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Topology Optimization of Gripping Jaws of Industrial Robot

Miroslav Cedzo (0000-0002-1872-0925), Richard Joch (0000-0002-9937-0057), Pavol Timko (0000-0002-2392-3153), Jozef Holubják (0000-0003-3226-9445), Tatiana Czánová (0000-0002-6943-6393), Michal Šajgalík (0000-0002-4908-1046)
Faculty of Mechanical Engineering, ŽILINSKÁ UNIVERZITA V ŽILINE, Univerzitná 8215/1, 010 26 Žilina, Slovakia. E-mail: miroslav.cedzo@fstroj.uniza.sk

There is a lot of applications for manipulating industrial robots nowadays. Maximizing the tasks that can be assigned to robot manipulators is one of the criteria for deciding if their application is appropriate. The article discusses the topology optimization of the gripping jaws of an industrial robot to reduce the jaws' weight. The previously used gripping element made of C50E steel was optimized to reduce the weight of the jaws. Shape optimization was performed based on analysis from CAD programs Inventor Professional 2022, Autodesk Fusion 360, and Ansys Discovery. The new jaws were manufactured by the additive technology of selective laser sintering (SLS) from PA12 material. The optimization resulted in a significant reduction in weight compared to the original jaws. As a result of optimizing the weight of the designed jaws, it was possible to increase the weight of the object of manipulation.

Keywords: Topology Optimization, Gripping Jaws, Additive Manufacturing, SLS, Generative Design

1 Introduction

Increasing productivity and ongoing automation in the industry result in a significant increase in the application of manipulators and robotic devices. As a result, there is a wide range of manipulators and gripping components on the market. However, for specific grip shapes, it is necessary to design components that will fulfil the required parameters such as strength, weight, or contact surface. When designing the shape of the gripping components, it is possible to employ strength analyses with the purpose of enhancing the structure and future application. Shape optimization could potentially be added to the list of applicable analyses. Topology optimization is a computational method for determining material distribution, shape modification and the number and shape of holes. As a result, topologically optimized designs result in energy savings, weight reduction, efficient material utilization and faster, more sustainable production. [1] With the support of topology optimization technology the weight and number of required components of the proposed components can be decreased by a significant amount [2,3]. In addition to this, the product of topology optimization includes bionic shapes that can be utilized from both a functional and an aesthetic point. In topology optimization, shapes are generated directly and specifically for a specific case [4, 5, 6]. Furthermore the designer can reduce the weight and improve the performance of the designed components by using a complex mesh for the filling of the designed component. The properties of the filling can be focused for example on absorbing impact energy, dampening vibrations and noise. [5,6] To implement topology optimization during component design must the designer pre-specify certain constraints for the designed component such as required geometric properties, component weight, load conditions and material. [5] The material is used only where it is necessary due to the boundary conditions. Each designed model is thoroughly checked using FEM analysis. The material is defined only where it fulfils its purpose in terms of mechanical properties. [5,6] Compared to conventional components this technology enables the designing of parts with surfaces that are difficult to define mathematically. The result of the optimization can be a component with a complex shape that would be difficult to manufacture. In practice these parts cannot be produced without simultaneous five-axis milling and in many cases it is necessary to use additive manufacturing technology because they cannot be produced by other technology. [6,7]

Additive manufacturing (AM) is also known as ``rapid prototyping" or three-dimensional printing (3D printing). Additive manufacturing is a technology for manufacturing components from a 3D model which is based on connecting materials layer by layer. The input geometry of the objects consists of a 3D model in STL format which is often created from a meshed 3D model. [8,9] Additive technologies allow for unique flexibility in the production and design of components with complex geometries. [9,10,12] Using a 3D method such as selective laser melting (SLS) it is possible to print metal components that are complex [13], functional, lightweight and with even higher mechanical properties compared to their forged counterparts [14]. Due to the aforementioned benefits SLS technology has also found use in industry. SLM-produced components can be applied in a range of fields including the automotive, aerospace and medical industries [6,15]. SLS technology can print polymers and composite materials of complex geometries without the need to use supports. Furthermore parts made with SLS technology show an excellent ability to produce final products that have high strength, stiffness and chemical resistance. [10-14] The material spectrum of the products includes ceramics, metals and plastics. [9,114] The method of selective laser sintering or laser melting can be used with any powder substance. However, the material used must first be melted and then solidified by laser light after cooling. When compared to many other methods of additive manufacturing SLS technology has the significant advantage of not requiring the use of support structures during the printing process. [10,11] This ensures that the printed components do not collapse. Furthermore, we can use SLS technology to manufacture complex components that cannot be produced using other 3D printing technologies because the unsintered powder performs the function of support during the printing process. On the other hand, there are some problems with the SLS method especially with the porous surface and the low printing speed. [12,16] Therefore, SLS technologies are generally used for early-stage rapid prototyping. In recent years has been this technology also used for mass production, provided that the required materials are commonly available and can be produced at a cost that is appropriate for the application [12,13].

The aim of the presented work was to reduce the weight of the gripping jaws of the manipulating industrial robot. The industrial robot will thus be able to handle heavier objects and the possibilities of its use will increase. Initially, from the original design of the gripping jaws it was first considered to change the material of the jaws which would result in a weight reduction. Instead of the AISI 105 (C50E) steel that was originally used for the jaw materialwas utilized the aluminium alloy 6061-AHC (AlMg1SiCu). In later iterations the SLS additive technology was used to choose the PA12 material. The topology optimization of the geometry of the gripping jaws was required to maximize the benefits of additive manufacturing and achieve maximum weight reduction.

2 Methodology

The gripping jaws were designed specifically for the Schunk gripping system EOA-UR3510- EGP 40, the whole assembly is depicted in Figure 1. a). The designed jaws which can be seen in Figure 1. b) are mounted on the gripping system using M5 screws. The jaws were constructed from AISI 1050 steel but this material was not suitable due to the excessive weight of the jaws. Therefore, the weight of the initial structural design had to be recalculated when the material was changed while the geometry of the jaws was kept the same.

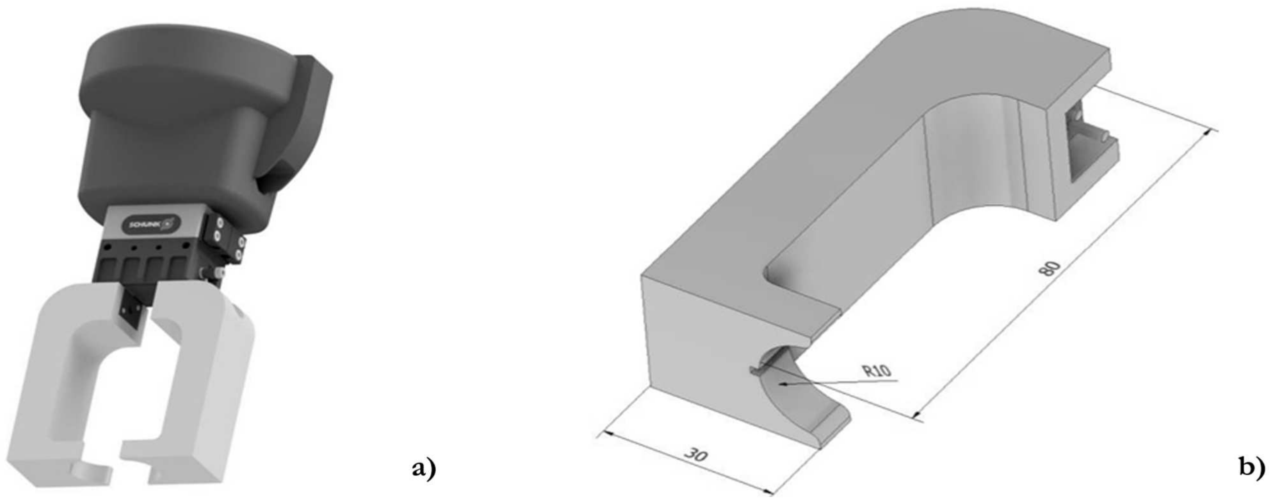

***Fig. 1** a) Designed jaws with gripper from Schunk company, b) Designed jaws*

As a new material, were selected an aluminium alloy that is manufactured by chip machining and a PA12 polymer that is manufactured by SLS additive technology. Jaws made of steel had an initial construction weight of 287.3 g, while for aluminium alloy jaws it was 98.8 g and for PA12 material jaws it was 36.6 g.

2.1 Used material

Polymer Polyamide 12 (PA12) has good chemical properties and a low coefficient of friction. Due to its high strength and outstanding print quality. It is a material that is employed in a wide range of industries. [12,15] PA 12 is the most common polymer used in the SLS technique, mainly for simple and flexible processing. This is a consequence of the wide temperature range that exists between the start of the melting process, which occurs during the heating process and the start of the crystallization process which occurs during the cooling process. This property allows the material to be kept molten without crystallization until cooling which maximizes consolidation and prevents the deformation of printed components [17,18,19]. Other properties such as reduced moisture absorption in comparison to other polyamides, good abrasion resistance and strong chemical resistance [17,19] are what make this material suitable for its intended use. Its mechanical properties are listed in Table 1.

Tab. 1 *PA12 powder properties [20]*

Property	Value
Flexural Strength (MPa)	47
Density of solid parts (g/cm^3)	0.95
Melting temperature (°C)	185
Tensile Strength (MPa)	32
Young's modulus (MPa)	1470
Impact strength Charpy method (unnotched) (kJ/m^3)	36

2.2 Setting input parameters

SLS technology enables the production of complex structures and non-standard shapes. The shape of the jaws was topologically optimized to reduce weight as much as possible and take advantage of the benefits of additive manufacturing. Topology optimization of the designed jaws was performed in Autodesk Inventor Professional 2022, Autodesk Fusion 360 and Ansys Discovery programs. In all cases were set for shape calculation identical input parameters. The first component was made of PA12 which was the first material option. The point of mounting of the jaw to the gripping system was where the rigid binding was set. The required load of 30N shown in Figure 2. a) on the shaped surface of the jaws with a radius of 10 mm was selected as were the surfaces that were to be preserved shown in Figure 2. b). After selecting the input requirements was generated a new shape of the jaws subsequently.

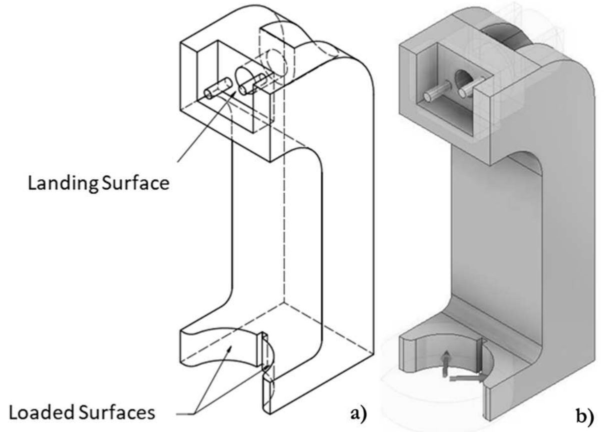

Fig. 2 *a) Landing Surface and Loaded Surfaces, b) Preserved Surfaces*

2.3 Topology optimization

In the Autodesk Inventor Professional 2022 program was generated a new shape of the jaws in Figure 3 based on the input parameters. The volume and weight of the new component were calculated once the shape was generated based on the material that was assigned to it. The generated component has a weight of 19 g and a volume of 7234.8 mm^3.

Fig. 3 *Jaws generated in program Inventor Professional 2022*

Using Autodesk Fusion 360 software, the weight of the generated jaw after topology optimization which can be seen in Figure 4 was 28.9 g and its volume was calculated to be 26274.3 mm^3.

Fig. 4 *Jaws generated in program Autodesk Fusion 360*

The software Ansys Discovery during topology optimization generated a new shape of the gripping jaw which can be seen in Figure 5 with a weight of 27.4 g and a volume of 24883.2 mm^3.

Fig. 5 *Jaws generated in program Ansys Discovery*

3 Results

3.1 Weight and volume

From the graphic comparison of the calculated weights and volumes of the designed jaws in Figure 6, it can be concluded that topology optimization with the software Inventor Professional 2022 resulted in the highest weight reduction, to be more specific the weight of the jaw was 19g. Using Ansys Discovery software for shape optimization the weight of 27.4g was the second lowest. With the original shape of the jaw, the lowest weight was achieved when using PA12 material. The weight of the original jaws made of PA12 material was 36.6g.

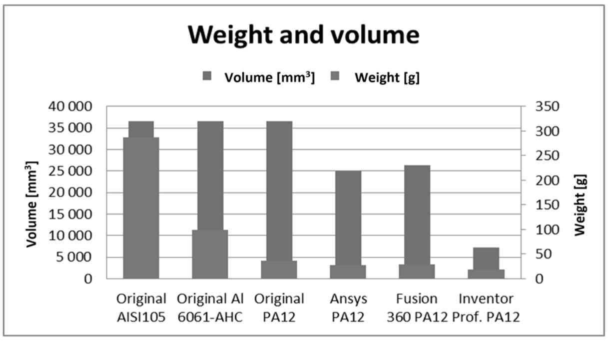

Fig. 6 *Graphical evaluation of weight and volume*

The calculated weight and volume values for each sample are given in Table 2.

Tab. 1 *PA12 powder properties [18]*

	Original AISI 105	Original Al 6061-AHC	Original PA12	Ansys PA12	Fusion 360 PA12	Inventor Prof. PA12
Weight [g]	287.3	98.8	36.6	27.4	28.9	19.0
Volume [mm³]	36604.6	36604.6	36604.6	24883.2	26274.3	7234.8

3.2 Von Misses stress

To verify the results and functionality of the designed jaws, a FEM analysis was used to determine the stress and deformation when the designed parts were loaded with a force of 30N. For the original design of the steel gripping jaw was the calculated stress 47.27 MPa, for the aluminium alloy 46.54 MPa, and for the PA12 material 49.76 MPa. For the topologically optimized shape with Autodesk Inventor Professional 2022 software was the maximum load calculated to be 66.14 MPa, with Autodesk Fusion 360 software the stress was 105.50 MPa and 6.91 MPa with Ansys Discovery software shown in Figure 7.

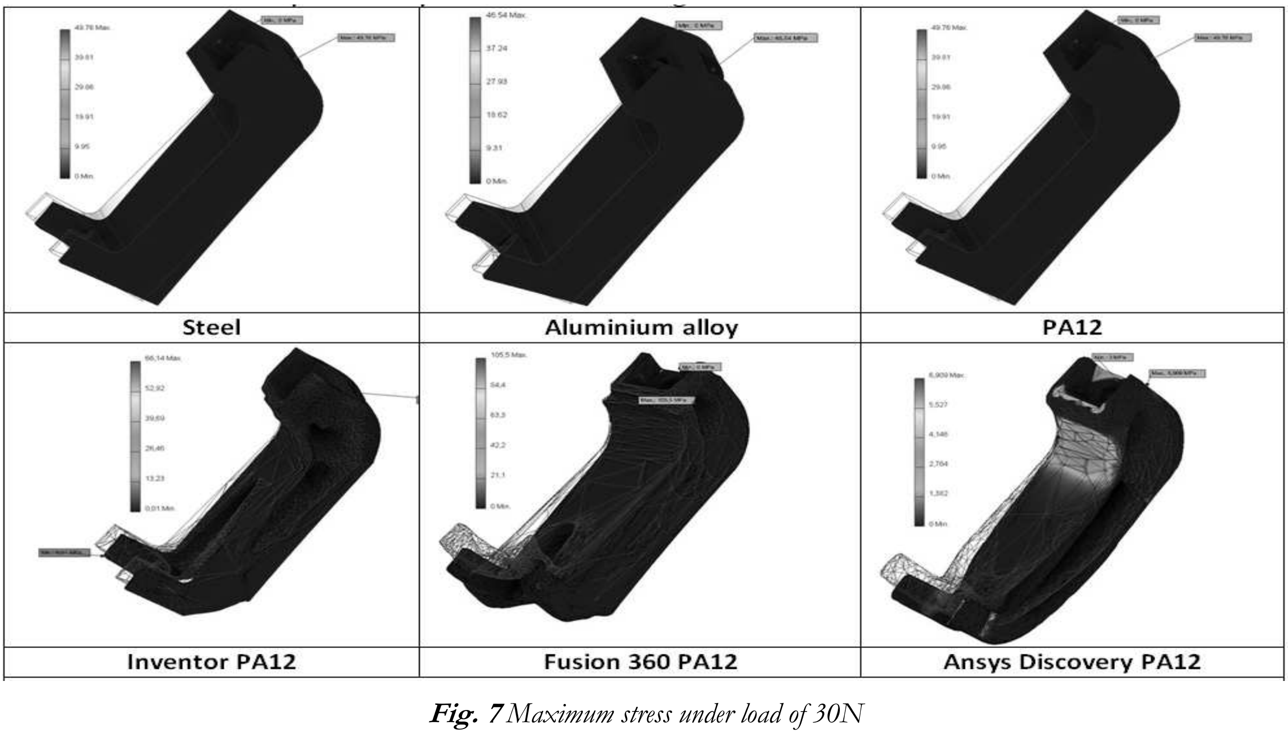

Fig. 7 *Maximum stress under load of 30N*

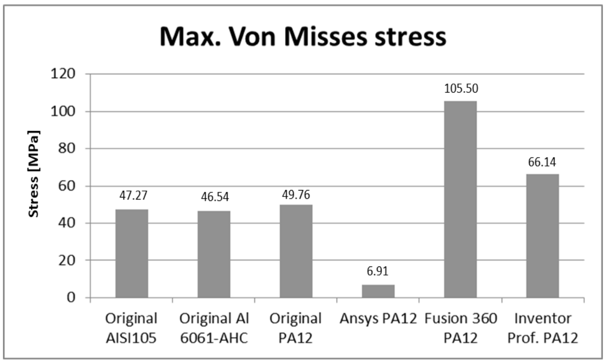

Fig. 8 *Graphical evaluation of stresses*

From the graphic comparison of stresses in Figure 8 when loaded with a force of 30N was the lowest stress for the aluminium alloy 46.54 MPa and the highest was for the PA12 material 49.76 MPa for the original geometry. After topology optimization was the lowest stress in the Ansys Discovery software sample 6.91 MPa and the highest in the Autodesk Fusion 360 software design. Overall, the highest stress was measured in the Autodesk Fusion 360 software sample. The stress of the jaws with the original geometry did not change significantly when the material was changed.

3.3 Deformation

Subsequently, the maximum deformation of the designs at the same load of 30N was calculated. For the original design of the gripping jaw made of steel, the calculated deformation was 0.0042 mm for aluminium alloy 0.0121 mm and for PA12 material 0.2883 mm. The deformation for the topologically optimized shape with Autodesk Inventor Professional 2022 software was 0.4839 mm, with Autodesk Fusion 360 software the deformation was 0.4210 mm and 0.3385 mm with Ansys Discovery software. It can be seen in Figure 9.

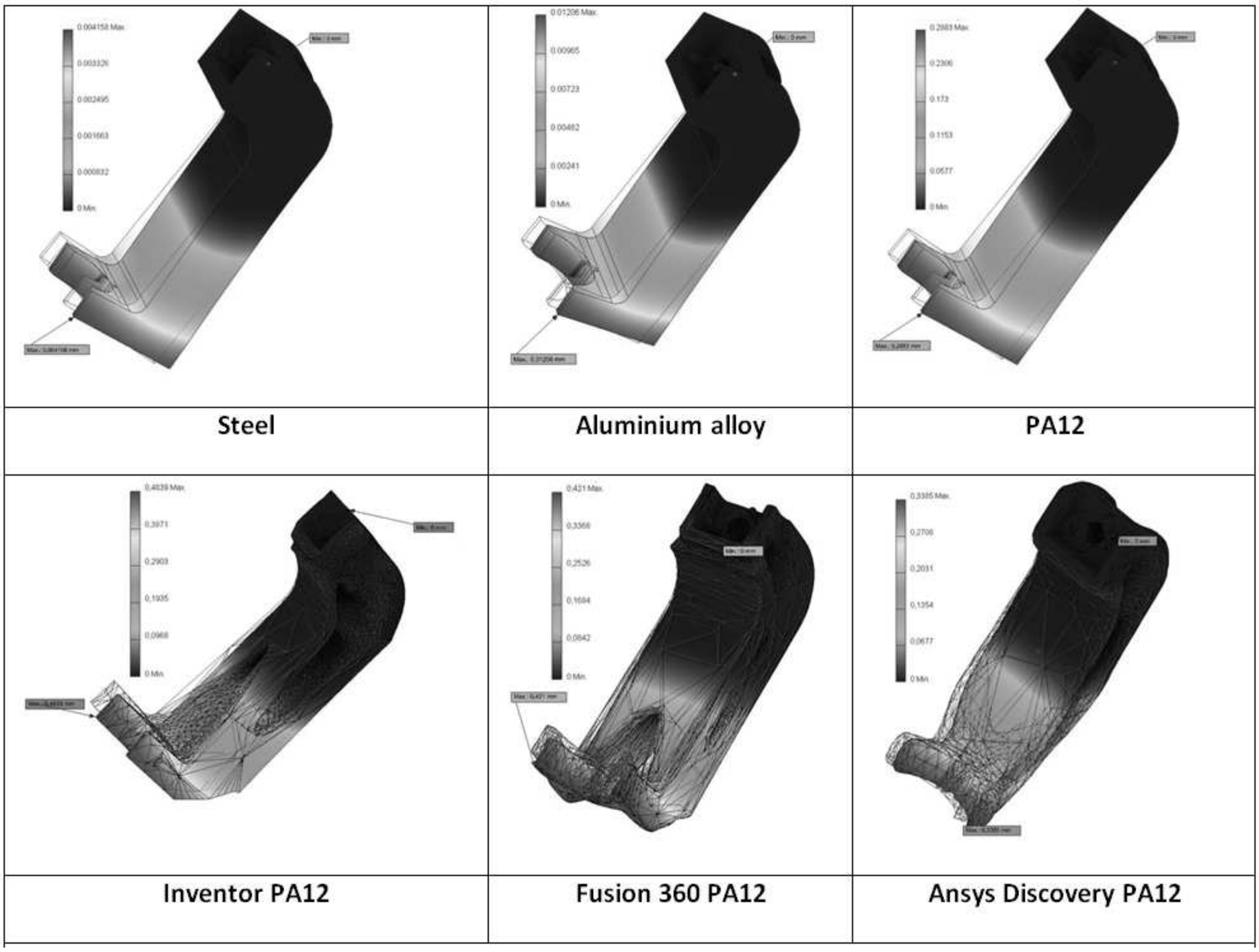

Fig. 9 *Maximum deformation*

From the graphic representation of the calculated deformations in Figure 10 we can note that the original design of the steel jaw structure had the minimum overall deformation 0.004158 mm under the load force of 30N. In the original design material PA12 caused the largest deformation. Among the topology optimization designs the Autodesk Inventor Professional 2022 software design had the largest deformation with the following value 0.4839 mm. In this instance it was the largest deformation in general. The design generated by the Ansys Discovery program had the least distortion at 0.3385 mm.

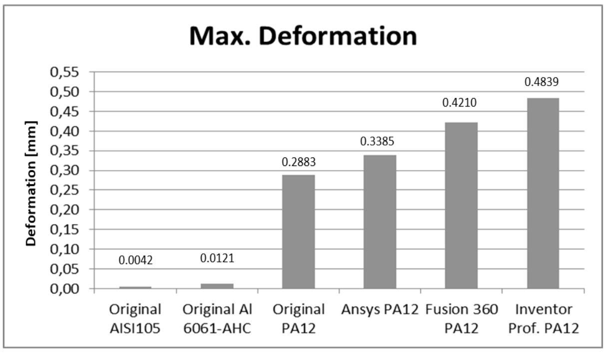

Fig. 10 *Graphical evaluation of maximum deformation*

4 Conclusion

This research focuses on the design and topology optimization of gripping jaws. In the original design of the geometry of the gripping jaws were studied three different materials. The materials that were used were Steel C50E (AISI 105), aluminium alloy 6061-AHC (AlMg1SiCu) and polymer PA12 all suitable for 3D printing employing SLS technology. The topology optimization of the shape of the jaws was performed in three different software and the results gained were subsequently compared. The jaws had the lowest weight of 19 g with design made in software the Autodesk Inventor Professional 2022. This represents a significant reduction in weight when compared to the original geometry made of steel. With the original shape of the jaw was the lowest weight achieved using PA12 material. Functionality of the designed jaws was verified using the FEM analysis for all designs. Furthermore FEM analysis was designed to determine the stress and deformation. In this anayses were designed parts loaded with force of 30N. For the original design of the steel gripping jaw was the lowest stress calculated for the aluminium sample and the highest for the PA12 sample. For samples after topology optimization software Autodesk Fusion 360 produced the highest stress. The maximum 6stress of the jaws with the original geometry did not change significantly with the change of the material. The choice of material and topology optimization had a significant impact on deformation. In the original design of the jaw structure made of steel was deformation 0.0042 mm. The PA12 material caused the largest deformation in the original design. Among the topology optimization designs software Autodesk Inventor Professional 2022 designed part with the largest deformation measuring 0.4839 mm. In this instance it was the largest deformation in general. The design generated by the Ansys Discovery software had the smallest deformation measuring 0.3385 mm.

Based on a comparison of the available data of the strength analyses done for all experiments we can conclude that the software Ansys Discovery produced optimal results. Under the simulated load the topologically optimized design achieved the smallest deformation, the lowest stress, and an acceptable weight.

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