The technology of manufacture of the pistons of the heat engine by the method of liquid stamping

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Abstract. Modern methods of production of heat engine pistons allow to strengthen individual parts of the piston with composite materials based on ceramics. The considered manufacturing technology allows reinforcing the bottom of the piston, thereby increasing the reliability of individual parts of the piston that perceive maximum temperatures during operation. The pistons obtained by this method have an increased heat transfer coefficient and a finer-grained metal structure. Also, the use of ceramic materials in pistons can increase the reliability and service life of engines.

1. Introduction
The choice of material and technological process for the production of certain parts, as well as the method of their hardening, are determined primarily by the working conditions of the parts, the amount and nature of stresses that occur during operation, as well as the size and shape of the parts.

Analysis of the working conditions of pistons of modern engines shows that they perceive significant dynamic loads during operation. The pistons of automotive engines must ensure stable operation of the engine for more than 6000 hours. A special feature of the working conditions of the pistons is the high temperature of the combustion products. The resulting gases, whose temperature can reach 2000°C, cause the bottom of the piston to warm up under certain operating conditions to 350...400°C [1-3].

The complex configuration of the piston, rapidly changing in size and direction of heat flows affecting its elements, lead to an uneven distribution of temperatures over its volume and, as a result, to significant time-varying local thermal stresses and deformations.

When designing a piston, statistical data is used on the structural parameters of its elements related to the cylinder diameter. When designing and manufacturing pistons, special attention should be paid to the temperature field and the main stresses of the piston. These indicators, in case of their critical values, determine the choice of material for the manufacture of the piston [4-6].

2. Requirements for modern materials of heat engine pistons
Aluminum alloys have a low density, which allows you to reduce the weight of the piston and, consequently, reduce the inertia loads on the elements of the cylinder-piston group and kshm. This also simplifies the problem of reducing the thermal resistance of the piston elements, which, combined with the good thermal conductivity inherent in these materials, allows you to reduce the heat stress of the parts of the piston group.

Currently, two types of silumins are used in the manufacture of pistons: eutectic with a si content of 11...14 % and zaeutectic with a si content of 17...25 %.
An increase in Si content in the alloy leads to a decrease in the coefficient of linear expansion, an increase in thermal and wear resistance, but at the same time its casting quality deteriorates and the cost of production increases [7-10].

To improve the physical and mechanical properties of silumin, various alloying additives are introduced into them. Adding up to 6% copper to an aluminum alloy increases fatigue strength, improves thermal conductivity, provides good casting qualities and, consequently, lower manufacturing costs. However, this slightly reduces the wear resistance of the piston. The use of sodium, nitrogen, and phosphorus as alloying additives increases the wear resistance of the alloy. Alloying with Nickel, chromium, and magnesium increases the heat resistance and hardness of the structure.

Currently, we are actively working on the use of ceramic materials for pistons that best meet the requirements for materials of the piston group. This is a low density with high strength, heat resistance, wear resistance, low thermal conductivity and the required value of the linear expansion coefficient [11-13].

3. Features of the technological process of liquid stamping

Liquid stamping technology can be used to produce precise blanks of internal combustion engine pistons with a ceramic fiber insert and a niresist ring. There is also a special technology for producing inserts made of ceramic fibers of the required structure, density and geometry.

The piston material (matrix alloy) is cast aluminum alloy. The production method is liquid stamping with through impregnation of a fibrous ceramic insert. The material of the ceramic insert is aluminum-silica fibers with a diameter of 2...4 microns, a modulus of elasticity of 150 GPA, a strength conversion of 1700 MPa, a density (volume content of fibers) of 10...20 % and a non-fibrous component content of no more than 5 %.

Liquid stamping is a technological process for obtaining workpiece parts, in which the crystallization of liquid metal, poured into the tool cavity, occurs under high pressure. This provides an increase in the heat transfer coefficient and, consequently, the cooling rate, so the metal structure is obtained more fine-grained than in castings. The scheme of filling the form with liquid stamping is shown in figure 1.

![Figure 1. Scheme of filling the form with liquid stamping.](image-url)

Pressure crystallization and deformation prevent the formation of shrinkage shells and gas porosity (since the solubility of hydrogen increases with increasing pressure). In accordance with this, increased mechanical properties of forgings are obtained. The presence of high pressures improves the filling of die cavities and surface quality. They use different schemes of the stamping process. According to the
basic scheme, the metal is poured into the die cavity corresponding to the shape of the forging, compressed with a punch and produced, thus, crystallization under pressure. The second scheme involves partial solidification of the metal under pressure in a cavity other than the final shape of the forging; this is followed by deformation in a semi-liquid state until the final dimensions of the forging are obtained. In the third case, after complete crystallization by pressure, deformation in the solid state follows to obtain the final dimensions of the forging. This scheme should be distinguished from the production process of hot stamping of the workpiece-casting, which was not crystallized under high pressure [14-16].

Smelting and metered pouring of metal into the die cavity is the first stage of the technological process for all schemes of the technological process of liquid stamping.

Metal smelting can be performed either in the volume necessary to obtain a single forging, or in a melting unit of a larger volume (than is necessary for stamping a single forging), followed by a dosage when pouring the metal into the stamp. Each of these methods has its advantages and disadvantages: in the first case, the metal is in the molten state for a short time, which ensures the preservation of its chemical composition, and melting and pouring devices with induction heating can be installed directly on the press. In another case, it is difficult to maintain the chemical composition of the metal during prolonged exposure at temperatures above the melting point; it is technically difficult to dose the liquid metal on a portion of a given mass. However, the need to melt each batch of charge at a high speed during the first method (the melting time is 4 ... 10 min) to maintain the working stroke of the press requires high-power induction heaters and a large consumption of electricity [17-20].

For non-ferrous metals, melting and maintaining the temperature of the molten metal can be carried out in furnaces with a sufficiently large capacity.

When filling, it is very important to maintain the optimal temperature of the metal, sufficient to ensure its fluidity and fill the die cavity, and, on the other hand, eliminating overheating of the metal. The latter increases the thermal loads on the tool and worsens the structure of the forging metal. It is necessary to exclude the ingress of slag inclusions into the molten metal during filling. The speed of pouring metal into the stamp should not be too high, so as not to destroy the working surface of the stamp and exclude welding of the workpiece with the stamp. To do this, use the protective covering of the cavity of the stamp based on lime, graphite, kaolin, etc [21-23].

Liquid metal stamping is performed on specialized hydraulic and friction presses. Specialization of presses is due to the need for a high idle speed; adjustable, smooth pressure on the punch without sudden jumps in its movement; the need for ejectors and the possibility of mounting melting and filling devices. When installing the stamp on the press, thermal insulation must be provided between them.

Dies for liquid stamping in most cases consist of three forming parts: a liner, an ejector (forming a matrix) and a punch mounted on a movable press slider. The great value has the correct clearance between the punch and the matrix, because with a large gap possible jamming, while small - welding to the liner punch - matrix or burrs on the contact surfaces. The material of stamps is usually molybdenum-doped steel; for non-ferrous metals, carbon steels with a maximum carbon content of about 0.5 % are recommended [8].

The stamping process (crystallization and subsequent deformation of the metal in the die) determines the quality of the resulting forging. In this case, an important parameter of the process is the time from the end of filling the matrix with liquid metal to the beginning of crystallization under the required minimum pressure. The crucial condition for obtaining a high-quality forging is that the time should be greater than or equal to the time of the punch approach from the upper starting position to the closing of the die and the time spent on the development of the minimum necessary pressure in the die cavity.

Crystallization under such pressure is a determining factor for the formation of a fine-grained, dense metal structure and increasing its mechanical properties. The pressure value is recommended to be applied in the range of 100...00 MPa, and the holding time under pressure depends on the complexity and size of the forging and is 2...10 s.

The scope of application of liquid stamping is determined primarily by the advantages of this process over foundry technology and traditional processes of hot volume stamping. Compared to castings,
Forgings made by liquid stamping have higher mechanical and operational characteristics, higher dimensional accuracy, and lower metal consumption. In contrast to forgings obtained by traditional methods of hot forging, liquid forging is used to produce forgings with both thick and thin walls; without jumpers in the holes; with fewer transitions; with lower machining costs and other material and energy costs.

4. Conclusion

A method of liquid forming in combination with the hardening of the piston head ceramic fiber compared to traditional technology chill casting allows to reduce metal consumption by 30...40%; to obtain dense and fine-grained structure without defects and gas porosity, improve mechanical and physical properties of the material of the piston 15...20%, to achieve high thermal stability of the reinforcing effect, significantly increase the thermostability and reduce the wear of the working surfaces of the piston without the appearance of thermal cracks on the edges.

The use of composite materials in engine parts allows you to reduce fuel consumption, increase power, reduce noise, improve environmental safety and increase durability.

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