or filamentous SIC silicon carbide crystals. Reinforcement with ceramic fibers improves mechanical characteristics: strength, yield strength of the base aluminum alloy, especially at elevated temperatures, reduces the coefficient of linear thermal expansion, increases wear resistance.
The most loaded part of the piston is its head. The requirement to ensure the durability of the piston under the combined action of mechanical loads from gas pressure forces and thermal loads due to high temperatures led to the development of composite pistons with a head made of steel and a piston skirt made of aluminum alloy (figure 1) (pistons of Elko and Cummins diesel engines). However, the best technical solution to this problem is the design of the piston, reinforced in the head with ceramic fibers.

![Composite piston made of aluminum and steel.](image)

Studies have shown that the use of composite pistons (by reducing the side gaps of the aluminum skirt) can reduce noise, release of toxic substances, and increase the average temperature of the working process, which can improve the efficiency of turbocharging [18-22].

Further work in this direction is very promising, as manufacturers of carbon pistons based on the results of testing and operation of gasoline and diesel engines give the following arguments in favor of carbon structures:

- significant reduction of exhaust gas emissions;
- reduced fuel consumption: 3...8%;
- reduction of oil consumption for carbon monoxide: by 40...55%;
- low density: 1.5...2.2 g/cm³ (reducing the weight of the piston by 10 ... 20%, reducing the moment of inertia by 30...40%);
- low coefficient of thermal expansion: 5 ... 10 1/K, and therefore ensuring a minimum gap in the coupling of the piston - cylinder skirt at high thermal loads;
- reduction of crankcase gas breakout;
- increase the compression ratio by about 10%;
- increase in mechanical strength when the temperature increases: 2...5% at 400 °C;
- constant hardness HRB = 90 ... 125 over the entire temperature range.

For example, cast composite materials based on the AK12 alloy were obtained by mixing non-metallic particles into an aluminum melt with a significant decrease in the temperature coefficient of linear expansion. The wear resistance of the developed alloys also increases significantly.
4. Conclusion
Currently, cast composite materials of the Al-Si/SiC system are increasingly used in the automotive industry. They are characterized by increased wear resistance, high resistance to cracking, a lower coefficient of thermal expansion, improved strength indicators, and heat resistance. The increasing complexity of technology and the corresponding increase in production costs constrain the spread of these materials.

The use of cheap reinforcing elements made of carbon materials instead of expensive ceramic and boron fibers, silicon carbide particles will significantly reduce the cost of composite materials based on aluminum alloys and make them more affordable for mass production [23-26].

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