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Feeding Devices Design for Selective Laser Melting Formation of Heterogeneous Powder Structures

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Abstract. The article presents the principles of selective laser melting technology for manufacturing of polymetallic products. The results of theoretical investigations of heat and mass transfer at the border of materials are shown. Types of feeding devices design have been demonstrated.

1. Introduction

The Additive Manufacturing (AM) industry has undergone tremendous growth in recent years. Although it seems to be a relatively new technology, it has been present over the last twenty years, but it is in the late decade when a big development has taken place [1]. One of the type of additive manufacturing is selective laser melting technology (SLM) [2].

The major AM trends are improvement of quality and shape complexity of manufactured products. SLM technologies allows to produce products of the functionally graded materials (FGM) [3,4], characterized by a continuous change from one layer to another following characteristics: chemical composition, morphology and crystalline structure.

Further SLM-technology development is impossible without the development and manufacturing of specialized equipment for its implementation [5,6]. SLM machines for the manufacture of products from FGM differs from usual SLM machines by feeding devices. These feeding devices provide in layer the formation of heterogeneous powder structure of two different metals/alloys and each of the metal/alloy has its own predetermined plane coordinates.

Heterogeneous powder structures forming methods and equipment development provides an opportunity to combine the materials during the laser sintering process and polymetalic products manufacturing [7,8].

There are some practical applications of development, such as:

- Gradient structures manufacturing;
- Improving products strength characteristics and decreasing weight and size;
- Improving products heat resistance, abrasion resistance, corrosion resistance.

2. Heat and mass transfer at the border of materials during laser synthesis

According to theoretical investigations of heat and mass transfer and blending of materials at the border during laser synthesis the size of transition zone was determined. The size of transition zone in a vertical direction is about tenths of millimeter, and around half millimeter in a horizontal direction. Therefore resolution of powder feeders should be within 1 millimeter range.

The thickness of the powder layer has a size in a few powder fractions [9]. It is necessary to provide melting of material on the whole layer thickness and solid adhesion between the layers for the production of a homogeneous product. In this case, heat problem can be described as a two-dimensional problem. It means that the temperature field is determined similarly to the temperature field created by a linear heat source in the plate. In the case of using different powders (heterogeneous materials) the situation can also be modeled as a result of laser irradiation on the plate composed of two materials (see figure 1).

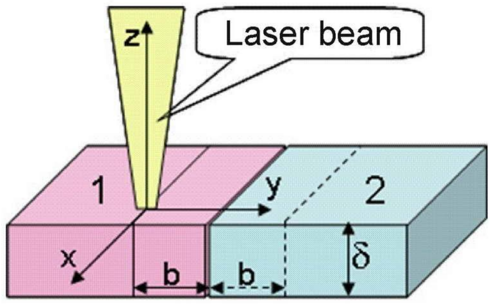

Figure 1. Scheme of the heat source movement

For the calculation of the heat transfer between layers it was accepted that contact area between the powder is negligibly small and change of powder fraction during melting was disregarded. At the border of the two materials continuity conditions of temperature field and of continuous heat flow were applied:

$$T_1\big|_{y=b} = T_2\big|_{y=b} \quad \text{and} \quad \lambda_1 \frac{\partial T_1}{\partial y}\bigg|_{y=b} = \lambda_2 \frac{\partial T_2}{\partial y}\bigg|_{y=b} \tag{1}$$

Where T1, λ1 and T2, λ2 are temperature field and coefficients of heat conductivity of the 1st and 2nd material.

The fundamental solutions of the heat equation were used for the solving heat problem. Thermal field for the 1st material was determined as superposition of thermal fields from the real heat source and the reflected source (1). Thermal field for the 2nd material was determined as field of source located at a distance "c" from the border.

It is impossible to obtain an exact solution for any value of "x", so area was limited from x = 0 to x = l, where l — value equal to the length of the molten bath, this will allow to minimize an error in the most important area of calculation. Considering conditions above an approximate determination of the required distance has been obtained as a result of serial changes:

$$c \approx 2l \frac{\chi_1 - \chi_2}{\chi_1 \chi_2} + b \frac{\chi_2}{\chi_1} \tag{2}$$

Where χ1, χ2 are thermal coefficients of the two materials.

In contrast to the 1st material, solution of the problem of the second material thermal field determination is an approximation suitable for use at the large distances from the heat source. It is necessary to have an exact solution of the heat problem in the second material for determination the temperature when the heat source moves near the border of materials. The linear theory of heat conduction has been used to obtain the solution as before. Thermal field can be described by the equation with boundary conditions:

$$V_0 \frac{\partial T}{\partial x} = \chi \Delta T \qquad T\big|_{y=b} = T(x) = \frac{2\lambda_1}{\lambda_1 + \lambda_2} T_1^{(0)}(x,b,z), \mathrm{T}\big|_{y\to\infty} \to 0, \mathrm{T}\big|_{x\to\pm\infty} \to 0 \tag{3}$$

T1(0) – thermal field from the real heat source in the first material.

The temperature distribution in the second material was calculated using the following expression. The heat source moves in the first material parallel to the border of materials. The source speed is constant.

$$T = \frac{V\lambda_1 c_2 \rho_2}{\pi\lambda_2(\lambda_1+\lambda_2)} \int_{-\infty}^{\infty} T_1^{(0)}(x',0,z) e^{\frac{V(x-x')}{2\chi}} \frac{y}{\sqrt{y^2+(x-x')^2}} K_1\left(\frac{V}{4\chi}\sqrt{y^2+(x-x')^2}\right) dx' \tag{4}$$

Thermal properties in a molten zone and the melt surface tension were taken in view of percents of the materials in the melt. Example of calculation of the thermal field is shown in figure 2.

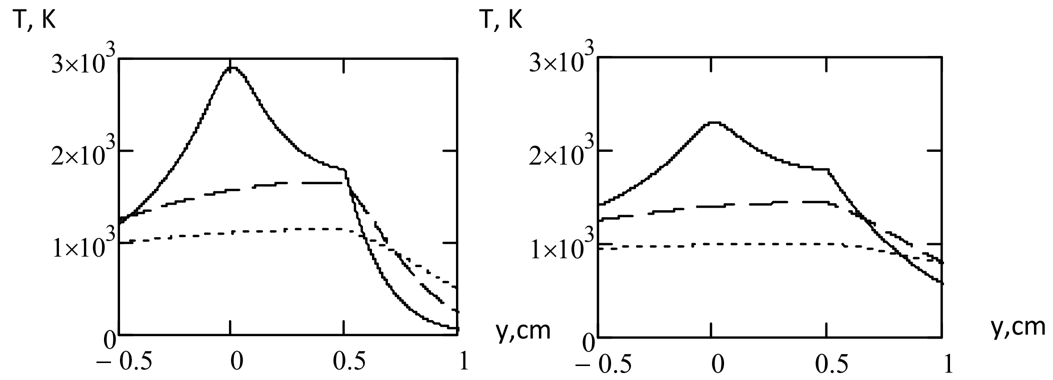

Figure 2. The thermal field in the contact zone (y=0.5 cm – the border of the two materials) The solid line corresponds coordinate "x" of the heat source, dash line – offset back at 1 cm, dotted line – at 3 cm.

3. Feeding methods in laser sintering

Heterogeneous powder structure formation process of two different metals or alloys can be realized in two basic ways: using the multi-nozzle dispensing system and using a controlled feed from the feeding bunkers.

The order of formation is shown in figures 3 and 4.

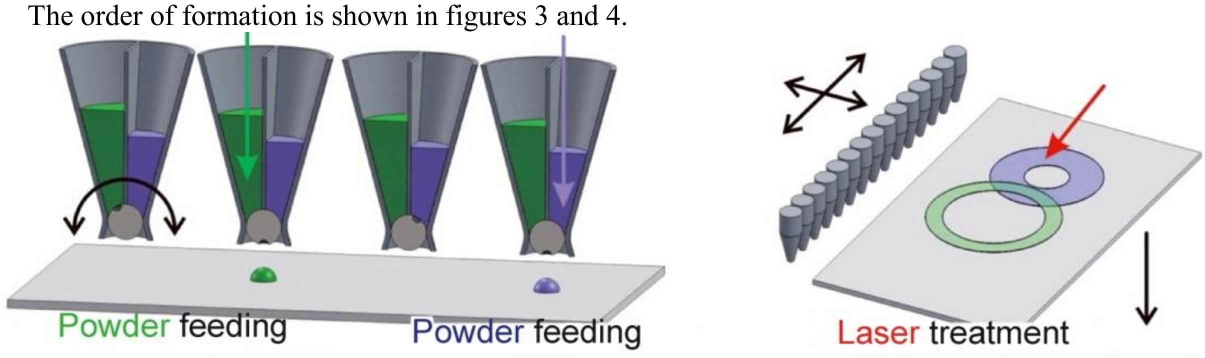

Figure 3. Heterogeneous powder structure formation order using the multi-nozzle dispensing system

Layers formation occurs by moving the multi-nozzle system over the building platform and feed of required powder at each point, then laser treatment starts.

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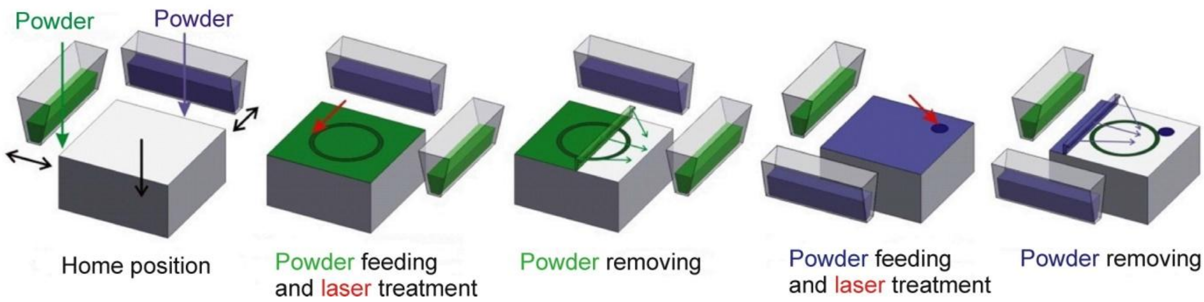

Figure 4. Heterogeneous powder structure formation order using a controlled feed from a feeding bunkers

Process of layer formation with using bunker system divides into two steps:
- deposition of the first powder , laser treatment and removing the untreated powder
- deposition of the second powder , laser treatment and removing the untreated powder

Feeder may include powder collector for the untreated powder removing from the building surface area.

The powder layer removing can be realized by using the «vacuum cleaner» principle. Powder removes through the moving slot nozzles, which are moving at low height (~1mm) above the building plane. But by using such nozzles it is hard to provide stable powder collecting characteristic. This makes necessary to collect the powder with a large margin over the layer thickness, order to avoid the cavities and overhangs formation, which can enter into the new powder layer from another material. This significantly increases an amount of the extracted and fed powder amount.

Alternatively, it is proposed to use a moving rotor as a powder collector working tool. Rotor tube is made from the porous material such as sintered metal powder (see figure 5). There is vacuum in the rotor inner. When the rotor is rolling along the powder plane, there will be the gasostatic force attracting the powder to the collector outside surface. The value of this force and thickness of collected powder layer are proportional (in the first approximation) to the vacuum inside of the rotor (gas pressure falling between the inner volume and the outside rotor surface).

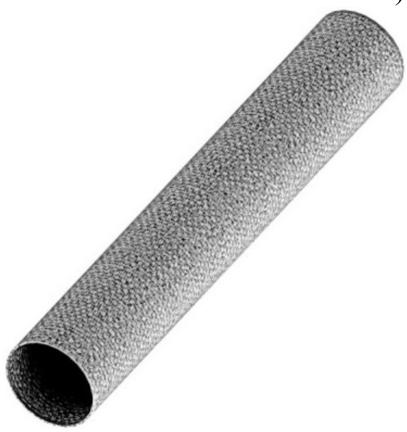

Figure 5. Powder collector rotor (tube from a porous material)

The rotor can roll across the whole powder surface.

The pressure required to hold the powder on the rotor surface, in the first approximation, does not depend on the powder diameter, and is calculated by the formula:

$$\Delta P=4/3*\rho*g*\Delta R \quad (5)$$

At $\Delta R>>R$, where:

ΔP – the pressure difference between the processing area and the rotor inner;

ρ – powder density;
g – the free-fall acceleration;
ΔR – the rotor wall thickness;
R – the rotor tube radius.

It should be mentioned that the powder feeding bunker device provides productivity on a few orders higher [10].

4. Structure of feeding devises

The model of the feeding devise was designed for the comparing experiments of two methods described above. The model allows to realize both methods.

The main parts of powder feeder are:

- The moving system
- The feeder

General view of the moving system is shown in Figure 6.

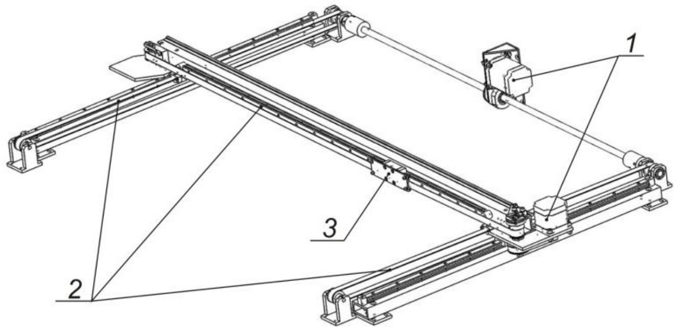

Figure 6. General view of the moving system (1 – drives; 2 – rails; 3 – carriage for fixation of the feeder)

Moving system is designed as a two-axis portal with linear guides, stepper motors and toothed belts as the motion transmission elements.

The multi-nozzle dispensing feeder and the bunker feeding device are shown in figure 7 and 8.

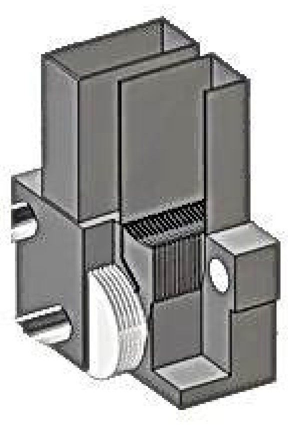

Figure 7. The multi-nozzle dispensing feeder with dispensing roller consisted of a set of thin discs (about 1mm), each of which is equipped with individually controlled drive.

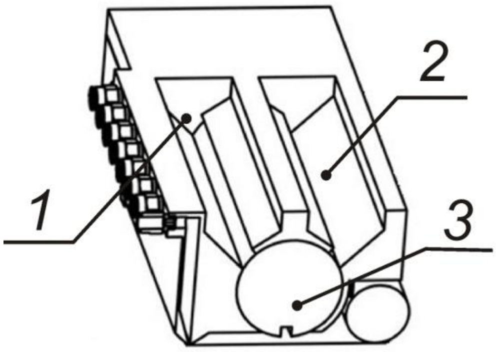

Figure 8. The bunker powder feeding device with the dispensing roller
(1-first powder, 2- second powder, 3- dispensing roller)

5. Conclusion

According to theoretical investigations of heat and mass transfer and blending of materials at the border during laser synthesis technical requirements for powder feeding devices for SLM machines were formulated. Models of powder feeding devices were designed for experimental research of heterogeneous powder structures formation processes.

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