Numerical simulation of the selective laser melting process using the example of a turbine blade

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Abstract. Additive manufacturing is widespread in the modern world. Many foreign companies are moving to mass production of parts using additive technologies. To reduce the risks associated with the building up parts it is necessary to use numerical methods for predicting the deformation and internal quenching stresses and to optimize the support structures of parts. In this work, it was simulated the process of selective laser melting in the Amphyon software package to predict internal quenching stresses and strains using the example of a gas turbine engine blade. The calculation results are presented and the deformed as well as the pre-deformed models are presented.

Introduction

Additive manufacturing is the process of making parts by adding material layer by layer. This technology allows to obtain finished products with a very complex configuration, which is difficult or impossible to manufacture at all by traditional methods. [1]. The additive technologies include such technologies as VAT photopolymerization (SLA, etc.), material extrusion (FDM), material jetting, binder jetting, powder bed fusion (SLS, SLM, etc.), direct energy deposition (LENS, EBAM, etc.) sheet lamination (LOM) [2]. One of the most rapidly developing technologies for additive manufacturing is the selective laser melting of metallic powder materials, which is widely embedded in technological chains. [1].

During building up process of the products, each subsequent layer is melted by a laser beam, melting with the previous layer, instantly freezing [3,4,5]. Due to this stratified fabrication process, high quenching stresses occur in the details. This leads to the fact that the details deform, which means that the geometry of the grown parts will differ from the original 3D model. Thermal treatment is usually used to relieve internal quenching stresses after the printing process [6,7]. This allows minimizing quenching stresses, while the geometry is fixed in the state in which it turned out after manufacturing (provided that heat treatment was carried out before the part was separated from the substrate). However, deviations in the shape of the build-up part from the original 3D model will be significant.

In consequence of using of numerical simulation methods, it became possible to predict such important parameters in the printing process as quenching stresses, deformations, interference of a printed part with a recoater, temperature history, and others. To reduce the possible warping in the software product Amphyon there is the possibility of carrying out the process of optimization of supports [8]. In addition to the above, numerical simulation of the selective laser melting process allows generating 3D models in a warped state, and also, to reduce the deviation of the shape of the final part from the original 3D model, it is possible to generate a so-called pre-deformed model [9,10]. In the general case, such a model is a deformed model, in which the calculated strains are taken in absolute value and with the opposite sign.

As part of this work, it was shown the possibility of numerical simulation of the selective laser melting process to predict the possible deformation of parts in the manufacturing process, as well as preparing the 3D model for printing to obtain the final part with minimal deviations of the shape from the original 3D model.

Materials and Methods

The turbine blade was manufactured at the selective laser melting installation SLM280HL manufactured by SLM Solutions GmbH (Fig. 1). The material was adjusted using the mechanical characteristics of 316L stainless steel (Table 1), obtained after selective laser melting.

Table 1. Mechanical characteristics of stainless steel 316L [11,12]

Yield stress, [Mpa]	Young's modulus, [Gpa]	Poisson's ratio	Layer thickness, [μm]
540	151	0.3	0.05

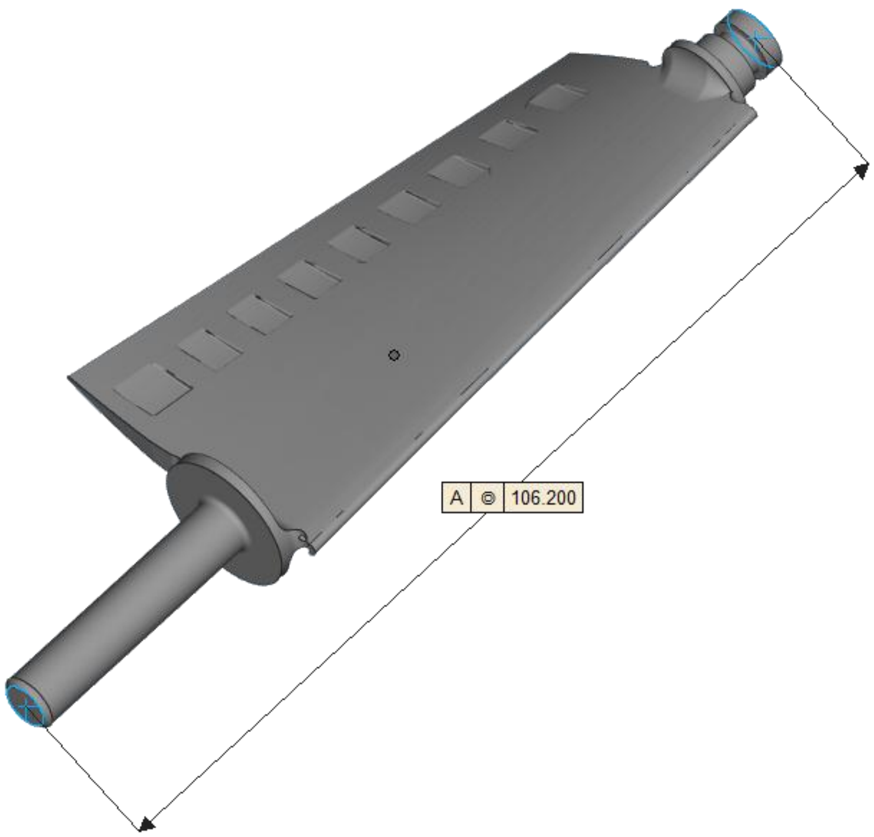

Figure 1. Turbine Blade 3D model

Numerical simulation was carried out in the software package Amphyon company Additive Works. This program allows you to determine the optimal location of parts on the platform according to several criteria (construction time, support volume, post-processing, deformation, capacity in the work area), generate and optimize support by two criteria (minimizing deformation and reducing the amount of material for supports), model the process of selective laser melting (prediction of deformation of the part in the printing process), generate a deformed and pre-deformed model.

Results and Discussion

1.1 Software calibration

In order for the results of numerical simulation to be as close to reality as possible, it is necessary to tune the software package for the relevant material. Amphyon was calibrated on special specimens shown in Fig. 2 [8]. They were also made from 316L.

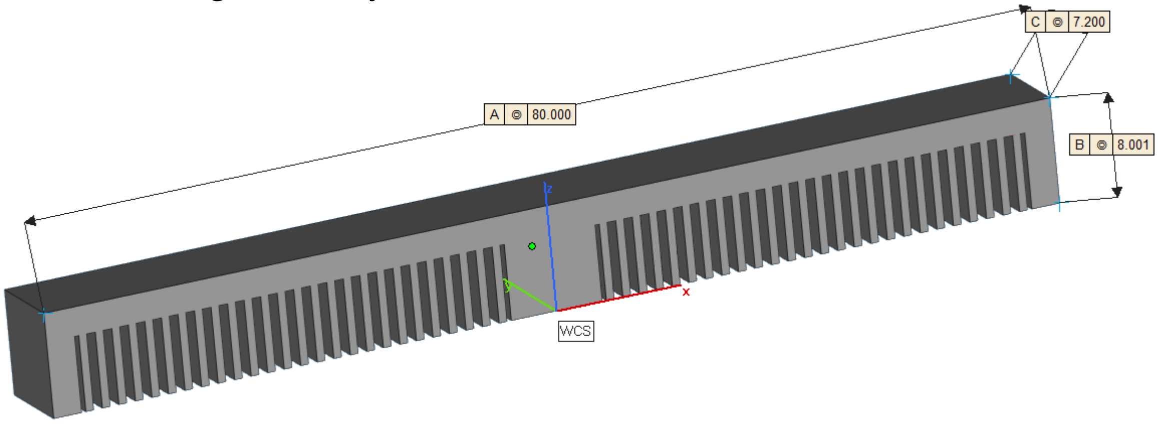

Figure 2. Calibration specimen

Calibration specimens were made for 3 variants of scanning strategy:

- Hatching perpendicular to the calibration pattern
- Hatching type "chessboard"
- Hatching perallel to the calibration pattern

After manufacturing, calibration samples were separated from the substrate by EDM cutting. The bend measurements of the calibration samples are given in Table 2, the values of which are entered into the Amphyon program.

Table 2. Deformation oft he calibration specimens

No.	Material	Strategy	Deformation, [mm]
1	316L	Orthogonal	1.451
2		Chess	1.406
3		Parallel	1.607

1.2 Selective laser melting process simulation

To simulate the process of selective melting, it is necessary to reproduce the layered construction of the part, as well as its geometrically accurate representation. To do this, the part is divided into a mesh consisting of hexagonal elements generated on the basis of the sections of the part.

The mesh must be selected in such a way that it describes the part with sufficient accuracy, but it is not too small. The calculation time directly depends on the size of the grid, and the accuracy of the calculation itself will not increase when certain values are reached, which is characterized by the convergence of the calculation. In the framework of this work, the mesh size is 0.362 mm at the base and 0.724 mm in height, the number of elements is 331 945. Fig. 3 shows a model with a mesh.

Figure 3. 3D model with mesh

After the mesh has been generated and the initial data are set, you can start the calculation process. Numerical modeling takes place layer by layer, by analogy with the actual process, as a result of which the deformations and quenching stresses of each layer are calculated. In Fig. 4 presents the results of numerical simulation.

a) b)

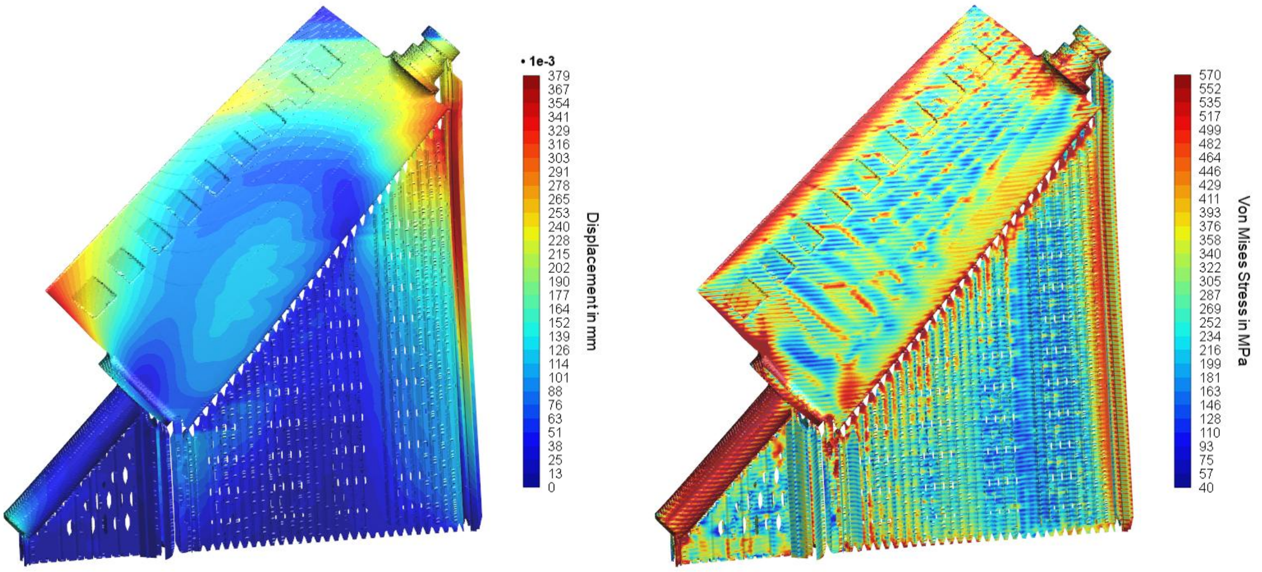

Figure 4. Calculation results a) Deformation; b) Stress (von Mises)

According to the results of the calculation, it can be said that these support structures are sufficient in terms of internal quenching stresses and strains. Such minor deformations can be leveled by generating a pre-deformed model, which will subsequently be printed. In Fig. 5 shows the deformed and pre-deformed models.

a) b)

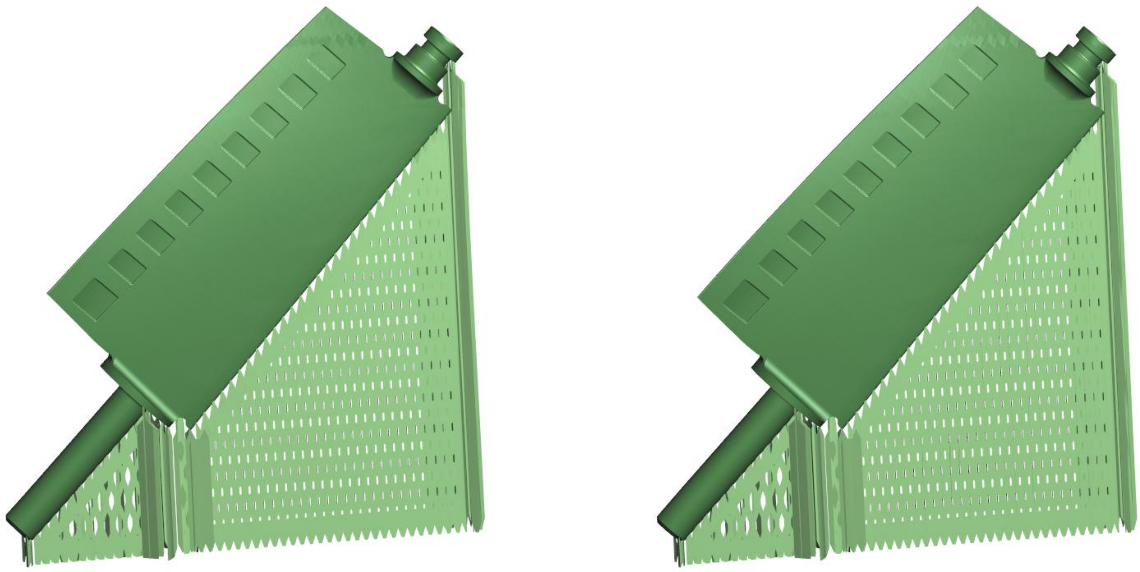

Figure 4. a) Deformed and b) Pre Deformed models

However, after the thermal calculation, you can see that there is a local overheating of the part [13]. This suggests that in this place were not enough heat sink parts, and therefore you need to add supporting devices to increase it [14]. The results of the thermal calculation are confirmed experimentally (Fig. 5).

a) b)

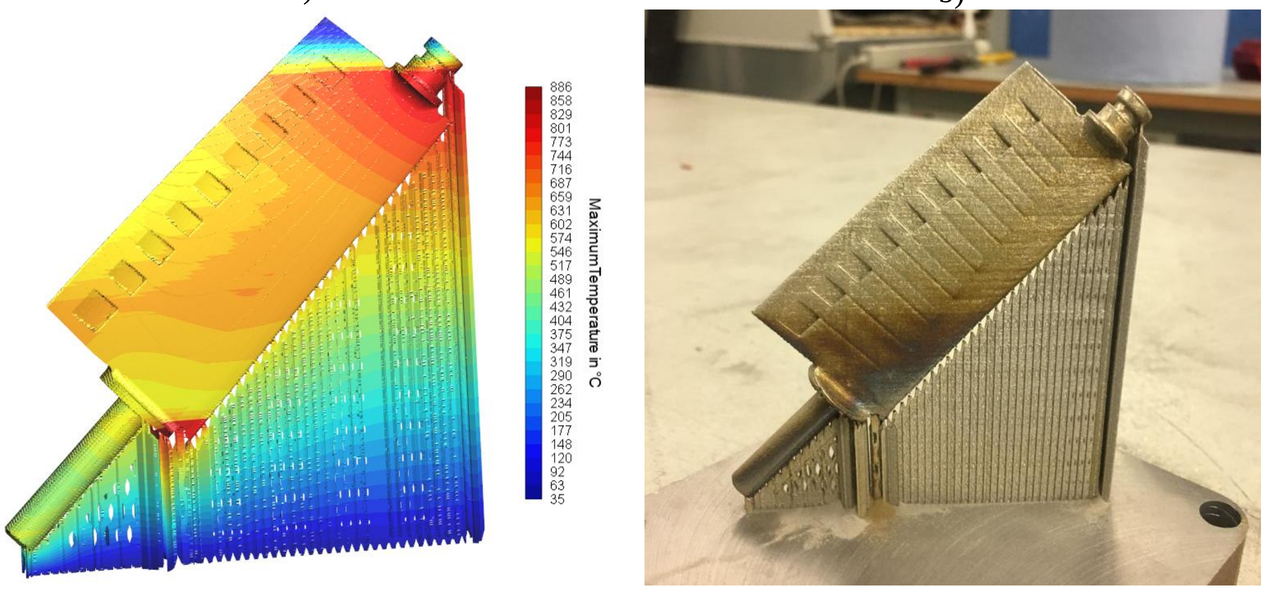

Figure 5 a) Results of thermo calculation and b) results of the real process

Summary

Using such a tool as a numerical simulation of the selective laser melting process, it is possible to predict how the part will behave when printed, what the deformations will be and, if small deformations occur, it is possible to generate a pre-deformed model. For large deformations, it is necessary to change the configuration of the supporting devices and their number. Not unimportant point is that there is the possibility of a thermal calculation. Despite the small deformations of the part, it may be locally overheated during the printing process. This affects both the appearance of the part and its properties.

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References

[1] Anatoliy Popovich and Vadim Sufiiarov (2016). "Metal Powder Additive Manufacturing", New Trends in 3D Printing, Chapter 10, InTech, DOI: 10.5772/63337.

[2] AM Technologies Infographic

[3] Sufiiarov V. S. et al. The effect of layer thickness at selective laser melting //Procedia engineering. – 2017. – T. 174. – C. 126-134

[4] Popovich A. A. et al. Anisotropy of mechanical properties of products manufactured using selective laser melting of powdered materials //Russian Journal of Non-Ferrous Metals. – 2017. – T. 58. – №. 4. – C. 389-395.

[5] Popovich V. A. et al. Functionally graded Inconel 718 processed by additive manufacturing: Crystallographic texture, anisotropy of microstructure and mechanical properties //Materials & Design. – (2017). – T. 114. – C. 441-449.

[6] Sufiyarov V. S., Borisov E. V. Effect of Heat Treatment Modes on the Structure and Properties of Alloy VT6 After Selective Laser Melting //Metal Science and Heat Treatment. – 2019. – C. 1-4.

[7] Popovich V. A. et al. Impact of heat treatment on mechanical behaviour of Inconel 718 processed with tailored microstructure by selective laser melting //Materials & Design. – 2017. – T. 131. – C. 12-22.

[8] Amphyon 2017 Documentation. Additive Works GmbH.

[9] Schmutzler C. et al. Pre-compensation of Warpage for Additive Manufacturing //Journal of Mechanics Engineering and Automation. – 2016. – T. 6. – C. 392-399.

[10] Paul R., Anand S., Gerner F. Effect of thermal deformation on part errors in metal powder based additive manufacturing processes //Journal of Manufacturing Science and Engineering. – 2014. – T. 136. – №. 3. – C. 031009.

[11] Zhang B., Dembinski L., Coddet C. The study of the laser parameters and environment variables effect on mechanical properties of high compact parts elaborated by selective laser melting 316L powder //Materials Science and Engineering: A. – 2013. – T. 584. – C. 21-31.

[12] Smelov V. G., Sotov A. V., Agapovichev A. V. Study of structures and mechanical properties of products manufactured via selective laser sintering of 316L steel powder //Chernye Metally. – 2016. – T. 9. – C. 61-5.

[13] Gusarov A. V и др. Heat transfer modelling and stability analysis of selective laser melting. // Applied Surface Science. (2007). **No 254**. C. 975–979.

[14] Bugeda Miguel Cervera G., Lombera G. Numerical prediction of temperature and density distributions in selective laser sintering processes //Rapid Prototyping Journal. – 1999. – T. 5. – №. 1. – C. 21-26.