DOI: https://doi.org/10.37434/tpwj2025.01.02

# COMPENSATION OF SPATIAL DEFORMATION IN PRODUCTS AT ADDITIVE ELECTRON BEAM SURFACING

**V.A. Matviichuk**

E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

**ABSTRACT**

The aim of the work is to analyze and optimize the shaping of GTE blade in the process of fabrication using additive electron beam technology. Using the method of computer simulation in the Simufact Additive software, the influence of technological printing parameters on product shaping was investigated, and shrinkage phenomena that occur during the printing process were analyzed. The printing simulation was performed and the results were compared to the reference model. The optimized computer models of GTE blades were created. According to the calculation results, when optimized models are used, the deviation in the geometric dimensions of printed blades does not exceed the product size tolerances of ±0.3 mm.

**KEYWORDS:** additive technologies, electron beam, surfacing, simulation, shaping, 3D printer

## INTRODUCTION

When metal products are created by the additive manufacturing method, local shrinkage phenomena occur at the process of layer-by-layer heating and cooling, resulting in overall residual deformations — distortion of linear dimensions of the printed part [1–3]. In order to compensate for residual deformations, it becomes necessary to correct the product model by taking the expected deformations into account.

A number of factors influence the shape of products at the printing process:

- material from which a part is made;
- technological parameters of printing;
- spatial position of a product relative to the platform;
- location of a part in the product assembly;
- shape of technological supports;
- overall temperature of the product assembly and the environment.

Given that products usually have a complex geometric shape, it becomes problematic to fabricate the end product with the required dimensions within tolerances. To solve this problem, it is planned to apply computer simulation methods of the printing process with the subsequent correction of the model, based on which a product will be printed [2].

## THE AIM

of this work is to analyze and optimize the GTE blade shaping in the process of fabrication using additive electron beam technology.

The software product Simufact Additive, developed by MSC Software, was used in the work. This is a specialized software package designed to simulate 3D printing of metal parts using Powder Bed Fusion technology, including Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), Selective Laser CUSING of metal powder materials, Electron Beam Melting (EBM) and a number of other processes [4].

Simufact Additive provides an opportunity to:

- calculate deformations of a part and reduce or avoid distortion of its shape;
- compare simulation results with the reference shape;
- select the optimal printing direction;
- optimize the supporting structures (supports);
- obtain the state of a part after heat treatment, removal of the base plate and supporting structure;
- minimize residual stresses.

The MARC solver [5] is the basis of the Simufact Additive software. MARC has advanced capabilities for conducting a coupled temperature and thermomechanical analysis of the stress-strain state of a product at layer-by-layer printing, taking into account thermal deformations and material properties depending on temperature.

A special voxel mesh generator is used for calculations. Voxels are elementary cells that make up the studied product model. A regular mesh is created, that is used to simulate layer-by-layer printing of a part. The MARC solver has added the ability to sequentially activate voxel layers. New methods for simulation of the cutting process have also been added, which are necessary to simulate the process of removing the base plate and supporting structure.

Simufact Additive uses two approaches for prompt calculation of product deformations during printing [4]: on the base of the approximate method of shrinkage (Mechanical inherent strain approach) within the mechanical problem of elasticity theory or as a result

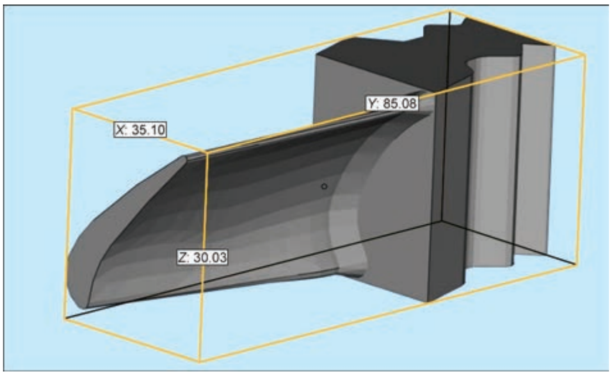


**Figure 1.** GTE stator blade model

of a more general coupled analysis of the thermoplastic deformation of a product material during printing, assuming the same simplified thermal printing cycle for each voxel.

The first approach is based on the determination of the shrinkage function (residual plastic deformations) from printing a single elementary volume (voxel) depending on the technological parameters of a layer-by-layer product formation by means of experimental calibration of the mentioned deformations on a standard printed sample of a beam type of a limited size. The heating kinetics of a product during printing is not calculated; residual deformations and stresses are determined as a result of solving the mechanical loading problem of the finite element model of a product by additional shrinkage deformations for each printed voxel, which allows significantly reducing the calculation time while maintaining sufficient accuracy from an engineering point of view.

The second calculation approach is more general and is based on a coupled thermal and thermomechanical analysis at layer-by-layer printing of a product. However, to reduce the calculation time, the assumption of an identical (simplified) thermal cycle for each voxel of the printed material is used, which gives an opportunity not to analyze the nonstationary thermal conductivity problem for the entire model during the printing process. As a result of the calculation using this approach, the approximate kinetics of heating, as well as stresses and deformations of a product are determined.

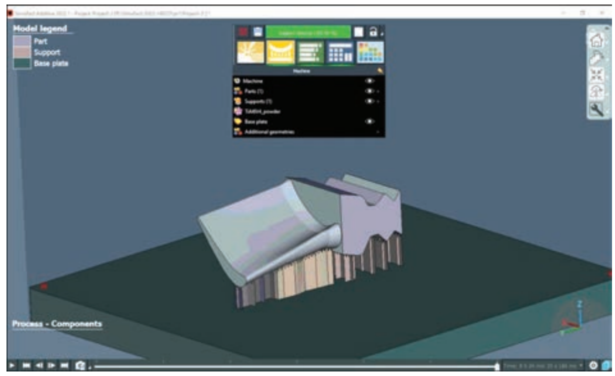


**Figure 3.** Interface of the Simufact Additive software with the integrated GTE blade model

In order to compensate for residual deformations of a product, it is possible to export a model of the deformed geometry with any scale factor. Therefore, it is possible to select the initial shape of a part, which, after the printing process, gives a minimum deviation from the required shape, compensating for deformations that occur during creation of this part [3].

Using the Simufact Additive software product, it is possible to determine the influence of printing technological parameters on the end product parameters and predict deformations of the part shape. In this work, a model of a gas turbine engine (GTE) blade was used (Figure 1).

Using the Materialise Magics software product, technological supports for further printing of a product were generated. Several spatial positions of the parts shown in Figure 2 were used.

The models in Figure 2, *a*, *b* provide the shortest time for building a product in the printing process. The model of Figure 2, *c* provides an opportunity to place on the printer platform and print the largest quantity of parts in one production cycle.

The files of product models and technological supports were exported in STL format to the Simufact Additive software.

The further actions are aimed at optimizing the geometric shape of a part and obtaining information on the impact of technological parameters on the shaping of products and their properties.

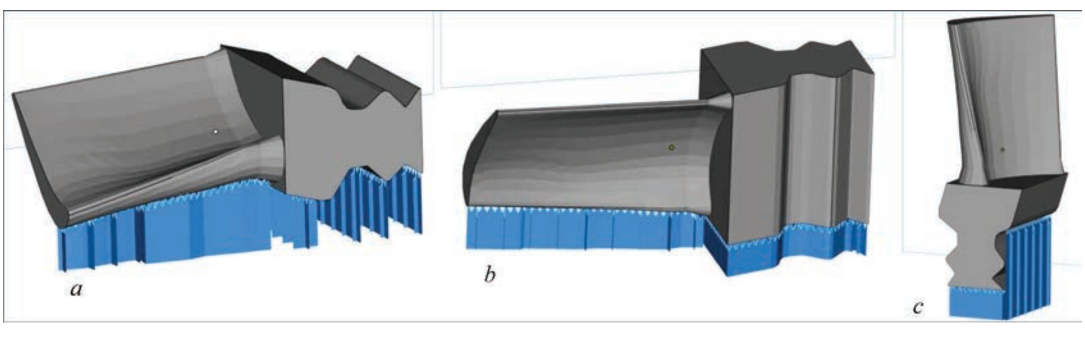


**Figure 2.** Product models with technological supports

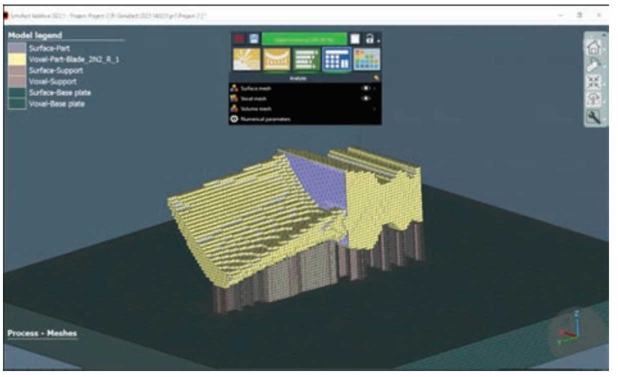

**Figure 4.** Creation of elementary cells — voxels

In the Simufact Additive interface, a project is created, settings are set, where the parameters of equipment and technological process, part and platform materials are specified, and product models are imported along with technological supports (Figure 3).

The technological parameters like power, speed and diameter of electron beam, powder layer thickness, scanning method, thermal characteristics of printing are set in the interface settings in the Build-Properties tab.

Further, voxels (elementary cells that make up the model of a studied product) were generated by the software (Figure 4).

The next step was simulating the layer-by-layer printing of a product. The graphical interface of Simufact Additive, which displays the printing process, is shown in Figure 5.

Shrinkage strains were determined using a different, more general approach to the analysis of thermoplastic deformation of the material. Therefore, the procedure for calibrating shrinkage strains for material voxels was not carried out, but the analysis of the kinetics of the temperature problem of product heating at layer-by-layer shaping and the coupled thermoplastic analysis of the stress-strain state were performed.

The colour corresponds to the temperature value of a product, technological supports and platform at each stage of the printing simulation. The colour pal-

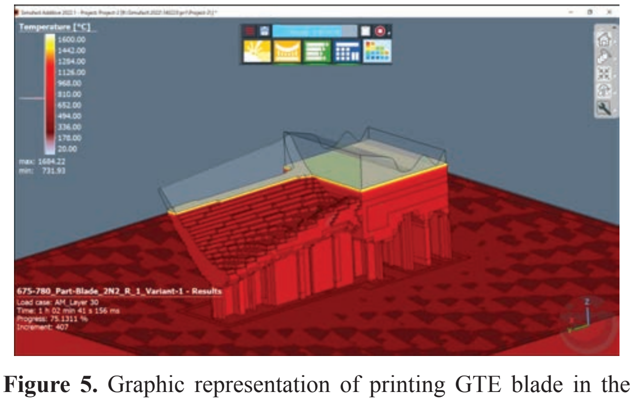

**Figure 5.** Graphic representation of printing GTE blade in the Simufact Additive software

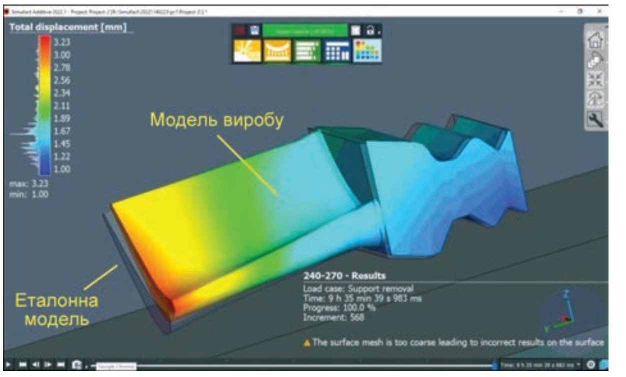


**Figure 6.** Deviation of the printed product model dimensions from the reference model

ette with temperature values is shown in Figure 5 in the Temperature table.

Based on the simulation results, a file was obtained (Figure 6), where deviations of the GTE blade dimensions from the reference model were calculated. Deviations in dimensions arise due to the product shape deformation at the printing process. The values of possible deformations correspond to the colour and are shown on the palette in the Total displacement table.

The next stage of research is correction of the model, calculation of spatial deformations of the corrected model and its comparison with the reference model.

The GTE blade model is corrected to compensate for spatial deformations in the Shape comparison menu of the Simufact Additive software. The model obtained as a result of the additive process simulation is compared with the reference model. In the programme interface, the deviation in the dimensions of the corrected model from the reference one is displayed by the colour palette (Figure 7).

The obtained model is then processed by the software. A new file is created taking into account the shape optimization. The printing simulation process is consistently repeated. The next GTE blade model is created, which is compared with the reference model.

If the obtained model does not match the reference model within the tolerances, the process is repeated.

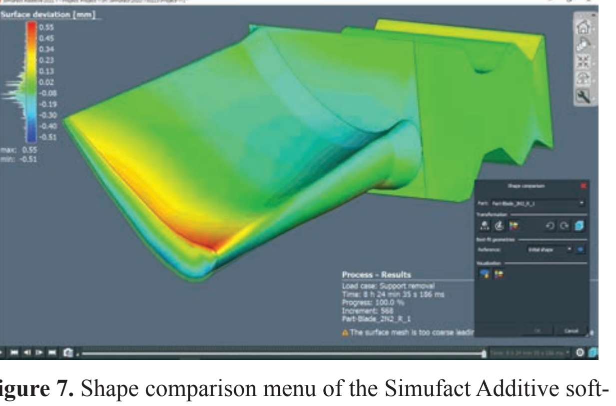

**Figure 7.** Shape comparison menu of the Simufact Additive software

The dimensional deviation of printed products from the reference model should not exceed ±0.3 mm.

The corrected model file is exported in stl format and accepted for printing.

Comparing the reference (base) and optimized models of the GTE blade, it can be noted that linear dimensions of the end product model have been increased from (35.1; 85.08 and 30.03) mm in the *X*, *Y*, *Z* coordinates to (35.69; 85.378 and 30.411) mm. I.e., the model has been enlarged with taking into account the compensation of shrinkage phenomena and other factors that lead to deforming the product shape at the printing process.

## INFLUENCE OF TECHNOLOGICAL PARAMETERS ON THE SHAPE OF PRODUCTS

The technological parameters of printing products from titanium alloy Ti–6A1–4V ELI powders, which are defined in [6] and given in Table 1, were used in the study.

To simulate printing of the products shown in Figure 2, *a*, three projects with different technological parameters were created in the Simufact Additive software. In each project, spatial deformations and deviations of the GTE blade dimensions during printing were determined, which differ depending on technological parameters of printing (Table 2).

The spatial deformations for each of the technological modes are individual. Therefore, it is necessary to study printing of each of the products shown in Figure 2, for all the modes indicated in Table 1. Then, the shape of products should be corrected and the end models of the GTE blade should be obtained. The created models will be suitable for further printing.

## OPTIMIZATION OF DIGITAL MODELS OF THE GTE BLADE

Using the software product Simufact Additive, optimized computer models of the GTE blade were obtained in accordance with the applied technological modes of printing and spatial position of the parts. The simulation results are shown in Table 3.

The optimized models of product assembly with technological supports are exported in stl format and are suitable for further printing.

**Table 1.** Technological parameters for printing products

| Product number | Beam power, W | Travel speed, mm/s | Trajectory shift, mm | Layer thickness, mm | Power density, J/mm$^3$ |
|---|---|---|---|---|---|
| 1 | 240 | 270 | 0.2 | 0.1 | 44.4 |
| 2 | 495 | 540 | 0.2 | 0.1 | 45.8 |
| 3 | 675 | 780 | 0.2 | 0.1 | 43.3 |

**Table 2.** Spatial deformation values

| Product number | Beam power, W | Travel speed, mm/s | Dimensional deviation, mm | |
|---|---|---|---|---|
| | | | from | to |
| 1 | 240 | 270 | 1.00 | 3.23 |
| 2 | 495 | 540 | 0.97 | 2.85 |
| 3 | 675 | 780 | 0.98 | 2.70 |

**Table 3.** Results of GTE blade models optimization

| Product number | Spatial position in accordance with Figure 2 | Beam power, W | Travel speed, mm/s | Dimensional deviation, mm | |
|---|---|---|---|---|---|
| | | | | from | to |
| 1 | *a* | 240 | 270 | –0.03 | 0.13 |
| 2 | *a* | 495 | 540 | –0.02 | 0.08 |
| 3 | *a* | 675 | 780 | –0.03 | 0.09 |
| 4 | *b* | 240 | 270 | –0.05 | 0.11 |
| 5 | *c* | 240 | 270 | –0.26 | 0.14 |
| 6 | *c* | 495 | 540 | –0.25 | 0.14 |
| 7 | *c* | 675 | 780 | –0.25 | 0.13 |

**Table 4.** Dimensions of the digital model and the product “GTE blade”

| Parameter | Digital model, mm | Printed product, mm | Dispersion, mm | Tolerance, mm | Compliance mark |
|---|---|---|---|---|---|
| Height | 35.1 | 35.21 | 0.11 | ±0.3 | Matches |
| Width | 30.03 | 30.16 | 0.13 | ±0.3 | |
| Length | 85.08 | 85.06 | –0.02 | ±0.3 | |

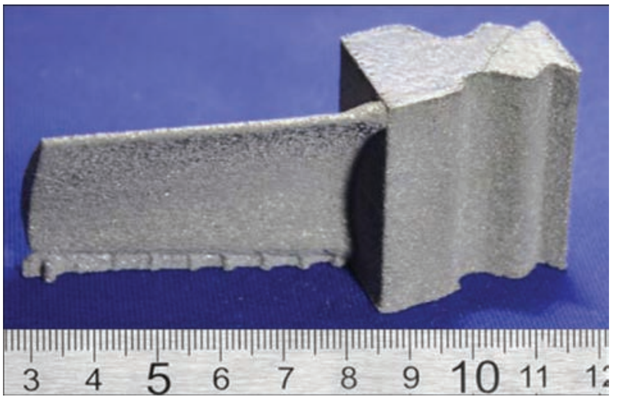


**Figure 8.** GTE blade

## FABRICATION AND STUDY OF THE GTE BLADE GEOMETRY

Based on the optimized computer model (Figure 2, *b*), in accordance with the specified technological parameters (Table 1, product No. 2), GTE blades were fabricated by the method of additive electron beam surfacing (Figure 8).

An analysis of the product shaping was carried out. The geometrical dimensions of the reference computer model and the printed product "GTE blade" are given in Table 4.

It was determined that dimensions of the printed GTE blade match the digital model. According to the calculation results, when using the optimized models, the deviation of the geometric dimensions of printed blades does not exceed the product size tolerances of ±0.3 mm.

## CONCLUSIONS

In terms of the technological preparation for the additive manufacturing of experimental samples of GTE working blades, a computer simulation of printing was carried out using the Simufact Additive software product and the obtained results were compared with the reference model. The optimized computer models of the GTE blade were obtained taking into account the spatial deformations that occur during the printing process. According to the calculation results, using the optimized models, the deviation of the geometric dimensions of printed blades does not exceed the tolerances for the product size of ±0.3 mm.

## REFERENCES


1. Makhnenko, O.V., Milenin, A.S., Velikoivanenko, E.A. et al. (2017) Modelling of temperature fields and stress-strain state of small 3D sample in its layer-by-layer forming. *The Paton Welding J.*, **3**, 7–14. DOI: https://doi.org/10.15407/tpwj2017.03.02
2. Sahini, D.K., Ghose, J., Jha, S.K., Behera, A., Mandal, A. (2020) Optimization and simulation of additive manufacturing processes: challenges and opportunities – A review. In: *Additive Manufacturing Applications for Metals and Composites*, 187–209. DOI: https://doi.org/10.4018/978-1-7998-4054-1.ch010
3. Derrer, J.P. et al. (2022) *Simufact engineering provides the green team & renishaw with a complete AM process simulation solution. SIMUFACT Case study*. https://enteknograte.com/wp-content/uploads/2022/06/hexagon_mi_simufact_casestudy_renishaw_a4_en_screen.pdf
4. *Simufact additive*. https://hexagon.com/products/simufact-additive
5. *MSC. Marc volume A: Theory and user information*. https://simcompanion.hexagon.com/customers/s/article/msc-marc-volume-a--theory-and-user-information-doc9245
6. Matviichuk, V., Nesterenkov, V., Berdnikova, O. (2022) Determining the influence of technological parameters of the electron-beam surfacing process on quality indicators. *Eastern-European J. of Enterprise Technologies*, **1**, 21–30. DOI: https://doi.org/10.15587/1729-4061.2022.253473



## ORCID

V.A. Matviichuk: 0000-0002-9304-6862

## CORRESPONDING AUTHOR

V.A. Matviichuk
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.
E-mail: matviychuk@technobeam.com.ua



## SUGGESTED CITATION

V.A. Matviichuk (2025) Compensation of spatial deformation in products at additive electron beam surfacing. *The Paton Welding J.*, **1**, 10–14.
DOI: https://doi.org/10.37434/tpwj2025.01.02

## JOURNAL HOME PAGE

https://patonpublishinghouse.com/eng/journals/tpwj

Received: 12.06.2024
Received in revised form: 14.10.2024
Accepted: 23.01.2025