

# THE LASER TEXTURING OF OVERCOAT PISTON OF COMBUSTION ENGINE FOR ENLARGEMENT OF HIS RESISTANCE ON THE WASTE IN THE CONDITIONS OF THE FRICTION

Wojciech Napadlek

Military University of Technology, Faculty of Mechanical Engineering  
Gen. Kaliskiego Street 2, 00-908 Warsaw, Poland  
tel.: +48 22 6837357  
e-mail: wnapadlek@wat.edu.pl

## Abstract

The results of investigations laboratory of laser texturing overcoat piston combustion engine in the aim of producing on his surface the containers of oil were introduced in the article. The best parameters of laser processing (the length of the radiation, the thickness of the power, geometrical arrangement) were chosen in first stage of audits on samples from the melt of aluminum, near which the texturing of the sheath real piston of the engine was made. The topography of the surface of the sheath piston after the traditional mechanical processing and after laser texturing was analysed in second stage of comparative audits. The selection of the parameters of the laser processing was realized in the support about got results from the analysis of the topography of surface, microhardness and microstructure. Pulse laser ablative micromachining enables the oil micro trays production on the coat and the hub of the piston made of aluminum alloy such an AlSi12Cu1Ni1Mg (EN AW-2816). Using a laser beam with power density of  $q = 0.90 * 10^6$  W/cm<sup>2</sup>, pulse duration  $\tau = 155$  ns, repetition frequency  $f = 5$  Hz, the oil micro trays with reproducible geometrical dimensions: diameter = 70-Ø 100  $\mu$ m, the depth  $H \leq 20$   $\mu$ m, height of micro burr  $h \leq 2$   $\mu$ m, were obtained. Audits showed very profitable and repetition geometrical arrangement of the containers of oil what, about the shape cubic spherical, augurs large he will impale on the possibility of the farther continuation of audits on the real object – the combustion engine.

**Keywords:** laser ablation, piston, surface layer topography

## 1. Introduction

The piston in the engine fulfils many responsible tasks. Its bottom is the movable part of the combustion chamber, so it is exposed to high pressure and high temperature. Pressures reach of 7-15 MPa, and temperatures of about 250-500°C. The shape of the piston must ensure heat transfer from the bottom and allow to grasp and carry out the piston rings sealed the combustion chamber. In addition to these tasks the piston has yet to meet additional conditions. It should be light to facilitate balancing the crank system and to reduce the engine load caused by the forces of inertia. In addition, the material from which the piston is made must have a large thermal conductivity, high abrasion resistance, sufficient strength at elevated temperatures, good sliding properties, low coefficient of expansion [1].

Unfavourable working conditions of piston create diverse demands on the materials from which the piston is made. Materials used in the manufacturing of pistons can be divided into the following groups: non-alloy and iron alloy, aluminum alloys, special steel, composite materials.

The main way to manufacture pistons is sand or metal casting. Casting in metal forms, used in lightweight alloys, results in a more fine-grained material structure and better strength properties. Forged pistons are also used. Forging produces beneficial changes in the structure of the material, causing fragmentation of precipitated alloy component and rounding of its grains [1].

## 2. Laser micromachining of surface

During the interaction of laser radiation with matter the following phenomena may occur [2-8]:

- absorption of radiation,
- heating of matter,
- thermal conductivity,
- generation of pulse pressure or elastic strains, and possibly shock waves,
- melting of solids,
- diffusion or dissolution of matter originating from the crystalline grains of different composition, leading to the creation of a homogeneous medium,
- evaporation of liquid or sublimation of solids,
- emission of electromagnetic radiation,
- ionization of matter that is, generation of plasma,
- ablation of matter.

Of the above-mentioned phenomena, ablation, ionization and shock waves occur at very high power densities (above  $10^{10}$  W/cm<sup>2</sup>) and high energy (above 10 J/cm<sup>2</sup>). These processes occur during the laser pulse. In the laser-treatment of materials laser pulses with a duration of  $10^{-15}$  s (femtosecond lasers) to  $10^{-6}$  s and more are used, the energy density from 1 mJ/cm<sup>2</sup> to 1000 J/cm<sup>2</sup> and power density of  $10^3$  W/cm<sup>2</sup> to  $10^{12}$  W/cm<sup>2</sup> are applicable. Thanks to the laser pulse application a very high rate of temperature changes is reached, even up to  $10^{12}$  K/s, unattainable with conventional methods of heat treatment. This large rate of temperature changes determines the characteristics of the laser heat treated materials.

Generation of shock waves can be achieved without partial melting of the surface layer (by, for instance, covering the surface layer with a protective coating of an adequate thickness - absorbent) or with an initiation of laser ablation (melting process and the eruption of molten metal in a very short time - ns and  $\mu$ s). This phenomenon offers a wide range of modification of the surface layer. An innovative approach to form high surface tribological properties of machine parts is to use laser micromachining. Laser micromachining allows for precise surface modification and combining of technical surface as well as their bending, partitioning, cleaning and polishing. Some laser-processing technologies can be implemented also at the macro level, but not all and not always, it depends on the laser power, and almost always on the way the laser beam affects the treated material. Types of laser surface micromachining are shown in Fig. 1

One can distinguish two types of the laser beam interaction with the material:

- thermal: relying on the rapid increase of the surface temperature until it melts,
- ablative: relying on the rapid temperature increase until the evaporation of surface material and manufacture of mechanical shock exerted on the material.

Laser ablation is the evaporation of surface layers of different materials: metals, ceramics, plastics and others. Ablation process occurs during the laser pulse as a result of laser radiation interaction (absorption and scattering) with the material and the material disposal (in the form of vapour and liquid). As a result of irradiation the surface of materials by using pulsed laser radiation of sufficient energy density (power density), the phenomena occur such as: the absorption of radiation, thermal or photochemical phenomena.

A small reflection coefficient of radiation is desired, and sufficiently large surface area excitation requires laser beams with high intensities and small absorption depth of laser radiation. Material ablation process can be divided into several stages:

- deposited energy (in volume) reaches a threshold value of the ablation process,
- evaporation of the surface layer of material can occur through thermal (pyrolytic) or photolytic (for ultraviolet radiation) way,
- created plasma cloud is composed of: fragments of material particles, of electrons/ions, of the reaction products,

- plasma cloud causes the absorption and dispersion of the incident pulsed laser radiation,
- generated sound wave (into the material) after reflection from the interface may increase the reaction products.

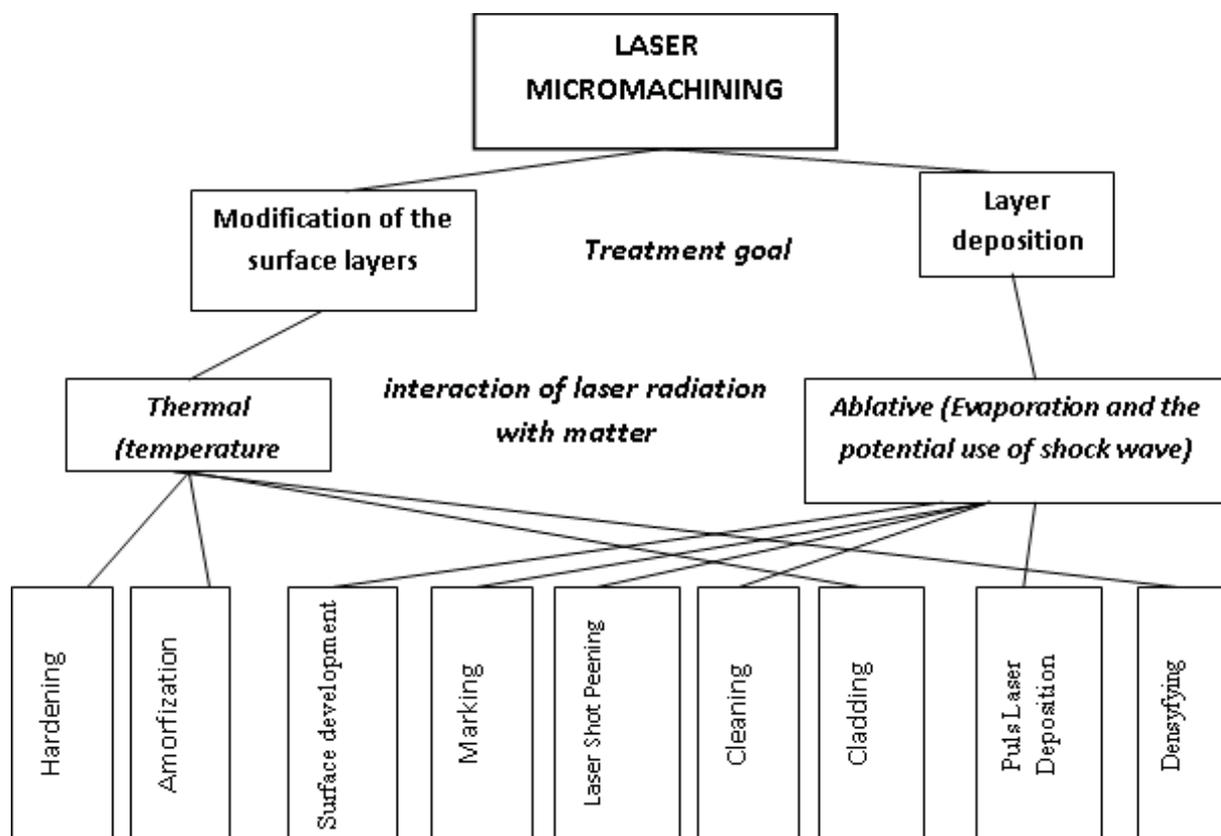


Fig. 1. Types of laser surface micromachining [4]

### 3. Research methods and facilities

The research object was a piston engine with self-ignition (ZS), a model of UTD-20. It is the forged piston made of aluminum alloy AlSi12Cu1Ni1Mg (EN AW-2618), whose chemical composition is shown in Tab. 1.

Laser micromachining in sensitive areas of the piston (mantle, the hub) was performed using Nd: YAG laser with wavelength of 1064 nm, 50 W and the repetition frequency of 3-65 kHz. The study of microstructure of the samples was taken by using a scanning electron microscope Philips XL30 and an optical microscope Keyence VHX - 600ESO.

Surface topography studies were carried out on the scanning profilometer Form Talysurf Series 2 from Taylor Hobson company.

Tab. 1. The chemical composition of alloy EN AW-2618 PN-EN 573-3:1998

|            | Chemical composition [%] |         |      |       |       |       |         |         |          |      |
|------------|--------------------------|---------|------|-------|-------|-------|---------|---------|----------|------|
|            | Si                       | Fe      | Zn   | Mn    | Zr+Ti | Ti    | Mg      | Cu      | Ni       | Al   |
| EN AW-2618 | 0.15-0.25                | 0.9-1.4 | 0.15 | <0.25 | <0.25 | <0.20 | 1.2-1.8 | 1.8-2.7 | 0.81-1.4 | rest |



Fig. 2. Production piston engine UTD-20

#### 4. The results

Laser micromachining of piston concerns the leading area of "piston cover". The study was conducted on the samples and the real piston made of aluminum alloy AlSi12Cu1Ni1Mg. Fig. 3 shows the object of study with the selected zone micromachining. On the surface of the piston oil micro pods was done with a degree of cover of 25%.

The proposed variant of the technological modification of sensitive areas exposed to friction wear in a piston engine UTD-20 is, among others, the modification by using laser micromachining for:

- the manufacture of oil micro pods (the micro channels system) in the mantle zone,
- the manufacturing of oil micro pods (the micro channels system) in the hub area of the piston.

Conducting the experiments the correct layout of oils trays was selected, whose geometry and extent of cover meets the requirements. To cover 25%, the best matched micromachining parameters are: scan speed  $v = 500$  mm/s, repetition frequency of 3 kHz, five repeated passages in the same zones. Using these parameters the following geometric dimensions of the trays were obtained: the depth of the trays in the range of 7-8  $\mu\text{m}$ , the diameter of the canopy measured on the surface of the material is about 70  $\mu\text{m}$ , the height of burr is 3-5  $\mu\text{m}$ .

The characteristic arrangement of the oil trays covering the extent of 25% is shown in Fig. 4, which proves that the repeatability of the manufacturing process of the trays is very high. Geometric shape and dimensions of the trays are in line with accepted technological objectives.

Analysis of chemical composition in the micro zones of piston mantle after laser texturing confirmed the piston material compliance with the applicable standard. Ablative micromachining practically does not change the chemical composition in microzones.

Piston mantle surface profile of the laser-produced oil micro pods is shown in Fig. 5. From this figure it is evident that the depth of the oil trays is between 7-8  $\mu\text{m}$  and a height of burr is 3-5  $\mu\text{m}$ .

The analysis of the tray shape performed on the transverse slices taken from the piston (Fig. 6) has showed that the size of S1 and S2 are different and less than 70  $\mu\text{m}$ , since the cross section does not coincide with their geometric axes. From the cross-section of the trays it can be concluded that the trays have the appropriate geometric shape and small micro burr (3-5  $\mu\text{m}$ ).

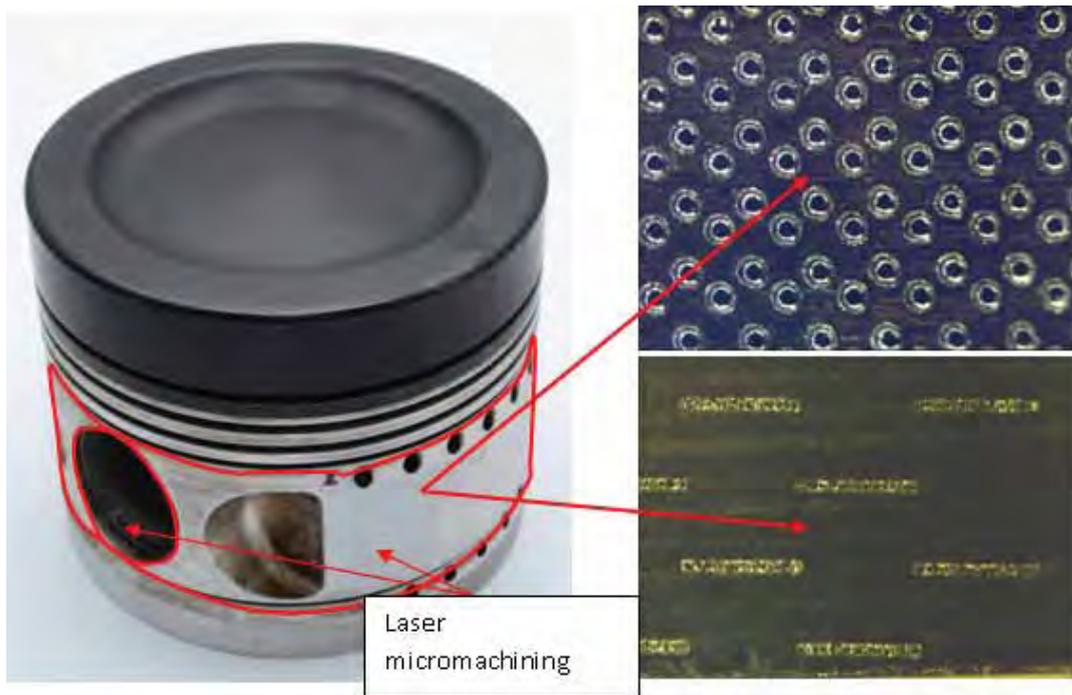


Fig. 3. Proposed technological options of modification of the mantle and hub of piston engine UTD-20 using laser micromachining; the view of pistons with the marked zones of laser micromachining

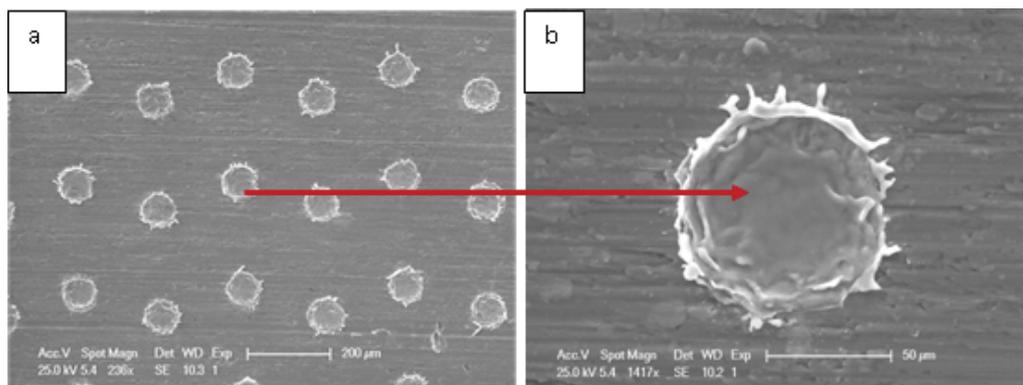


Fig. 4. Surface topography of the piston mantle with micro pods (cover 25%) were performed on the scanning electron microscope FEI XL 30

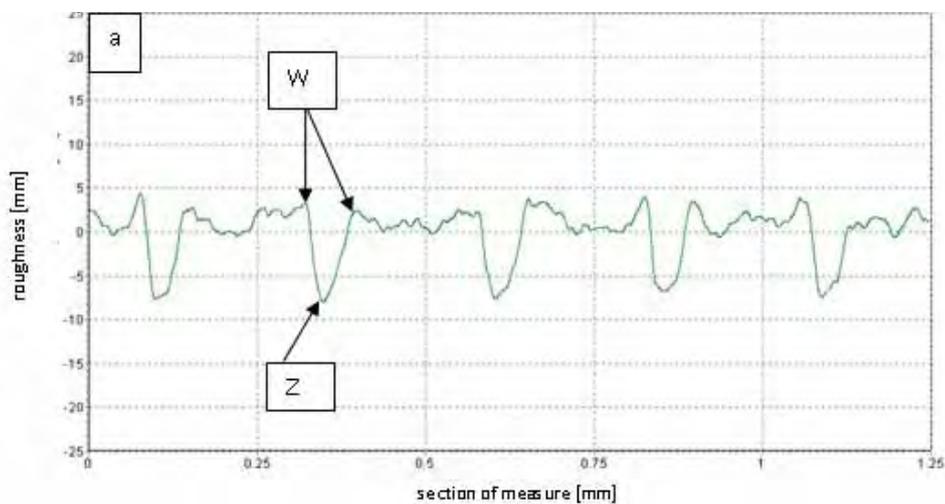


Fig. 5. Roughness profile of piston mantle after laser micromachining: W- the burr, Z – the tray

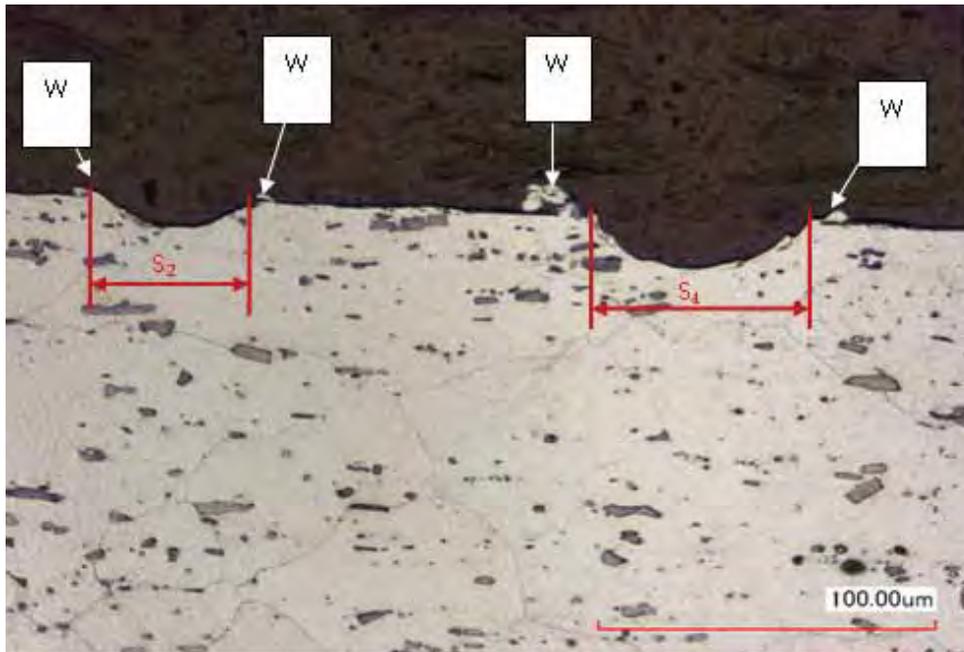


Fig. 6. Transverse section of piston oil micro trays made of an alloy AlSi12Cu1Ni1Mg. Photos made on the confocal microscope Keyence VK 8710 Laser Scanning Microscope,  $S_1$ ,  $S_2$  - the width of the tray with axial shift,  $W$  - the burr

## 5. Conclusions

1. In the processes of laser beam interaction with matter correct diagnosis of the nature of the impact of the laser beam on material, the selection of the appropriate type of radiation and selection of the correct treatment process parameters (power density  $q$ , pulse duration  $\tau$ ,  $f$  repetition frequency, scanning speed  $v$ ) are of great importance. Pulse laser ablative micromachining enables the oil micro trays production on the coat and the hub of the piston made of aluminum alloy such as EN AW-2816. Using a laser beam with power density of  $q = 0.90 \cdot 10^6 \text{ W/cm}^2$ , pulse duration  $\tau = 155 \text{ ns}$ , repetition frequency  $f = 5 \text{ kHz}$ , the oil micro trays with reproducible geometrical dimensions: diameter  $\varnothing = 70\text{-}100 \text{ }\mu\text{m}$ , the depth  $H \leq 20 \text{ }\mu\text{m}$ , height of micro burr  $h \leq 2 \text{ }\mu\text{m}$ , were obtained.
2. Piston coat surface layer modified by laser machining requires further finishing, to remove the micro burrs of 3-5 microns. For proper implementation of laser modification of the mantle and the piston hub, the use of hybrid technology is needed, that is a combination of mechanical and laser treatment. In the first stage of the process a semi-finishing machining is carried out, and in the second the oil micro trays is produced and mechanical machining is applied.
3. As a result of laboratory tests on samples and specimens of the actual elements of the diesel engine favourable geometrical parameters of the oil trays for two variants of the surface covering 25% were obtained:
  - depth of the oil trays - 7-8  $\mu\text{m}$ ,
  - diameter of the trays - 70  $\mu\text{m}$ ,
  - the height of the burr - 3-5  $\mu\text{m}$ .
4. In order the layer of the mantle and the piston hub after laser texturing was characterized by high resistance to wear in the friction conditions, it seems the that the optimum solution is to produce the oil trays in spherical shape with a diameter of 70-80  $\mu\text{m}$ , a depth ranging from 5-15  $\mu\text{m}$  with minimal overcapacity in the finishing treatment, which removes the burr formed adjacent to the zone trays. The proposed variant of surface covering by the trays of 25% seems to be an optimal for technological applications for the above mentioned engine components.

5. To verify the initial laboratory testing of laser texturing of the mantle and the piston hub in future durability tests on the test bench engine should be carried out.

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