Plasma electrolytic treatment of products after selective laser melting

L N Kashapov\textsuperscript{1,2}, N F Kashapov\textsuperscript{1} and R N Kashapov\textsuperscript{2,3,4}, D G Denisov\textsuperscript{2}

\textsuperscript{1}Institute of Physics, Kazan Federal University, Kazan, 420008, Russia
\textsuperscript{2}Engineering Institute, Kazan Federal University, Kazan, 420008, Russia
\textsuperscript{3}Laboratory of Radiation Physics, Kazan Physical-Technical Institute of the Kazan Scientific Center of the Russian Academy of Sciences, Kazan, 420029, Russia
\textsuperscript{4}Kazan State Medical University, Kazan, 420012, Russia

E-mail: kashramil.88@mail.ru

Abstract. The aim of the work was to study the possibilities of plasma electrolytic treatment for cleaning surfaces of metal products obtained by the SLM-technology. We found that the most effective cleaning from the large alloy particles occurs in the "hydrodynamic" mode, when the occurrence of hydrodynamic pulses observed. Further smoothing of irregularities eliminated by a stable burning of discharge in vapor shell. Analysis the morphology of the surface of difficult specialized products, such as crown conical gears, after plasma hydrodynamic treatment showed efficiency and advantages in comparison to conventional methods of final cleaning such as shot blasting.

Introduction

Additive manufacturing technologies are increasingly used in industry and move from the area of prototyping in small-scale production of functional objects. This is especially true for selective laser melting (SLM) and selective laser sintering (SLS). SLS technology was created and developed by Carl Deckard and Joe Beaman at the University of Texas at Austin in the mid 80s of the twentieth century for the manufacture of plastic products. SLM-technology is the next step of SLS, as it allows obtaining metal products by melting metal powders. It was on the developed in 1995 in Fraunhofer Institute for Laser Technology ILT in Aachen, Germany [1]. The melting of the metal powder is achieved by using a more powerful laser compared to SLS-technology. In these capacities observed intensive heating of the product, which may lead to deformation. To prevent overheating phenomena was used the system of substrate which support hanging elements of products and conduct heat to the platform of SLM-installation. Now more and more efforts is aimed at the development of new compositions of alloys of powders and study of the effect of particle size on the properties of the resulting products. Powders of instrumental and stainless steels most commonly used in SLM-production. After receiving of fabricated metal products need to remove mechanically the substrate and to clean the surface from the sintered powder particles and drops of molten metal. In this way, finishing mechanical machining is necessary step in obtaining high quality products with a desired surface roughness. One of these widespread methods is sandblasting. This method has several drawbacks, namely the creation of a large amount of dust, which must be removed with special suction devices, the gradual destruction of the nozzle, the flow of sand, the presence of micro- and nanoparticles of aluminum oxide on the
surface of the metal, which deteriorate the adhesion of the coating. This causes the necessity of searching a new method of removing the excess of fused metal particles and polishing the surface without changing the basic geometry of the product. In recent years the increasing distribution began receiving plasma electrolytic method of treatment [2,3]. One of its features is the ability to generate hydraulic impacts in the liquid [4, 5]. The aim of this work was to research of process of plasma electrolytic treatment of steel products, which are obtained by selective laser melting, and determine the possibility of replacing the sand blasting.

**Experimental**

In experiments on selective laser melting was used the installation Realizer SLM 50. This machine has a table top mounting and is very well suited for research purposes, as it has a small working area 70 mm in diameter and 40 mm in height. Working chamber of the machine filled with high-purity argon environment. To start the machine must be loaded three-dimensional model of the product in the form of stl-file. Using the software are generated the automatic supports, manual control is also possible. SLA-unit is equipped with Nd: YAG fiber laser, with maximum power 100 W and 1.064 μm wavelength. It is possible to adjust the laser power to 100 W and a scan speed of 200mm/s. Laser spot 0.2 - 0.4 μm. The thickness of the layer of construction was 30 μm. The energy density varied from 1.5 to 2.5 J/mm². In the experiments the powder steel 316 L (X2CrNiMo17-12-3) was used, particle diameter of 20 - 40 μm.

Research the dependence of the relative density of a product from the applied energy density of laser spot showed that when the energy density of 1.5 J/mm² relative density was ~ 93% and increases up to the maximum 99% at a power of 2.5 J/mm². Metallographic research has shown that the relative density of 93% - 98% have a pore size of 50 - 250 μm. With the increase in the relative density of defects decreases the average size of 5 μm and is at 99%. The surface morphology of the obtained samples were investigated by scanning electronic microscope EVO 50 CarlZeissAG. Figure 1 shows images of the surface of products produced by SLM.

![Fig. 1. SEM images of the surface of products produced by SLM.](image-url)
To initiate plasma electrolyte discharge on the surface of the workpiece used an experimental setup, which described in [4]. In this paper investigated the influence of ripple voltage. In the process of initiating, the discharge can occur intense sputtering of the electrode, and processing area will be different at different times. Therefore, the main focus was on the initiation of the discharge on prongs of gears which is 10 mm lower than the surface of the electrolyte. The area of the workpiece was 20 times less than the area of the electrode. An electrolytic bath filled with different electrolytes - aqueous solution of Na2CO3 or aqueous NaCl solution concentration of 5% by weight. The main operating parameters of the electrode system was the voltage on the electrodes, the magnitude of the discharge current and the current density on the electrodes. Changing the shape of the current and voltage at the time of discharge ignition was determined by an oscilloscope FLUKE 105 SCOPEMETERSERIESII, timebase varied from 5 ns to 60 s. The measurement of voltage at the anode was carried out with a digital multimeter device APPA 105, relative measurement error is 0.1%. Using a digital multimeter APPA 305 temperature measurement of the electrolytic cathode was carried out using chromel-copel thermocouple. The temperature of the electrolyte before the experiment and then measured by a mercury thermometer.

For comparison, treatment was conducted by the standard method with using a stream of particles of aluminum oxide 99.5% Al2O3 and SiO2, less than 0.06% grit 110 - 150 microns (Cobra, Renfert) on the installation APO-5U (Aveyron, Ekaterinburg). Figure 2 shows the image of the surface of the obtained samples.

For comparison, treatment was conducted by the standard method with using a stream of particles of aluminum oxide 99.5% Al2O3 and SiO2, less than 0.06% grit 110 - 150 microns (Cobra, Renfert) on the installation APO-5U (Aveyron, Ekaterinburg). Figure 2 shows the image of the surface of the obtained samples.

Before the experiment of the plasma-electrolytic treatment and cleaning, the current-voltage characteristic of discharge burning on workpiece in an aqueous solution of Na2CO3 was obtained, presented in Figure 3. Watching the glow of discharge occurs at a voltage of 130 V. Before that, at 30 V are recorded the occurrence of noise that increases with increasing voltage and goes to the appearance of the hydraulic pulses at a voltage of 60V. The highest intensity of hydraulic impulses observed in the voltage 120 - 140 V. Further, with increasing the voltage reduction in current
observed, but the glow of the discharge increases. At the same time stable combustion takes place in the of the discharge voltages above 190 V. Plasma electrolytic treatment and cleaning were carried out in the hydrodynamic regime, when the discharge was ignited on the product-anode and observed the occurrence of water hammer. When initiating of the discharge on the product-cathode there is a sharp rise in temperature, which is difficult to control and in its turn may lead to melting of the gear prongs.

![Current-Voltage Characteristics of Plasma Electrolytic Process of Steel 316L](image)

**Fig. 3.** The current-voltage characteristics of plasma electrolytic process of steel 316L.

After treatment were obtained two kinds of samples, the first processed in Na2CO3, represented in Figures 4a (magnification 20 times), 4b (magnification 400 times) and 4c (magnification 5000 times), the second processed in NaCl - 4d, 4e and 4f. The treatment in both instances was conducted at a voltage of 130 V, in the case of Na2CO3 solution under the action of the hydrodynamic impulses are removed sintered powder particles is about 75% of the irregularities, but the fused powder particles remained (Figure 4b).

![Micrographs of Samples](image)

**Fig. 4**

In the case of treatment in a solution of sodium chloride, in addition to the impact of the hydrodynamic impulses, also anodic dissolution of surface occurs, which leads to a more efficient
cleaning process. Namely, the separation of larger particles under the influence of hydrodynamic impacts and smoothing fused powder particles. This is clearly seen when compared to sand blasting treatment (Figures 2a and 4d are similar).

Conclusions
We found that the most effective cleaning from the large alloy particles occurs in the "hydrodynamic" mode, when the occurrence of hydrodynamic pulses observed. Further smoothing of irregularities eliminated by a stable burning of discharge in vapor shell. Analysis the morphology of the surface of difficult specialized products, such as crown conical gears, after plasma hydrodynamic treatment showed efficiency and advantages in comparison to conventional methods of final cleaning such as shot blasting.

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

References
[1] L Lu, JYH Fuh, YS Wong. Laser-Induced materials and processes for rapid prototyping. Boston: Kluwer Academic publishers; 2001.
[2] L. Kashapov, N. Kashapov and R. Kashapov, 2013 J. Phys.: Conf. Series 479 012011
[3] Kashapov L N, Kashapov N F and Kashapov R N 2013 J. Phys.: Conf. Series 479 012003
[4] Kashapov L, Kashapov N and Kashapov R 2014 J. Phys.: Conf. Series 567 012025
[5] Denisov D, Kashapov N and Kashapov R 2015 IOP Conference Series: Materials Science and Engineering 86 012005