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STATISTICAL METHODS FOR ANALYZING THE EFFICIENCY OF THE LASER SINTERING PROCESS OF POWDER

Summary. In this article shows the author's method aimed at improving the performance of products received by the technology of laser fusion of the powder material. The task was implemented using statistical techniques, namely the construction of a mathematical model of the performance of the second order, followed by analysis of the response function. Developed in the paper, the method allows to manage the performance of the process of laser fusion of the powder material.

As a result of the studies cited in this article are of both scientific and practical interest. The author shows the possibility of applying statistical techniques to control the output of the process of laser fusion of the powder material.

Key words: laser technologies, powder, productivity.

Formulation of the problem. «Rapid Prototyping» technology, the basic part of which is the process of laser fusion of powder material, is widely used by highly developed countries around the world for production, such as stamps, molds, etc. For example, compared to traditional high-speed cutting, «Rapid Prototyping» technology, which uses a focused laser beam as a tool, which allows to create products not only from metal but also from ceramic materials. Despite the impressive advances in the development of laser technology, in front of developers face challenges with the issue of improving the productivity and quality of products made by «Rapid Prototyping».

Analysis of previous research. Considering a high difficulty of the physical processes associated with the introduction of laser fusion of powder material in this article, was used an active experimental strategy, which gives an opportunity more reliable results compared to the passive strategy. Analysis of literary sources [1-4] showed the different degree of statistical significance of technological factors, which has an impact on the

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productivity of the laser fusion of powder material. Let's look at them in more detail. Changing the position of the substrate providing the device for feeding powder material, influences in such indicators as morphological properties, internal microstructure (hollow fragments, shells, microcracks).

Mass consumption of powder material is an important factor of influence the productivity of the laser fusion process of the powder composition, but the increase of the mass consumption it is necessary to increase the power of laser radiation. The thermodynamic properties of the powder material, such as the melting temperature depend on the power of the laser radiation, the higher the temperature of melting of the powder material, the greater the power is needed for its efficient fusion. Given these circumstances assume that among the basic powder materials which used for the technology of laser fusion widely used powders based on nickel, titanium, cobalt. The widest of this group powder it called PGSR-3 the basic component of which is nickel it has the smallest temperature of melting 1453°C [5] compared with other powders of this group. The type of transporting gas significantly influences the quality of fusion powder material that is for more efficient fusion of powder transport of the dispersed phase must be carried out in an inert environment, such as argon, noted in [6, 7]. This makes an ability to prevent the formation of oxide pellicle while exposed to laser radiation, which has a large gradient of temperature of melting but this requires a special equipment with the ability a constantly of refuel expensive inert gases (argon, helium, neon). Therefore, in terms of economic feasibility the experiment was conducted with the use of compressed air. One of the main factors which influence the productivity and quality of fusion of the powder composition is the configuration of the device for feeding the powder material (nozzles of different constructions) [8, 9]. So based on the analysis of literature information the main technological factors which influence the productivity of the laser fusion of powder material can divide into two groups. The first is the factors the values of which need to fix in a stable state, they include the length of wave, power of the laser radiation, the type of powder composition, the geometric properties of the powder, the type of transporting gas. Factors that need to set a certain range of variation are the configuration of the feeder and the mass consumption of the powder material, the speed of movement of the substrate, the position of the substrate.

Formulation of the aim of work. The aim of this work is finding of solutions which are aimed at increase of productivity of the process of fusion of the powder composition PGSR-3.

The main part. For a study of the productivity of the laser fusion process of powder material, PGSR-3 was chosen non-composite plan of Box-Benken for 4 technological factors, which have good statistical characteristics and are realized by the regression equation of the second-order [10].

$$y = b_0 + \sum_{i=1}^{i=k} b_i x_i + \sum_{i \le j}^{i=k} b_{ij} x_i x_j + \sum_{ii=1}^{i=k} b_{ii} x_i^2, \qquad (1)$$

where k – amount of technological factors;

b_0, b_i, b_{ij}, b_{ii} – coefficients of the regression equation;

i, j – indexes.

As productivity (T) was used as a response function. As technological factors that influence the productivity of the laser fusion process of the powder composition (previously defined) provided the stabilization of the factors of laser beam diameter, density, and power of laser radiation, the geometry of nozzle angles (x_1), mass flow rate of powder (x_2), speed of movement substrate (x_3), the position of the substrate relative to the cut nozzle (x_4). The coefficients of the regression equation b_0, b_i, b_{ij}, b_{ii}-model (1) were calculated by using specialized software using the mathematical apparatus of linear algebra [10], dependence (2). The matrix of conditions of experiment was formed using a balanced block diagram for 4 independent variables (x_1, x_2, x_3, x_4), which consist of 6 blocks (full-factor experiment 22) [10], variation of technological factors was conducted on three levels (minimum, center, maximum).

$$B = \left(X^T X\right)^{1} \left(X^T Y\right), \qquad (2)$$

The hypothesis about the adequacy of the received mathematical model of the productivity of the laser fusion process of the powder material was checked using Fisher's criteria F [10]. The certainty of the experimental results according to this criterion corresponds to a 5% error (3).

$$F^{calc.} <= F^{tabl.}, \qquad (3)$$

where $F^{calc.}$– calculating value of Fisher criteria [10];

$F^{tabl.}$ – tabled value of Fisher criteria [10].

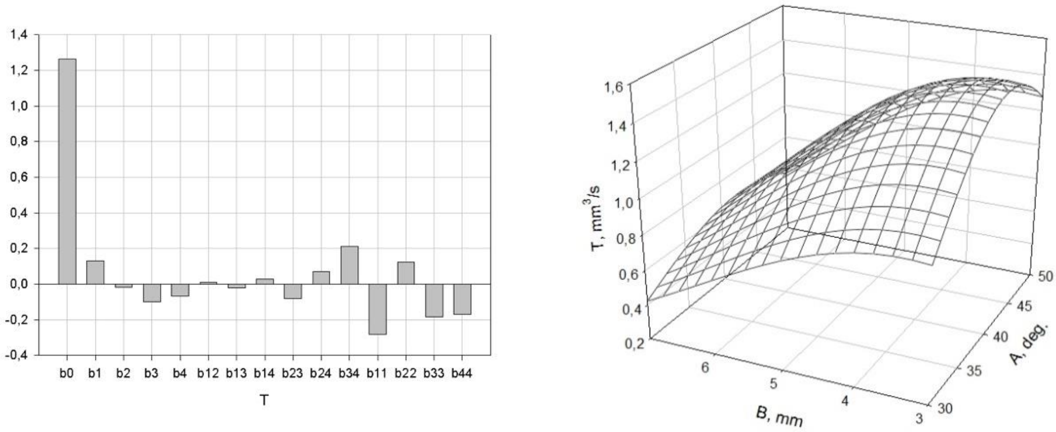
Levels of variation of technological factors (x_i) were identified experimentally (tabl. 1).

Table 1

Levels of variation of technological factors

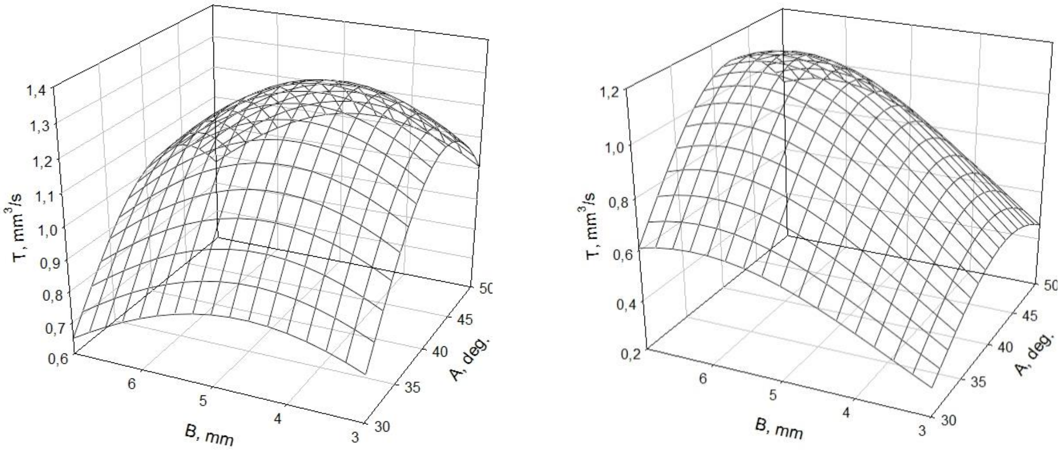
Levels of variation of technological factors	Independent variables			
	x_1	x_2	x_3	x_4
Dimension	deg.	g/s	mm/s	mm
Main level	40	0,3	2,0	5
Interval of variation	10	0,1	1,0	2
Upper level	50	0,4	3,0	7
Lower level	30	0,2	1,0	3

It was conducted the statistical processing of the results of experimental studies which showed that all the coefficients of the regression equation are statistically significant for the obtained mathematical model of the productivity of the laser fusion of powder material (*T*) the statistical hypothesis of adequacy has been confirmed the regression equation is adequate so the condition is fulfilled (3). For a more detailed idea about the degree of statistical significance of each of the technological factors on the productivity of the process of laser fusion of powder, PGSR-3 was built rank chart (fig. 1, a).



a) b)

Figure 1. Rank diagram of the degree of statistical significance of technological factors on the response function (*T*) (a) and the dependence of the productivity of the fused component (*T*) from the geometry of generatrix angles of nozzle (*A*) for different positions of the substrate (*B*) with mass consumption of powder 0,2 g/s and the speed of movement of the substrate 1 mm/s (b).



a) b)

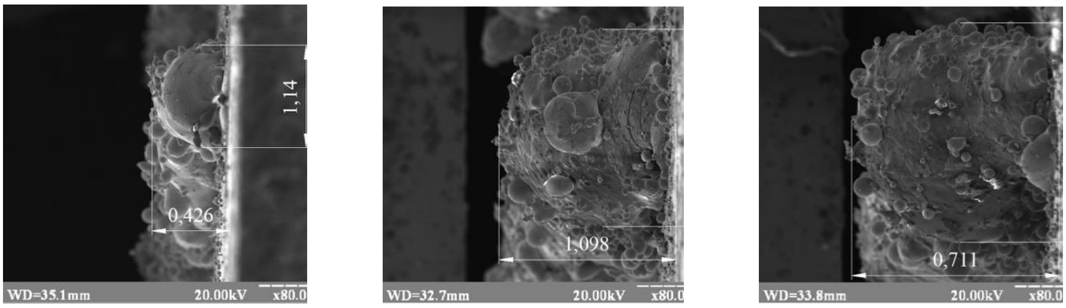
a)-mass consumption of powder 0,3 g/s, speed of movement of the substrate 2 mm/s, b)-mass consumption of powder 0,4 g/s, speed of movement of the substrate 3 mm/s.

Figure 2. Dependence of productivity (*T*) from the geometry of generatrix angles of nozzle (*A*) for different positions of the substrate (*B*)

As can been looked from fig. 1, a) the most significant linear influence on the response function has the geometry of the nozzles, the speed of movement and the position of the substrate relative to the cut of the nozzle, factors x_1, x_3, x_4 and coefficients b_1, b_3, b_4. Also, it should note that all factors have a significant quadratic effect on the response x_1, x_2, x_3, x_4 coefficients b_{11}, b_{22}, b_{33}, b_{44}. A more detailed picture of the change in the response function can watch guiding the graphical dependencies which presented in fig. 1, b) і 2, a), b). Reduction productivity (T) in general case to the figure 0,7...0,8 mm^3/s (fig. 1, a) and fig. 2, a), b) happens by removing the position of the substrate in both directions from the "focus" of the gas powder flow. Also, an important factor in reducing productivity (T) is a geometry of generatrix angles of nozzle, so nozzles with angles 30° and 50° form large cross-sectional areas of the powder gas flow with low dispersed phase in the area influence of laser radiation (fig. 1, b) and fig. 2, b). Increase of productivity, range 1,1...1,3 mm^3/s happens due to the location of the substrate in the "focus" of the gas powder flow, for the nozzle with geometry of generatrix angles 40° (fig. 1, b) and fig. 2, b), as a result in the zone of laser processing forms, gas-powder flow with a high content of the dispersed phase. Also, it should note that the maximum productivity (T) 1,3 mm^3/s (fig. 1, b) observed at the following values of independent variables, the geometry of the geometry of generatrix angles of nozzle 40°, the mass flow rate of the powder material 0,2 g/s, the speed of movement of the substrate 1 mm/s, the position of the substrate relative to the cut nozzle 5 mm (area of «focus» of gas-powder flow), this is due to the high content of the dispersed phase in the area of focused laser radiation. Minimum productivity (T) 0,2 mm^3/s (fig. 2, b) it was got by the following indicators of technological factors the geometry of generatrix angles of nozzle 30°, the mass flow rate of the powder material 0,4 g/s, the speed of movement of the substrate 3 mm/s, the position of the substrate relative to the cut nozzle 3 mm, it can explain the low dispersed phase in the zone of laser processing due to the distance of the substrate from the "focus" of the gas powder flow. In fig. 3, a)-c) as an example are photos of the morphological structure of the fused components of the powder material for different geometry of generatrix angles of nozzles.

Conclusions

1. It was received the mathematical model of productivity of process of laser fusion of powder composition PGSR-3 which can use as calculation of the controlled influences directed on growth of productivity of future products.
2. It was confirmed the adequacy of theoretical calculations and the possibility of using mathematical models of the process of laser fusion of powder material for their further use in the implementation of technology of laser fusion of powder material.



a) b) c)

Figure 3. Morphological structure of fused components with real dimensions in height and width at eighty times the optical zoom: a)-geometry of generatrix angles of nozzle 30°, mass flow rate of the powder material 0,2 g/s, speed of movement of the substrate 3 mm/s, position of the substrate relative to the cut nozzle 7 mm, b)-geometry of generatrix angles of nozzle 40°, mass flow rate of the powder material 0,3 g/s, speed of movement of the substrate 1 mm/s, position of the substrate relative to the cut nozzle 5 mm, c)-geometry of generatrix angles of nozzle 50°, mass flow rate of the powder material 0,2 g/s, speed of movement of the substrate 2 mm/s, position of the substrate relative to the cut nozzle 7 mm.

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СТАТИСТИЧНІ МЕТОДИ АНАЛІЗУ ЕФЕКТИВНОСТІ ПРОЦЕСУ ЛАЗЕРНОГО СПЛАВЛЕННЯ ПОРОШКУ

Анотація

Широке застосування технології «Rapid Prototyping», базовою складовою якої є процес лазерного сплавлення порошкової композиції обумовлено подорожчанням сировини, енергоносіїв, мінімізацією часу, який витрачається на впровадження у виробництво нових видів продукції. Дана технологія, завдяки використанню в якості інструменту технологічного лазера дозволяє значно розширити спектр використовуваних матеріалів, а також отримувати вироби складної геометричної конфігурації. Тому перед розробниками стоять питання підвищення продуктивності та якості формоутворення виробів з порошкових матеріалів.

У даній роботі була показана розроблена автором методика, спрямована на підвищення продуктивності виробів, отриманих технологією лазерного сплавлення порошкового матеріалу. Були проаналізовані та встановлені основні технологічні фактори впливу на продуктивність процесу лазерного сплавлення порошкового матеріалу. Поставлена задача була реалізована з використанням методів математичної статистики, а була побудована математична модель у вигляді поліному другого порядку з подальшим аналізом функції відгуку. В якості функції відгука була використана продуктивність процесу лазерного сплавлення порошкового матеріалу. Розроблений в статті метод дозволяє керувати а також находити оптимальні параметри керування продуктивністю процесу лазерного сплавлення порошкової композиції для різного технологічного обладнання зокрема засобів доставки порошкового матеріалу безпосередньо у зону сфокусованого лазерного променю.

Таким чином, результати досліджень, наведених у даній статті, представляють як науковий, так і практичний інтерес. Автором показана можливість застосування методів математичної статистики для управління продуктивністю процесу лазерного сплавлення порошкового матеріалу з урахуванням різноманітного технологічного обладнання.

Ключові слова: лазерні технології, порошок, продуктивність.