The manufacturing of TiAl6V4 implants using selective laser melting technology

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Abstract. In this article we study the technique for creating medical implants using additive technologies. A plastic skull model was made. The affected part of the skull was identified and removed. An implant was made of titanium alloy. The implant was installed in the model skull.

1. Introduction
Additive manufacturing is often used in high-tech areas such as aircraft engineering [1, 2] and the space industry [3, 4] for the manufacture of geometrically-complex products. At the same time, they are becoming more widespread in medicine [5, 6]. The main reason for the use of additive manufacturing in medicine is the possibility of producing a personalized implant within a short time. As a rule, selective laser melting (SLM) and electron beam melting (EBM) are used for the manufacture of implants [7]. Depending on the area of application, CoCr [8, 9] or titanium alloys [10-12] are more widely used as a construction material. These materials have high biocompatibility. There are studies on the use of additive manufacturing in craniofacial surgery [13, 14]. The aim of this work is the fabrication of a titanium implant to replace the affected area of a skull cancer patient.

2. Main part
In the first stage of work (figure 1), a model of the fragment of the skull with the affected part was made. Malyan Desktop 3D printer was used. The material is plastic ABS. The diameter of the plastic wire is 1.75 mm. The plastic feed rate is 50 mm/sec. The feed speed of the table is 90 mm/s. The temperature of heating the plastic is 230 ºC. The temperature of the heating base plate is 85 ºC. The fill factor of the volume of the walls of the sample is 30%.

The second stage of the work is determining the part of the skull, which we planned to remove (figure 2).

A metal implant was made to replace the affected part of the skull. The implant was manufactured using selective laser melting. A powder of titanium alloy TiAl6V4 was used as the feedstock.

Selective laser melting (SLM) is based on layer-by-layer laser fused metal powder. This technology allows us to produce parts with complex shapes in a short time. A schematic of the SLM process is shown in figure 3. The part is divided into elementary layers (with a thickness from 20 to 100 microns). A two-dimensional sketch is formed for each layer. The plate is lowered to the thickness of the layer and the layer is formed by the leveller. The manufactured part has a near-net shape.
The metal implant was made for replacement of the affected part of the skull. The implant was manufactured using selective laser melting. The powder of titanium alloy TiAl6V4 was used as feedstock.

The process of selective laser melting of metal is determined by a large number of parameters. Each parameter influences the properties of products (roughness, strength, density, hardness, wear resistance, etc.). The most important parameters are:
- Power Output (P) – laser output, W;
- Speed (V) – scanning speed (when using continuous melting), mm/s;
- Layer Thickness (h) – the thickness of powder layer, µm;
- Point Distance (PD) – the point spacing of the dotted laser path (if the machine allows dotted scanning of the exposure vectors, the spacing of points may be specified with this function), µm.
- Exposure time (ET) – exposure time on one point of the dotted laser path, µs.
- Hatch Space (HS) – the spacing between individual hatch lines, µs.
Figure 3. Selective Laser Melting process [15].

There are 2 groups of SLM machines:
- with continuous melting mode: the laser operates continuously; the laser beam runs over the surface of the powder with a constant speed;
- with "dotted melting" mode: the laser pulses; the laser beam moves from point to point.

The first type of machine requires the specification of one parameter – Speed (V). The second type of installation requires the specification of two parameters: Point Distance (PD) and Exposure time (ET). All other parameters for both types of machines are identical.

The machine SINTERSRATION® Pro DM125 SLM [16] is one of the second type of machines. This machine is equipped with a CO2 laser redPower SP-200C-04 with output power up to 200 W. The scanning speed can vary, up to 1000 mm/s. The laser beam diameter at powder surface is 35 µm. Layer thickness can be vary from 20 to 100 µm.

Alloy TiAl6V4 is characterized by low density, satisfactory ductility, and high biocompatibility. At the same time, the alloy shows a tendency to residual stresses, cracks, and microcracks [17-23]. Residual stress and cracks may appear in the process with high cooling rates. At the stage of implant manufacturing, the aim was to select parameters of selective laser melting which provide for the density of the product structure.

The large number of SLM process parameters makes it complicated to analyze the influence of mode selective laser melting on the characteristics of the resulting products. Often, researchers use, density of absorbed laser energy to describe the mode of SLM. In this paper, two types of energy densities are used - surface and volume - to describe SLM modes.

\[ E_s = \frac{P \cdot ET}{PD \cdot HS}, \]  

\[ E_v = \frac{P \cdot ET}{PD \cdot HS \cdot h}. \]  

Parameters used for implant manufacturing are shown in table 1.

| P, (W) | h, (µm) | PD, (µm) | ET, (µs) | HS, (µm) | E_s, (J mm^{-2}) | E_v, (J mm^{-3}) |
|-------|---------|----------|----------|----------|-----------------|-----------------|
| 100   | 50      | 50       | 100      | 75       | 2,7             | 53              |

Apart from SLM modes, scanning strategy also affects the properties of the produced material. In this paper the "alternating" scanning strategy was used (figure 4). Hatch direction for the new layer was changed to 90 degrees.
The metal implant (figure 5) was installed in the skull model in a remote area (figure 6). The analysis showed a satisfactory pair of surfaces. The total duration of operations for 3d-modeling and production of the model and the titanium implant was 4 days. Density of obtained implant is 93.2% of the theoretical. Density was measured using Archimedes technique.

Figure 4. Alternating scanning strategy.

Figure 5. Medical implant: a - CAD-model, b – metal product.

Figure 6. The installation of the implant in the skull model.

3. Summary
We developed the technique to produce titanium implants using additive technologies. The analysis showed a satisfactory pair of surfaces between the skull model and implant. The production time of 4 days.
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