Optimization of the Weight and Size Characteristics of the Power Bracket for Additive Manufacturing Based on Topological Optimization Algorithms

A. V. Zhdanov, S. A. Baranov, and L. V. Belyaev

1 Introduction

Currently, one of the intensively developing technological methods of manufacturing products is the method of selective laser melting. This method has a number of technological advantages over traditional methods of material processing, allowing you to obtain products of almost any geometric complexity from a large range of materials (Sadeghilaridjani 2021; King et al. 2015). However, it is not economically feasible to manufacture products whose geometry is not adapted to the peculiarities of additive manufacturing (Bajaj et al. 2020).

One of the methods of such adaptation is the use of topology optimization. Topology optimization is a mathematical tool that allows you to optimize the distribution of material in a part at the design stage. There are various topology optimization algorithms developed over the past three decades. For instance, set level approach, homogenization method, SIMP method and density approach are among the main topology optimization techniques (Rozvany 2009; Sigmund and Maute 2013).

The purpose of this article is to investigate the possibility of optimizing the weight and size characteristics for additive manufacturing based on the selected algorithm of topological optimization.

2 Materials and Methods

The object of the study was a bracket used as a swivel mount and experiencing heavy loads, with overall dimensions of 176 × 170 × 95 mm (Fig. 1), made of EN-AW 2024 material and weighing 1.75 kgf. EN-AW 2024 alloy is a typical 2xxx

A. V. Zhdanov (✉) · S. A. Baranov · L. V. Belyaev
Vladimir State University, 87 Gorky Street, Vladimir 600000, Russia
e-mail: Zhdanov@vlsu.ru

R. K Agarwal (ed.), *Recent Advances in Manufacturing Engineering and Processes*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-19-6841-9_8

series (Al–Cu–Mg) wrought Al alloy, and it has the advantages of low density, high specific strength, excellent fatigue resistance and good machinability (Chen et al. 2019; Zhang et al. 2019; Bonfils-Lahovary et al. 2024). The EN-AW 2024 is resilient material with increased strength values, which is mainly used in the aerospace and automotive industries. The properties of the EN-AW 2024 material and its chemical composition are provided in Tables 1 and 2.

The use of aluminum is justified by the fact that the design of the bracket should be lightweight and at the same time withstand the loads applied to it. At the same time,

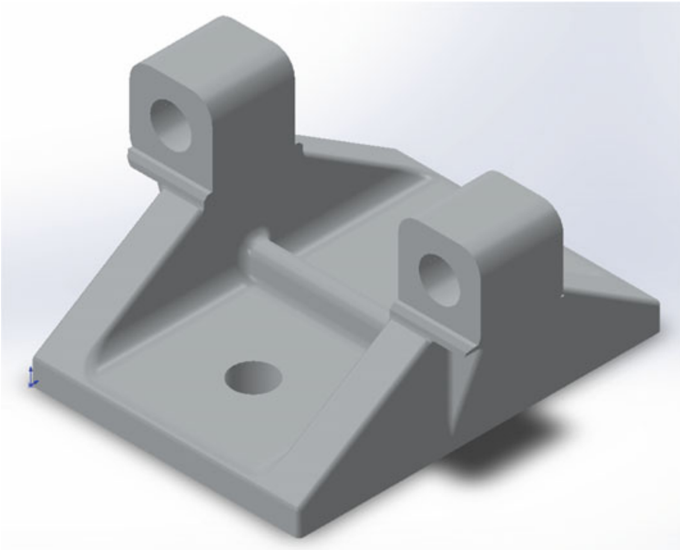

Fig. 1 3D-model of power bracket

Table 1 Physical and mechanical properties of the material EN-AW 2024

Parameter	Value
Modulus of elasticity, MPa	70,000
Poisson's ratio	0.3897
Shear modulus, MPa	27,000
Density, kg/m^3	2780
Tensile strength, MPa	440
Yield strength, MPa	290

Table 2 Chemical composition of the material EN-AW 2024 [% weight]

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other	Al
≤0.5	≤0.5	3.8–4.9	0.3–0.9	1.2–1.8	≤0.1	≤0.25	≤0.15	≤0.15	90.7–94.7

the use of this material imposes a number of significant restrictions on the physical characteristics of the product. These include lack of load capacity, high probability of fatigue failure and temperature resistance. Nevertheless, it is worth pointing out that in the process of optimization, fine-tuning of the design is possible, taking into account all complicating factors.

The original design of the bracket is an integral structure of complex geometric shape, consisting of several holes and stiffeners. Fixing the bracket to the surface of the fit is carried out through the lower plane and the corresponding hole in it. The fastening of the mating part of the moving structure is carried out through holes having a cylindrical shape.

The mechanical and physical properties of the material used are listed below.

Topological optimization was carried out in the SOLID WORKS 2020 software product (Dassault Systems, France). This software product uses the SIMP method for topology optimization (SOLID WORKS 2020).

The optimization conditions were as follows:

- the optimized geometry must fit within the original part envelope; minimum material feature size (wall thickness or central rib): 18.4 mm;
- the part was fixed through holes in the base;
- the load was 10 kN and applied at an angle of 90° to the base plane (horizontal plane);
- the aim of the study is to reduce the weight by 60%.

To determine the effectiveness of the topological optimization process, the stress–strain state of the initial and obtained geometries was evaluated under the same loading conditions.

3 Results and Discussion

As a result of the topological optimization of the initial geometry of the product based on the finite element method, a new geometry of the bracket in question was obtained (Fig. 2).

In the process of topology optimization, the product was transformed and geometrically underwent some complications. Thus, the resulting geometry had a less monolithic base, but an increased number of support points. Geometric cutouts were formed at the base of the product to reduce the weight of the entire structure. The stiffeners were also changed in the direction of complicating the geometry, but reducing the total mass and area.

The analysis of the stress–strain state of the part allowed us to obtain pictures of the von Mises stress distribution, deformations and the safety factor, which are shown in Figs. 3 and 4.

Stress fields have shown that the greatest load falls on the central stiffener of the product at the base. Nevertheless, these stresses are moderate values that are not critical for the applied loads and the material used.

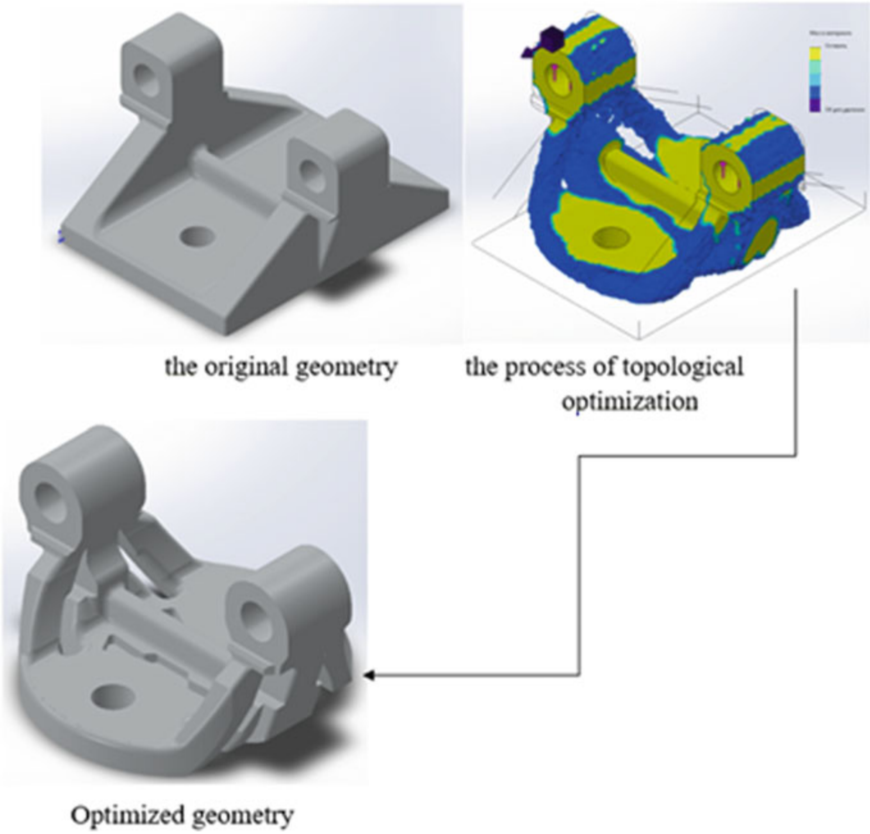

Fig. 2 Topological transformation of geometry

The von Misses stresses values were reduced and now they are about 133 MPa on average, over the entire length of the edge. The graph of rib loading along the length shows a sharp decrease in stresses in the area from 50 to 80 mm. This is due to the distribution of the load over the newly formed geometry, which allows us to delegate the load along the entire length of the edge. In addition, the graph shows that the average values of the emerging stresses do not exceed 140 MPa. This is a significant improvement.

The maximum values of these parameters are given in Tables 3 and 4.

A comparison of the results obtained from the tables above shows the possibility of reducing the mass of the part without losing its mechanical properties.

The reduction of weight saves huge amount of material and processing energy thus huge amount of money. It also shows that the capability of topology optimization can be fully utilized with additive manufacturing techniques, as the manufacturing constraints in the conventional methods are no longer available. As a result of the work, the weight of the product decreased by 31.5%, and the average values of stresses

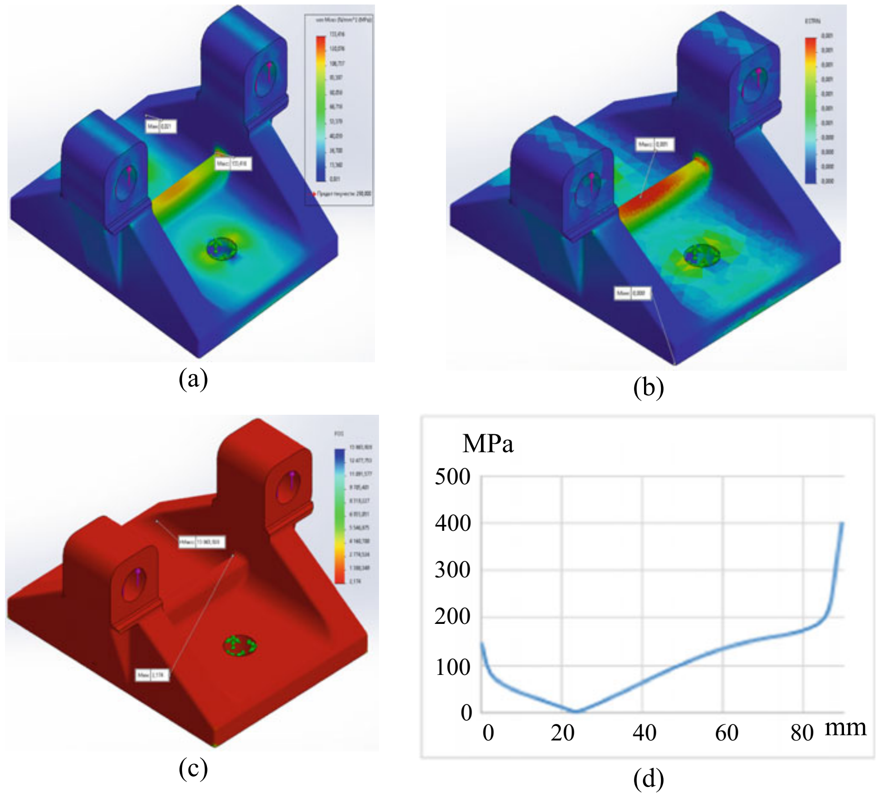

Fig. 3 Diagrams of stresses (**a**), deformations (**b**), safety factor (**c**), and stress distribution graph along the edge length (**d**) for the initial geometry of the product

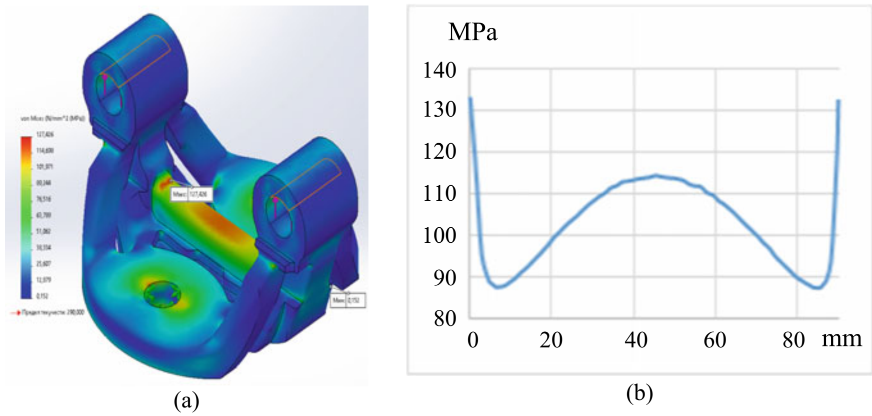

Fig. 4 Stress plots (**a**) and stress distribution graph along the edge length (**b**)

Table 3 Results of static analysis of the model without topological changes

Parameter	Value
Von Mises stresses, MPa	117.858
Deformation, ESTRN	0.002
Safety margin	2.461
Weight, kgf	1.180

Table 4 Results of static analysis of the model with topological changes

Von Mises stress, MPa	Deformation, ESTRN	Safety margin
113.416	0.001	2.174

arising during the load decreased by almost a half. The results require practical confirmation in working conditions, which is the next stage of the study.

4 Conclusion

From the case study, it can be concluded that topology optimization is a powerful design concept to reduce the weight of structural products. The reduction of weight saves huge amount of material and processing energy thus huge amount of money. It also shows that the capability of topology optimization can be fully utilized with additive manufacturing techniques, as the manufacturing constraints in the conventional methods are no longer available. From the case study result, which is 31.5% weight and 11.5 von Mises stress reduction, respectively, it can also be concluded that topology optimized design for additive manufacturing can reduce huge portion of the mass thus result in lightweight design.

Acknowledgements This work was supported by the Russian Foundation for Basic Research (Grant 20-08-00310) and was carried out using the equipment of the interregional multispecialty and interdisciplinary center for the collective usage of promising and competitive technologies in the areas of development and application in industry/mechanical engineering of domestic achievements in the field of nanotechnology (CCP VlSU).

References

Bajaj, P., Hariharan, A., Kini, A., Kürnsteiner, P., Raabe, D., Jägle, E.A.: Steels in additive manufacturing: a review of their microstructure and properties. Mater. Sci. Eng., A **772**, 138633 (2020)

Chen, G., Liu, J., Shu, X., Gu, H., Zhang, B., Feng, J.: Beam scanning effect on properties optimization of thick-plate 2A12 aluminum alloy electron-beam welding joints Mater. Sci. Eng. A **744**, 583–592 (2019) de Bonfils-Lahovary, M., Josse, C., Laffont, L., Blanc, C.: Influence of hydrogen on the propagation of intergranular corrosion defects in 2024 aluminium alloy. Corrosion Sci. **148**:198–205

King, W., Anderson, A., Ferencz, R., Hodge, N., Kamath, C., Khairallah, S., Rubenchik, A.: Laser powder bed fusion additive manufacturing of metals; physics, computational, and materials challenges. Appl. Phys. Rev. **2**, 041304 (2015)

Rozvany, G.: Struct. Multidiscipl. Optim. **37**(3), 217–237 (2009)

Sadeghilaridjani, M.: Review of powder bed fusion additive manufacturing for metals. Metals **11**, 1391 (2021)

Sigmund, O., Maute, K.: Struct. Multidiscipl. Optim. **48**(6), 1031–1055 (2013)

SOLID WORKS 2020. https://help.solidworks.com/2019/English/SolidWorks/cworks/c_simp_method_topology.htm. Last accessed 21 Nov 2021

Zhang, S., Zhang, T., He, Y., Liu, D., Wang, J., Du, X., Ma, B.: Long-term atmospheric corrosion of aluminum alloy 2024–T4 in coastal environment: surface and sectional corrosion behaviour. J. Alloys Compd. **789**, 460–471 (2019)