Research of deformation compensation method in laser metal deposition process of 316L stainless steel product

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Abstract. It is exists the problem of big product manufacturing with minimal dimensions tolerances. To solve this problem it is necessary to compensate the deformations influence. In researching of method, it became clear that deformation degree has changed and depended on size and form of part. However, the amount of deformation degree to dimension of part is still independent of size. This fact has observed after production of axis-symmetrical parts. The simple axis-symmetrical part was built up. The dimensions of part was measured, and the compensation coefficient was calculated. The dimensions of part was scaled on this coefficient for compensation of shrinkage effect. After that the experiment was repeated.

Keywords: Additive technologies, direct laser deposition, thermal shrinkage compensation, deformation compensation method.

1. Introduction

Direct laser deposition is method of product formation by layer-by-layer melting of metal powder on the metal substrate by using laser radiation. Local influence of laser radiation to the metal substrate in a short time allows melting of the surface layer of metal without excessive heating. Heat energy is dissipate quickly, as result the metal crystallized in the moment. This specialty of the process makes direct laser deposition a process related to welding with additive material. The crystallization of metal is accompanied by the formation of internal stresses which have a significant influence on the shape of the final product [1-6]. Moreover, in certain cases internal stresses can lead to destruction of the product. The advantages of the method are in possible to produce complex products with minimum mechanical processing. As a result, direct laser deposition is used in the aviation and aerospace industries. These industries impose high tolerances of the produced parts. Due to the formation of internal stresses directly during in the part buildup process, it is difficult to guarantee that products will be manufactured according to high geometric requirements.

The amount of stress and the degree of deformation of the article vary depending on the mark material. In other words, different materials are deformed differently in the part buildup process. It is a function of the elongation ratio of the material. Than higher the elongation ratio, those smaller the effect of deformation on the geometry of the part. Titanium alloys such as Ti-6Al-4V or VTi20 have low plasticity, with a relative elongation of 6-8%. Part buildup of these alloys creates the need for equal distribution of stress over the part. Otherwise, the internal stresses will exceed the material strength and the part will be destructed. It is important to note that almost any metal interacts with oxygen or nitrogen during heating and melting, making inert gas protection appropriate for any cultivation.

More plastic materials, like stainless steel, have a high elongation of about 20%. [4,8]. This is high enough to avoid the risk of destruction of the part buildup. However, the influence of deformation on geometry remains significant for the buildup of large-scale parts. In order to solve this problem, it is necessary to control tension and compensate for deformations.
The main source of stress in the part buildup process is the thermal shrinkage. When the metal cools, the linear size of the part decreases, which is essential for the large part buildup. It is necessary to compensate this negative influence on the part geometry.

2. Technological equipment
For experiments making used the robotic technological complex for laser metal deposition process. It based on welded massive cabin with hermetic working cabinet. The fiber ytterbium laser LS-3 is used as radiation source. The Complex also includes a six-axis robot arm Fanuc M-20iB-25, two-axis positioner Fanuc, which max payload is 500 kg. The volume of hermetic cabinet is 18 m³. The view of the complex presented in Figure 1.

![Figure 1. The robotic technological complex for LMD process](image)

The robot using is necessary for moving of technological instrument, which composed of the laser welding head and coaxial discrete nozzle. The movement repeatability of robot is ± 0.02 mm at maximum load of 25 kg. The mass of the technological instrument is 10 kg, so the robot provides the maximal accuracy of wall buildup. The positioner needs to expand the movement possibility of robot on part trajectory. It is important that maximal accuracy of wall buildup is not same that maximal accuracy of part buildup. The last depends by influence degree of part deformation.

Как средство контрольных измерений используется мобильный 3д-сканер модели: MetraSCAN 750 | Elite (Figure 2). Scanner accuracy is 0.050 mm.
3. **Experimental method**

The main objective of this work was research method of thermal shrinkage quantitative description on the example of 316L stainless steel product. Such experimental research is clarification of source [2].

The method of shrinkage quantitative description sounds simply:

1) It is need to build up the testing part with expected dimensions.
2) To scan the part after cooling.
3) To compare the scan with 3d-model of part and determination of shrinkage coefficient.

First it is necessary to choose which geometric form will has the part, which dimensions and material. The material of part is 316L stainless steel powder, fraction is 50-150 μm. This material used frequently in our practice, and it is relatively cheap.

The form is testing part is cylinder. This form is axisymmetric geometric figure, which means that part is able to flat deformation. In other terms the distribution of inner stress is equal in cross section of part. Therefore the risk of part destruction reduce through it.

The diameter of testing part is 300 mm, it is causes which least satisfactory value for getting result. Thermal shrinkage is gradual process for every form of part [2]. The stress increase with every added layer like and the value of deformation. At some point the stress increase stopped. In this point inner stresses are balanced by part reactive forces. There is a short area of part where stress and deformations value decreased. Cylinder height is 200 mm. It is necessary to observe clearly the shrinkage zone. Wall thickness is 4 mm.

It is important to note that every part buildup is accompanied with dimensions tolerances. The tolerance of this experimental part is ± 0.5 mm.

4. **Experimental results**

The part buildup has been done in inert atmosphere (argon 99.99% purity). The laser radiation power is 1.8 kW, laser point diameter is 2.6 mm, the substrate speed is 25 mm/sec, the thickness of applied layers is 800 μm. These characteristics of the process influence positively on forming of material structure. It is decrease a chance of porosity forming and the amount of solids that can reduce the mechanical
properties of the product material [3]. Product substrate is made of conventional structural steel A 107 (Whose Russian counterpart St3 steel). The photo of finished part is presented on Figure 3.

![Figure 3. The finished part](image)

The part was cleaned and scanned. The part scan was processed in program Geomagic control X. Results is present on figure 4.

![Figure 4. Comparison of scanning result and 3d-model with 2d-section](image)

For better understanding all results was transformed in liner diagram, and presented on figure 5.
The results shown that shrinkage value is stable on the 40 mm point. The volatility of shrinkage is equal to accuracy of laser scanner. This point is ground zero of cylinder shrinkage measurement. Radius deviation of testing model relatively finished part is 1.67 mm. That is 1.11%. Therefore, the diameter of testing part must be scaled in 1.011 times, for getting finished part with 300 mm diameter. On Figure 6 it is present comparison of scaled part scan and 3d-model.
The green areas is full-math zones. However to get the height of testing part on the point 200 mm, it is necessary to mark the tolerance ± 0.5 mm. It shown intolleranced zone of part which height need to add to part.

![Image](image.png)

**Figure 7.** Comparison of scaled part scan and 3d-model with ± 0.5 mm tolerance.

The comparison of scaled part scan shown that height of intolerance area of part is 20 mm. Therefore, the height of tested part should be more than 220 mm. Intolerance zone of part should be catted off. Eventually, to get final part which diameter is 300 mm and height is 200 mm, the diameter of testing part should me more than 220 mm and diameter should be 303.4 mm (300 mm*1.011).

5. Conclusion

That research shown that the shrinkage is finite in LMD process. The point of shrinkage compensation is in multiplying of linear dimensions to the coefficient. This coefficient is unique to every material. The size of testing par should be enough to calculate the shrinkage amount. The diameter is not less 300 mm, the height is not less 150 mm, if the wall thickness is 4 mm. The measure of shrinkage coefficient need to make in stable zone, the tolerance is not more ± 0.1 mm. The shrinkage coefficient for 316L stainless steel is 1.011 (1.1%).

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