Investigation of the process of additive formation of fusible materials using a low-power solid-state laser

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Abstract. The method was developed for the additive formation of fusible materials based on research. He suggests using a low-power solid-state (ytterbium) laser (maximum power 50 W) for this. A series of experiments were carried out and the elements were obtained for the shaping mode without complete melting while maintaining the shape of the workpiece, such as: power, focal length, travel speed. The results confirmed the possibility of using this type of equipment for the additive forming of products from fusible materials. They are the basis for further research on other materials, including with the additional use of a protective atmosphere.

1. Introduction
Additive Manufacturing are technologies of layer-by-layer building up and synthesis of objects. They have found wide application in production and industry and they allow you to quickly obtain a product or its prototype with a sufficiently high accuracy. The disadvantage of these technologies lies in the relatively high cost of equipment, and it is also associated with the complexity of obtaining products and parts of high precision without further processing.

One of the methods of additive shaping is laser shaping. The laser can fuse powders and solid materials. Low-power solid-state laser can be used for additive formation of fusible materials by partial reflow. This is justified due to the relatively low cost of equipment, the ability to change a large number of operating parameters and precise positioning of the laser beam.

Laser equipment has found wide application in industry for surfacing, engraving, cutting, welding and other processes. The advantages are presented of low power solid state laser below:

- the possibility to accurately dose energy, exposure time, penetration depth, exposure zone width;
- minimization of heat-affected zones due to rapid local heating and cooling;
- the cost of the equipment is relatively low.

The purpose of this study is to search for the possibility of using a low-power solid-state laser (up to 50 W) for the additive formation of fusible materials by the method of partial reflow. Partial reflow is a necessity because it allows a large number of layers to be fused without losing the shape of the workpiece. The task is to experiment in identifying modes of additive shaping with a solid-state laser for partial reflow of the previous and subsequent layers. Blanks were used from tin with a diameter of 1 mm for the experiment. The material has a low cost, good processing, in addition retains the form after laying and relatively low melting temperature.

Experimental studies were conducted to achieve this goal. The essence was experimental studies in identifying the elements of the modes of formation of products made of fusible materials by a solid-state laser and in constructing the ranges of parameter control to ensure partial reflow of the previous and subsequent layers. The elements are: laser power \( P \), W; beam speed, mm/s, focal length, mm. The experiments will be carried out without using a shielding gas. Solid-state (ytterbium) laser will be used...
with a maximum power of 50 W (made in Russia) as equipment. The zone was selected for laser action in accordance with the diameter of the workpiece and it is half of it - 0.5 mm. One workpiece was used with a diameter of 1 mm to derive the general mode and better visibility of the surface reflow.

The result is an experimental confirmation of the possibility of using a low-power solid-state laser (up to 50 W) for the additive formation of fusible materials by partial reflow, and it also made it possible to obtain elements of the forming mode without complete melting while maintaining the shape of the workpiece.

2. Experimental study

The first series of experiments includes the dependence of reflow on focal length and laser power. The speed of the movement of the laser was unchanged - 50 mm/s. The results are presented from the experiment in figure 1. The shaded area denotes the numerical values of the modes of the shaping elements to ensure partial reflow of the next and previous layer, in particular, such as focal length and power.

Metal evaporation was observed at a focal length of less than 5 mm. This is shown at the bottom of figure 1. The melting is represented by metal at a focal distance of 5 mm and a power of 45 W. This is shown in figure 3. Melting is achieved with the most satisfactory results at a power of 40-50 W and at the largest focal length for this experiment.

The experiments were directed in the next series to reveal the dependence of melting on the speed of movement and focal length. The power is set at 40 W, based on the results of the last series of experiments. The results are presented from experiments in figure 2. The shaded area denotes the numerical values of the modes of the shaping elements, in particular such as the speed of movement and the focal length. They are necessary to ensure partial reflow of the next and previous layer.

Burnout is observed in this series of experiments at a focal length of up to 6 mm. The surface reflow becomes more uniform and precise on the workpiece as the focal length is increased further. Figure 4 shows that at high travel speeds, the temperature influence is too small for melting at the set power. This is confirmed by the upper part of figure 2.
**Figure 2.** The graph shows modes of additive shaping to ensure partial reflow of the next and previous layer.

Conclusion – the focal distance is 20-30 mm at a travel speed of 5-20 mm/s, required for partial melting of the workpiece.

**Figure 3.** The appearance is presented by reflow at high power and a focal length of +5 mm.  
**Figure 4.** The appearance is represented by reflow at low laser power and high travel speed.

The distance is taken as the basis for the fixed focal point in the third series of experiments, and the power changes and the speed of movement changes. The focal distance is set to 20 mm based on the results of the previous series of experiments. The results are presented by the experiment on figure 5. The shaded area denotes the numerical values of the modes of the shaping elements, to ensure partial reflow of the next and previous layer, in particular, such as the power and speed of movement.
Figure 5. The graph shows modes of additive shaping to ensure partial reflow of the next and previous layer.

The laser generates insufficient energy to melt at high travel speeds and low power. Figure 5 examines the parameters for partial melting of the workpiece. They are within the following limits:

- the power should be: from 35 to 45 W;
- travel speed should be: from 5 to 15 mm/s.

Figure 6 shows the appearance of the desired fusion with the above parameters. The workpiece is melted evenly without burning. It retains its original shape.

Figure 6. The appearance is represented by reflow with a laser power of 45 W and a travel speed of 10 mm/s.

The modes were tested for the formation of products made of fusible materials by the additive method in the course of further analysis based on the results of the experiments (tin is a material, the diameter of the workpiece is 1 mm).

A series of experiments are presented with the aim of achieving shaping by the additive method without complete melting, which made it possible to derive the exact mode:

- the line width of the laser beam should be: 0.5 mm;
- speed should be: 9 mm/s;
• power should be: 38 W;
• focal length should be: +25 mm from table level.

Conclusion
Thus, the possibility has been confirmed of using a low-power solid-state (ytterbium) laser (maximum power 50 W) to accomplish the assigned tasks. A series of experiments were carried out and they revealed the dependence of wire reflow on changes in parameters (power, W; focal length, mm; travel speed, mm/s). The mode was deduced from the forming by the additive method without complete melting of fusible materials on the basis of the conducted experiments. Research can be continued in order to obtain the possibility of forming other metals by the additive method (such as copper or aluminum) (such as copper or aluminum) later, after the modernization of equipment in terms of creating a protective atmosphere in the melt zone and increasing the laser power.

References
[1] Saprykin A A 2006 Increasing the productivity of the process of selective laser sintering in the manufacture of prototypes Thesis of candidate of technical Sciences (Yurga: Tomsk Polytechnic University) p 153
[2] Pronikov A, Averyanov O I and Apollo Yu S 1994 Designing of metal-cutting machines and machine tools (Handbook-textbook vol 3) (Moscow: MSTU them NE Bauman: Mechanical Engineering) p 444
[3] Kuts V V, Razumov M S, Grechukhin A N and Bychkova N A 2016 Improving the quality of additive methods for forming the surfaces of odd-shaped parts with the application of parallel kinematics mechanisms International Journal of Applied Engineering Research 11 pp 11832-11835
[4] Dobroskok V L, Abdurayimov L N and Chernyshov S I 2010 Rational orientation of products with their layer-by-layer shaping on the basis of the original triangulation 3d model Scientific notes of the Crimean Engineering and Pedagogical University 24 pp 13-21
[5] Singhal S K, Pandey A P, Pandey P M and Nagpal A K 2005 Optimum part deposition orientation in stereolithography Computer-Aided Design & Applications 2 pp 319–328
[6] Hong S, Byun Kwan H Lee 2006 Determination of optimal build direction in rapid prototyping with variable slicing Int. J. Adv. Manuf. Technol. 28 pp 307–313
[7] Hur J, Lee K 1998 The development of a CAD environment to determine the preferred build-up direction for layered manufacturing Manuf. Technol. 14 pp 247–254
[8] Kim J Y, Lee K and Park J C 1994 Determination of optimal part orientation in stereolithographic rapid prototyping Technical Report. Department of Mechanical Design and Production Engineering (Seoul: Seoul National University) pp 356-366
[9] Lane P T, Chou S, Chent Y, Gemmill L D 1997 Determining fabrication orientations for rapid prototyping with stereolithography apparatus Computer-Aided Design 29 pp 53–62
[10] Masood S H, Rattanawong W Iovenitti P 2003 A generic algorithm for part orientation system for complex parts in rapid prototyping J. Mater. Process. Technol. 139 pp 110–116
[11] Masood S H, Rattanawong W 2002 A generic part orientation system based on volumetric error in rapid prototyping Int. J. Adv. Manuf. Technol. 19 pp 209–216
[12] Egorov I N 2010 Position-force control of robotic and mechatronic devices Vladimir State University Vladimir p 243
[13] Grechishnikov V A, Romanov V B and Pivkin P M 2017 Errors in shaping by a planetary mechanism Russian Engineering Research vol 37 № 9 pp 824-826
[14] Grechukhin A, Kuts V and Olenshitskiy A 2020 Development and research of technological equipment that implements dynamic control of process of additive fabrication of parts of complex spatial shapes based on mechanisms with a hybrid Layout IOP Conference Series: Materials Science and Engineering vol 709 DOI: 10.1088/1757-899X/709/3/033112
[15] Grechukhin A N, Kuts V V and Razumov M S Solving problem of curved surface approximation by layers with constant and variable sections during forming by additive methods Lecture Notes in Mechanical Engineering p 239-248 DOI: 10.1007/978-3-030-22041-9_28

[16] Grechukhin A N, Privalov A S and Garkavtseva P A Experimental studies of the process of additive electric arc forming in the environment of protective gases DOI: 10.1063/1.5138378

[17] Grechukhin, A.N., Kuts, V.V., Oleshitsky, A.V. Control of geometrical parameters of a single layer at additive forming of products by FDM technology AIP Conference Proceedings vol 2188 DOI: 10.1088/1757-899X/680/1/012004

[18] Grechukhin A N, Anikutin I S and Byshkin A S Management of space orientation of the end effector of generation of geometry system fiveaxis manufacturing machinery for additive generation of geometry MATEC Web of Conferences vol 226 DOI: 10.1051/matecconf/201822601004

[19] Song Q, Chai L, Chen J and others Optically Tuned Wide-Band Terahertz Modulation, Charge Carrier Dynamics and Photoconductivity of Femtosecond Laser Ablated Titanium Disulfide Nanosheet Devices IEEE Control Systems Letters Vol. 5, p. 821-833 DOI: 10.1109/LCSYS.2020.3010544

[20] Gonzalez-Romeo L.L, Reyes-Baez R, Guerrero-Castellanos J F and others Contraction-Based Nonlinear Controller for a Laser Beam Stabilization System Using a Variable Gain IEEE Control Systems Letters Vol. 5, p. 761-766 DOI: 10.1109/LCSYS.2020.3005445

[21] Halkon B J, Rothberg S J Establishing correction solutions for scanning laser Doppler vibrometer measurements affected by sensor head vibration Mechanical Systems and Signal Processing DOI: 10.1016/j.ymssp.2020.107255

[22] Liu G, Yuan J, Wu T, and others Ultrathin 2d nonlayered tellurene nanosheets as saturable absorber for picosecond pulse generation in all-fiber lasers(Article) IEEE Journal of Selected Topics in Quantum Electronics DOI: 10.1109/JSTQE.2020.2992625

[23] Bogris A, Mesaritakis C, Deligiannidis S and others Fabry-Perot Lasers as Enablers for Parallel Reservoir Computing IEEE Journal of Selected Topics in Quantum Electronics DOI: 10.1109/JSTQE.2020.3011879

[24] Du L, Lu D, Li J and others Antimony Thin Film as a Robust Broadband Saturable Absorber IEEE Journal of Selected Topics in Quantum Electronics DOI: 10.1109/JSTQE.2020.2969556