SELECTIVE LASER SINTERING TECHNOLOGY
IN LEAN MANUFACTURING CONCEPT

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ABSTRACT

The introduction of additive technologies in the concept of “lean manufacturing” in the enterprise can be con- sidered as an element of the company’s strategy to improve activities. Additive technologies include a rational use of resources, with a minimum of defects, loss, improving product quality. Selective laser sintering technologies are an effective tool for solving modern problems in many industries. These technologies allow not only to draw attention to the possibility and prospect of development of the technology, but also to revise the standards and methods of obtaining raw materials - powders with certain, in most cases, requirements to the size, shape and quality of products.

The process of selective laser sintering is directed at eliminating all types of losses, which is typical for “lean manufacturing”, at increasing productivity and economic effect, reducing time, resources, storage locations, in the use of raw materials high variability of growing parts of different composition of materials.

Experimental studies were carried out on the installation for selective laser sintering of Eosint M 280 made of EOS StainlessSteel PH1 alloy - stainless steel in the form of fine powder. This type of steel is characterized by high corrosion resistance and excellent mechanical properties, especially in the dispersion-hardening state. Quality control of the obtaining was carried out by computed tomography.

The practical significance of the research consists in the fact that its scientific results can be used in the organization of “Lean manufacturing” in the enterprise, aimed at improving the efficiency of the enterprise, improving product quality and competitiveness.

Keywords: lean manufacturing, quality, the selective laser sintering, fine materials, computer tomography, laser beam, corrosion resistance, resource saving.

INTRODUCTION

One of the most important and modern areas of industrial management is the concept of lean production, the essence of which is the orientation of the enterprise to maximize efficient use of resources, with a minimum of wedlock waste, improving product quality [1]. The problem is that the made products or services have to be rendered to the client in time, to be with appropriate quality and to conform to requirements of the customer. The majority of production business processes consist 90% of losses and only 10% of the work adding value. Everything that does not add any value for the consumer, can be classified as loss and has to be eliminated. Ideologists of lean production allocate eight types of production losses [2]:

Overproduction – production of products on which the order did not arrive leads to surplus of stocks and generates such types of losses as surplus of labor and warehouse and also costs of transportation;

Waiting time (loss of time) is that the workers who oversee the work of the automatic equipment, idle waiting for work operation, parts, delays in the progress of the downtime;

Excess transportation or movement – movement of work in progress of long distances; excess movement of materials, details and finished products in a warehouse and from a warehouse;

Excessive processing – unnecessary operations in processing details when inefficient processing because of poor quality of the tool and the unreasoned constructive
decision causes the losses connected with the overestimated requirements to quality of finished goods;

The surplus of stocks – excess of raw materials, work in progress or finished products increases time of orders, causes a products obsolescence, leads to damage of finished products;

Excess movements are all excess movements which have to be done by employees in the course of work;

Defect and alteration – production and correction of defective parts; repair, alteration, waste, replacement of products and its check lead to loss of time and forces;

Unrealized, creative potential of employees – loss of time, the ideas of skills, opportunities of improvement and acquisition of experience because of the inattentive attitude towards employees.

Though J. Vumek and D. Jones emphasize that its advantage is that the system for 80 % consists of organizational measures and, only 20 % make investments into technology [3], nevertheless investments into technology play a very important role in the concept of lean production. It is worth paying attention that at the expense of technological innovations, losses of excessive processing, defect and alteration and partially – losses from expectation, can be eliminated [4, 5].

For an example we will consider the flow map with the movement of materials during the manufacturing process (Fig. 1) [6].

Finished parts:

• The time during which value added is created is a small fraction of the total time.

• In the traditional approach, in order to reduce the cost of production, operations during which value added is created are taken into account.

• Lean manufacturing principles require consideration of the value stream as a whole in order to eliminate operations that do not add value.

Search of technologies which not only create added value but also reduce the loss, is a major element of the concept of lean production. These include the technology of selective laser sintering.

The main specificity of selective laser sintering technology is the fact that all of them are based on the use of fine materials - metal and composite powders in the size range: 10 - 50 microns, or 40 - 80 microns.

At the same time, the developers determined the main requirements to the powders, reasonable conditions compact packing of spherical bodies, thermodynamics processes of sintering and technological peculiarities of the process. These include: a specific range of particle size, the sphericity, the frequency of the surface.

To fully realize the technological benefits of these technologies and to provide the best quality products, the implementation of these requirements is necessary. It is also important to note that the process is one-step, i.e. the prepared melt is directly fed to the spray without additional operations. The speed of production is reduced tenfold and there are no treatment facilities and storage of waste [7].

The main advantages of the method of selective laser sintering are: modern equipment, high efficiency; high variability of cultivation details of the different composition materials; the speed is a huge plus in the manufacture of complex shapes; the minimum mechano- processing considerably reduces the time for production; the ability to promptly make changes in design, improved product quality [8]. These additive technologies reduce the loss of excessive processing, defects and rework and save time, materials, resources, and storage areas.

Also, they are characterized by production of environmentally friendly products with low energy con-

![Fig. 1. The flow map with the movement of materials during the manufacturing process.](image-url)
Russian manufacturers are working on creating new designs, developing technological solutions and getting their own powders. Working in this direction in the holding company “Voronezhselmash” in industrial Park “Maslovskiy”, “Saturn” (Rybinsk) Institute of Laser and Welding Technologies (SILT) in Saint-Petersburg and it is also worth noting the FSUE “VIAM”, Moscow. They have the necessary equipment, they have learned to get domestic powders from steel and nickel, suitable for the manufacture of parts of aircraft engines. I also want to mention the Scientific Centre of Powder Materials Science (NCPM) at Perm National Research Polytechnic University (PNRPU), they are working on a German installation of ALD VIGA-2B, which creates metal powders and alloys by gas-dynamic spraying. However, the organization of lean production at enterprises of powdered materials is not sufficiently developed and requires further research.

Table 1. Composition of material PH1.

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Mn</th>
<th>Si</th>
<th>Mo</th>
<th>Nb</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(balance)</td>
<td>(14 – 15.5 wt-%)</td>
<td>(3.5 – 5.5 wt-%)</td>
<td>(2.5 – 4.5 wt-%)</td>
<td>(max. 1 wt-%)</td>
<td>(max. 1 wt-%)</td>
<td>(max. 0.5 – 0.45 wt-%)</td>
<td>(max. 0.07 wt-%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Key parameters for cultivation of details from PH1 stainless steel.

<table>
<thead>
<tr>
<th>Model</th>
<th>Work area, mm</th>
<th>Step of construction, micron</th>
<th>Power, W</th>
<th>Productivity, cm³/h</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOSINT M280</td>
<td>250x250x350</td>
<td>20-200</td>
<td>400-1000</td>
<td>20-35</td>
<td>PH1</td>
</tr>
</tbody>
</table>

EXPERIMENTAL

In this work blanks obtained by the method of selective laser sintering were investigated. Layer-by-layer cultivation of billet parts was carried out on the Eosint M280 installation. Investigations of products made by selective laser sintering were carried out from an EOS StainlessSteel PH1 alloy - stainless steel in the form of fine powder. This type of steel is characterized by high corrosion resistance and excellent mechanical properties, especially in the precipitation hardening state. The composition of the powder is shown in Table 1.

Key parameters for cultivation of parts from PH1 stainless steel are specified in Table 2.

Production at standard parameters and 20 µm thickness of the construction layer and the parts are completely alloyed.

Quality control of the surface layer of the workpiece was carried out on the microscope, DIP-1. The essence of manufacturing method of selective laser sintering is a layer-by-layer sintering of powder materials using a laser
Fig. 3. Scheme of the process of selective laser sintering.
beam (Fig. 2). A laser beam sinters the powder layer by layer in a powder bin. The main part of the study focuses on the correlation of the main parameters of the process and their impact on the material.

Process parameters such as laser beam power, productivity, construction step, such as the height and width of the workpiece layer, as well as the quality of the surface layer and the depth of penetration of the laser beam have a significant influence on the dimensional characteristics of the material.

The speed and quality of 3D printing, which is inversely proportional to each other, depends on the laser power. That is, the higher the speed (laser power), the lower is the quality. The main task of the researcher is to achieve the ideal ratio.

During laser sintering, a laser beam with the diameter of 100 μm locally melts the top layer of powder on the powder sheet. The laser will be partially absorbed by metal powder particles, creating a molten layer that solidifies very quickly. Laser power typically ranges from 200 watts to 1000 watts [9]. At different stages of the process of selective laser sintering, there are different methods of control (Fig. 3).

RESULTS AND DISCUSSION

Undoubtedly, the very first stage on the way to quality of products is the quality characteristics of the powder. Changing some important factors, for example, the ratio of the powder, the aging of the powder and the moisture content, it is studied the effect on mechanical and physical properties, density and porosity. In Fig. 4 you can see the factors affecting the quality of the powder.

To understand how this occurs, consider that the quality control of each batch of material begins with the delivery (chemical properties, granulometric composition) and ends with analysis of the work. To achieve certain parameters in terms of quality, it is necessary to take into account the influence of such factors as laser power, spot size, layer thickness, laser beam exposure time, direction of movement tracks, as well as chemical and mechanical properties. And of course, there must be equipment class EOS. The SLS process usually operates by nuclear diffusion and binding of structural components of the powder at temperatures significantly below the melting point and then melted with a laser, thus enveloping the powder through capillary forces. Therefore, the particle size distribution, porosity and layer thickness have a great influence on thermal and mass transformations in the manufacturing process, which can affect the density, mechanical intensity and accuracy of the final molding of products [7].

Investigation of various influencing factors of the process of laser sintering on the material is selected by different methods. Thermal analysis is usually used to determine the crystalline melting point. In the course of these studies, it can be seen that the longer the material is exposed to thermal effects, the more are the structure of the material changes. Therefore, increasing popularity is the question of the quality of sintered powder layer [8].

As practice shows, in billet parts there can be such defects as rough surface which is detected by measurements on the contourograph and surface roughness sam-
Pores. You can also find non-fusion - a defect in the form of incomplete alloyage of material. It can be detected visually, using the metallographic method, X-ray computer tomography. Fig. 5 shows the voids (non-fusion) in the material. The main disadvantages of objects created by the method of selective laser sintering occur due to the porosity of the material, the most common pores are presented in Table 3. When controlling the quality of the workpiece using the computer tomography method, a defect in the form of darkening characteristic of discontinuity was detected (Fig. 6).

Table 3. Types of pores.

<table>
<thead>
<tr>
<th>Pores</th>
<th>Photo</th>
<th>Description</th>
<th>Typical sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small pores</td>
<td></td>
<td>The formation of pores due to the presence of gas in the bulk material.</td>
<td>5-20 µm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Depends on the material</td>
<td></td>
</tr>
<tr>
<td>Elongated pores</td>
<td></td>
<td>No metallurgical contact between the layers</td>
<td>50-500 µm</td>
</tr>
</tbody>
</table>

Porosity problems can be solved by a quality management process in the pilot study [9]. Development of feedback is necessary to improve, for example, reproducibility, accuracy, quality of the surface layer and microstructure of the manufactured components. Prior to the production of a specific product, a search and optimization of parameters of selective laser melting is carried out [10]. There are no optimum parameters of process which work in all cases. The differences in the thickness of the unit, height and angles can lead to heat concentration, resulting in, for example, phase transformations, residual stresses or recrystallization. The strength depends on the small grain size and microstructural components.

CONCLUSIONS

To date, research on the quality of the final part, made by the method of selective laser sintering, is made up of the quality of each applied layer, therefore, the
debugging of the modes is carried out on individual tracks. If we consider that the main concept of “lean production” is to increase the efficiency of production processes and identify and eliminate production losses, we can conclude that additive technologies meet the main criteria of the concept of lean production. Selective laser sintering, as well as lean manufacturing, aims to meet the needs of customers in terms of product quality. This requires, on the one hand, flexible and quickly customizable production, which is capable of producing not only a variety of goods, but also small batch goods.

Also, the stages of product processing are clearly spelled out in the program throughout the process, which eliminates the possibility of introducing unnecessary actions. Raw materials in powder form do not require a large room for their storage, the principle of «adding» excludes the use of surplus raw materials and the appearance of industrial waste. Summarizing, we can say that the introduction of additive technologies can be considered as an element of the strategy for implementing the concept of «lean production» in the enterprise.

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