12th Brazilian Congress of Manufacturing Engineering
May 10th-12th, 2023, Brasilia, DF, Brazil

REDESIGN OF AN INDUSTRIAL ROBOT GRIPPER BASED ON ADDITIVE MANUFACTURING

Luana Seixas Andril Araújo
Valter Estevão Beal
João Ricardo Lima de Oliveira
SENAI CIMATEC, Av. Orlando Gomes, 1845 – Piatã, Salvador – BA, 41650-010, Brasil
luandril@gmail.com; valtereb@fieb.org.br; joao.oliveira@fieb.org.br

Abstract. *In search of keeping competitiveness, the industry looks towards reducing costs and processing time while increasing the quality of their products. For this, industrial automation has been used, especially in Industry 4.0, making possible a standardization of processes, and increasing their efficiency. In this scenario, there are industrial robots whose one of their purposes is to move parts or manipulate tools through programmed movements in order to perform different tasks, which are performed thanks to a gripper, whose format depends on the task. In this sense, the present work aims to redesign the gripper of an industrial robot, using the advantages of additive manufacturing (AM), and to obtain economic viability. This technology consists in successively adding material layer-by-layer from a 3D virtual model, and has been widely used in different fields. Its advantages include design freedom which, allied to topological optimization, allows the manufacturing of parts with complex geometries. For the project, a virtual model of the original gripper was made to better understand its behavior under the forces applied to it. After that, an initial redesign was made. With the forces acting on the part calculated, static analysis and topology optimization were performed, resulting in a part that withstands those forces. The material and printing process chosen were PA12 (polyamide 12) and HP-MJF (HP's Multi Jet Fusion), respectively. With the final 3D virtual model, the parts were printed, and tests were made, which included closing the gripper, picking up the object from one transfer station and placing it to another. After those tests, the redesigned part meets the project requirements not presenting visual plastic deformation, and economic viability, having a lower production cost than the conventional part obtained from regular supplier.*

Keywords: *Industrial robot; end effector; additive manufacturing; topology optimization.*

1. INTRODUCTION

Since its beginnings, man has been bringing innovations in order to reduce physical efforts and assist in the execution of activities. It was in the 18th century, however, that industrial automation began to have a prominent place with the beginning of the Industrial Revolution in England. This scenario arose from the need to evolve the mode of production, in which companies began to produce goods on a larger scale (Roggia and Fuentes, 2016). Over the years, these demands have grown. Thus, for companies to remain competitive, it necessary to work on a series of factors, such as cost reduction and production time, while still delivering high quality products.

In the current industrial scenario, many functions are being performed with the help or even entirely by automated equipment. Among them, there are industrial robots, which, according to Amando and Soares (2022), are reprogrammable multifunctional manipulators designed with the aim of moving materials, tools, or special parts, through several programmed movements, for the performance of a variety of tasks.

This type of robot (see Fig. 1) can move parts in the transfer station of the laboratory's advanced manufacturing plant at SENAI CIMATEC. Among its components, the end-of-arm tooling stands out, since the function of an industrial robot is directly linked to it. According to the Robotic Industries Association (2022), traditionally, the gripper is expected to perform specific tasks several times. In addition, the gripper has removable fingers, allowing adjustment of the shape of the finger to the gripped part to be moved/translated.

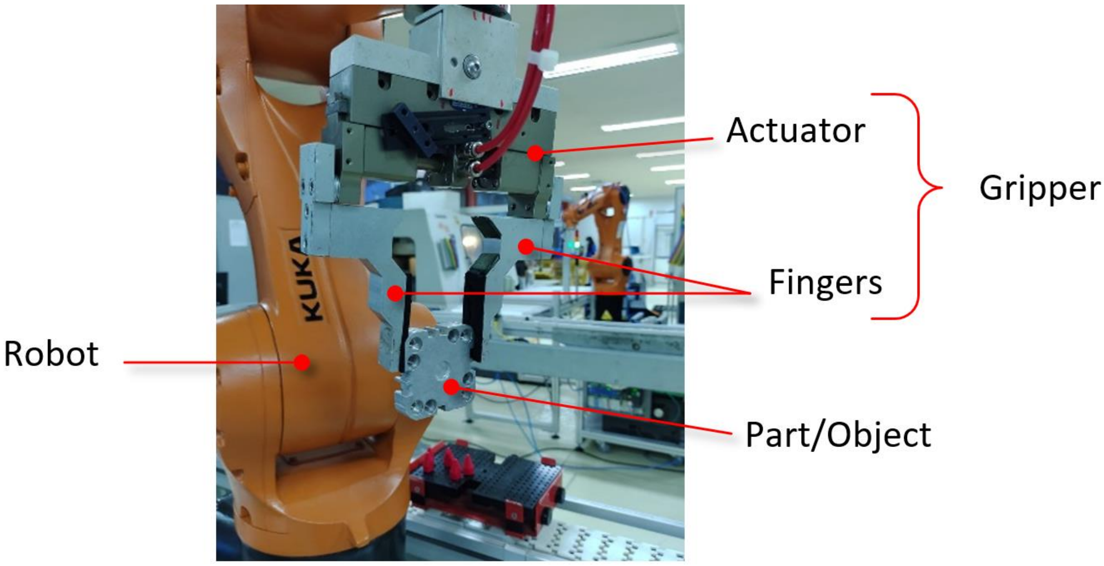


Figure 1. The gripper of an industrial robot holding an object.

At the laboratory, the grippers have the function of carrying certain objects from one place to another. Therefore, they have the movement of opening and closing, given through pneumatic actuators. The actuators programming, however, does not recognize the object when closing, which generates an impact of the finger's faces on the object, causing the gripper to often break after a certain period of use, thus requiring a replacement of the aluminum grippers. Currently, the replacement is made by the actuator manufacturer, being machined and having a high cost and delivery period of 42 days.

A recent manufacturing technology that has many advantages over more traditional technologies is Additive Manufacturing (AM). This technology encompasses a set of different manufacturing methods, but its main feature is manufacturing by successively adding material in the form of layers (layer-by-layer) from a 3D virtual model (CAD model) (Inácio *et al*. 2020). Also popularly known as 3D printing, this technology is increasingly used in different areas of the industry, such as aerospace, automotive and biomedical, thanks to its ability to produce parts with good surface finish, strength, lightness with inherent freedom of design (Dilberoglu *et al*. 2017). For these reasons, AM has also become an alternative to conventional manufacturing methods such as machining, forming and casting.

In order to obtain the full advantages of this technology, it is necessary to know its manufacturing and materials limitations, designing specifically for Additive Manufacturing. One of the ways to do this is through topological optimization (TO). TO is a structural automated method that seeks to optimize the distribution of the material for a given load and boundary conditions, resulting in more organic and lower mass geometries, difficult to obtain only from the designer's conception (Gebisa and Lemu, 2017).

Based on the time and cost problem for replacing the robot grippers mentioned before, the possibility of using MA to replace the robot fingers was considered. Therefore, topology optimization was used to improve the design in order to reduce the amount of material needed to manufacture new fingers without loss of performance, especially when replacing aluminum alloy by polyamide 12.

2. METHODOLOGY

Figure 2 shows a flowchart of the activities developed during the project. For the study of the original gripper design, the measures of it were taken and the software Solidworks was used to create the 3D part. Also, some geometrical limitations were taken into account, based on the dimensions of the actuator model KG 140 60 from the manufacturer Shunck (2022) and on the dimensions of the objects carried.

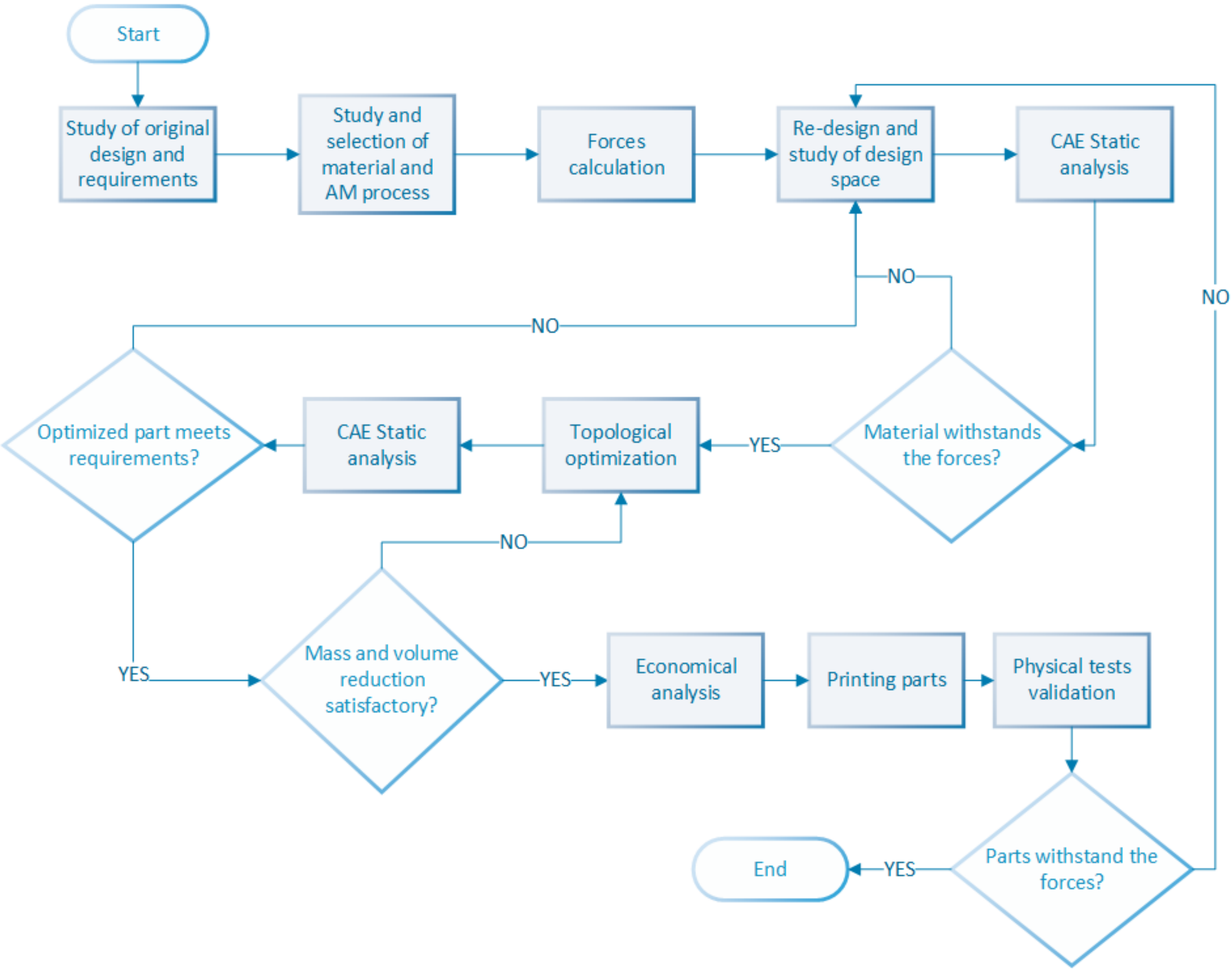


Figure 2. Flowchart of the activities.

Then, the material PA12 and the printing process HP-MJF were selected for the project. PA12 was chosen mainly due to its fatigue resistance (Guo *et al.* 2021). Also, the printing process chosen is associated with the material, once PA12 is one of the most applied material to HP-MJF.

Afterwards, the forces on the gripper were calculated. The first one to be considered was the closing force, given by the actuator manufacturer. On the other hand, the gripper also experiences an impact force by touching the object during its closure. For this reason, this force was calculated using Equation 1. This is an equation from the energy method presented by Hibbeler (2015) in which ***E*** is the modulus of elasticity, ***I*** is the area moment of inertia, Δ***máx*** is the maximum displacement when the part experiences the impacts, and ***L*** is the lever arm length. The area moment of inertia was obtained from Solidworks CAD software, through a simplification of the transversal section of the gripper. The maximum displacement was calculated from Eq. 2, in which ***M*** is the mass of the gripper and ***v*** is its velocity, calculated from Eq. 3, where Δ***S*** is the distance travelled during the gripper closure and Δ***t*** is the closing time, given by the actuator manufacturer.

$$F = \frac{3 \cdot E \cdot I \cdot \Delta máx}{L^3} \quad (1)$$

$$\Delta máx = \frac{M \cdot v^2 \cdot L^3}{3 \cdot E \cdot I} \quad (2)$$

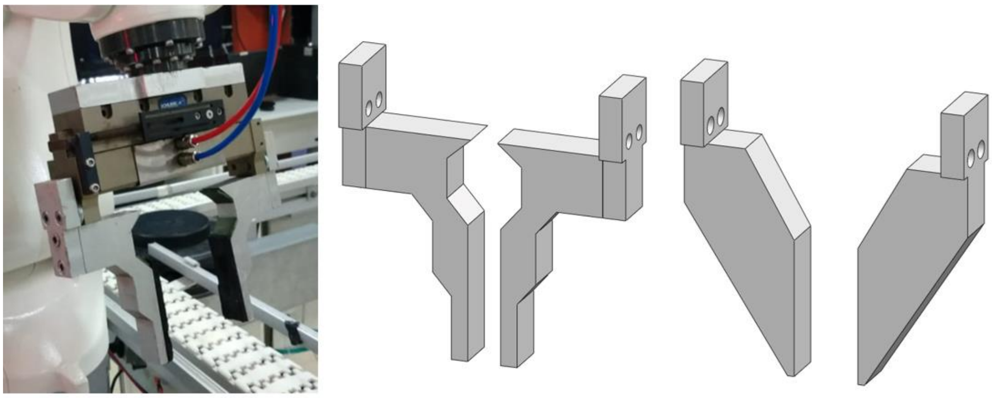
$$v = \frac{\Delta S}{\Delta t} \quad (3)$$

With the forces calculated, the one with a higher value was used on the project. Also, the maximum weight admissible for the actuator, according to its manufacturer, was considered. After all, the part redesign was made on Solidworks, resulting in a more robust shape to obtain a bigger design space. Then, a static analysis was run on Inspire. With the design space and the material chosen, the next step was to run a topological optimization, also on Inspire, to reduce mass and volume, and obtain a more organic shape. Next, another static analysis was run on this redesigned part plus the mass reduction was verified. Finally, an economic analysis was made for the final part.

After having a final part, the fingers were printed at the Additive Manufacturing Bureau, at SENAI CIMATEC Park, and taken to the advanced manufacturing plant at SENAI CIMATEC for tests with the robotic arm. The tests included closing the gripper, picking up the object from one transfer station and placing it to another.

3. RESULTS

A comparison between the original gripper, its CAD 3D and the initial redesign can be seen in Fig. 3. The original arrangement has a distance between faces of 74.79 mm when the gripper is wide open, and 14.97 mm when it is closed. Meanwhile, the objects carried by the gripper are cubes of 40 mm and 60 mm. The redesign also aimed to increase the distance between faces when the gripper is open to 89 mm and 29 mm when closed.



(a) (b) (c)

Figure 3. Original arrangement (a), CAD 3D of the original gripper (b) and initial redesign (c).

According to Erhad (2006), a good practice when working with polymers is to adopt the maximum allowable stress as the tensile referent to 80% of the maximum elastic strain. Using as reference the tests made by O'Connor *et al.* (2018), in which he used specimens made of PA12 using HP-MJF (see Fig. 4), it's observed that the material has a behavior almost linear on the plastic phase, and the tensile strength is similar to the yield strength. Thus, the stress values found by him (49 MPa) are very close to the ones given by HP (2022) (50 MPa). Therefore, to simplify the study, it was considered that the yield stress and tensile strength of HP's material have the same value. For this reason, the maximum allowable stress adopted was 40 MPa.

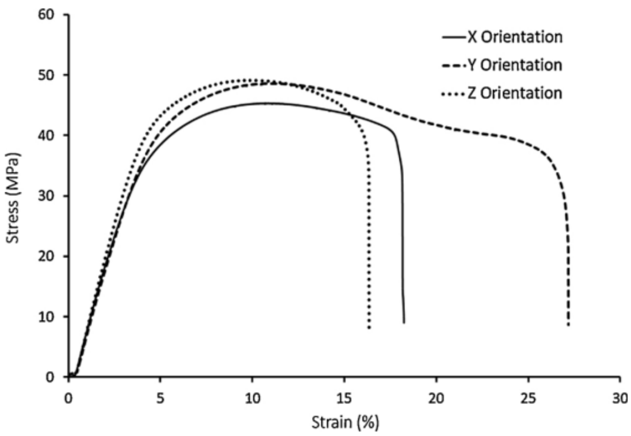


Figure 4. Stress-strain curve of the specimens of PA12. (O'Conor et al. 2018).

With the material chosen and having a preliminary design, the forces on the gripper were calculated. The first one to consider was the closing force of 290 N, according to the manufacturer Schunck (2022). To calculate the other forces, the closing velocity was used, considering a 30 mm distance. The closing time (17 seconds) was also considered. With that, the average velocity obtained was 0.176 m/s from Eq. 3.

To obtain the maximum displacement, some considerations were made. First, the gripper was simplified to a cantilever beam problem. Therefore, for the lever arm, the distance from the center of mass of each object to the center of the holes where the gripper is fixed to the actuator was considered. For the moment of inertia, the cross section of the gripper was simplified to a rectangle. The moment of inertia given by the software was 102491.58 mm^4. The result of the maximum displacement (Equation 2) and the impact force (Equation 1) for each object is in Tab. 1.

Table 1. Impact force for each object.

Object size [mm]	Maximum displacement [mm]	Impact force [N]
40	0.011	294.631
60	0.009	353.224

Considering that the critical force on the gripper was 353.224 N, this was the value considered for the next steps of the project. In addition, half force weight equivalent to a mass of 1.3 kg was also taken into account, the maximum supported by the actuator according to its manufacturer, whose value is 6.38 N. As a result, the part was redesigned with a more robust shape and a static analysis was run, from which the maximum stress was 96.77 MPa, higher than the allowed limit for PA12, what lead the project to another redesign. For this one, the maximum stress was 21.71 MPa. The results of the static analysis are in Fig. 5.

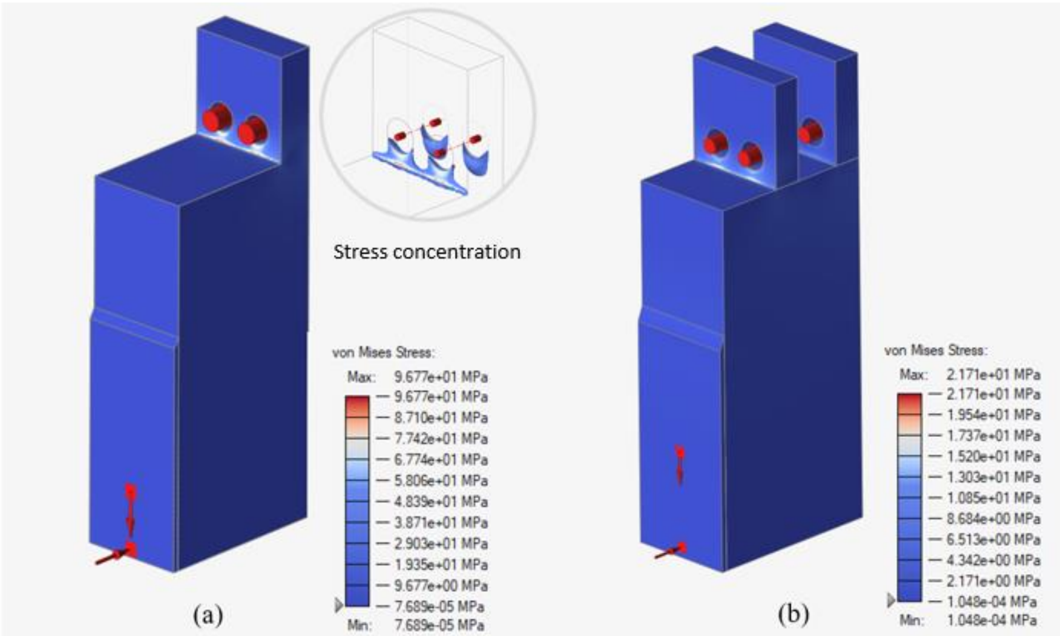


Figure 5. Results of the static analysis: (a) design with one support. (b) design with two supports.

For the topological optimization, a symmetry condition on the part was considered. After the optimization, the Polynurbs feature in Inspire was applied to the part. The results of the optimization, where the brown area is the design space, and the final part are in Fig. 6 and Fig. 7, respectively. The yield stress of the final geometry was 15.29 MPa, meeting the project requirements.

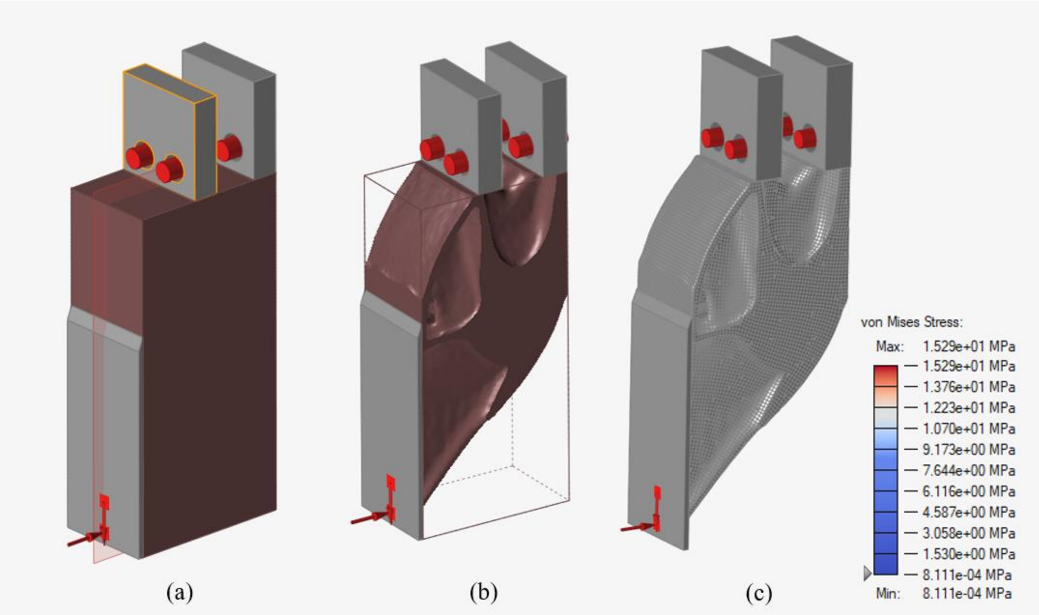


Figure 6. Boundary design (a); Topology Optimization result (b) and CAD polynurbs part (c).

The final geometry, after modelling refinement on Solidworks CAD, can be seen in Fig. 7. A sectional view also is presented to show the complexity of the part. The budget for printing the new AM designed gripper fingers was obtained. The calculated value to produce on finger was R$ 641.00 and the printing time of 2 hours and 45 minutes. This value was compared with the quotation by the manufacturer of the original gripper (R$ 5465.70 for each grip plus R$ 360.32 for shipping). Table 2 shows a comparison between the material, dimensions, and costs for the two alternatives.

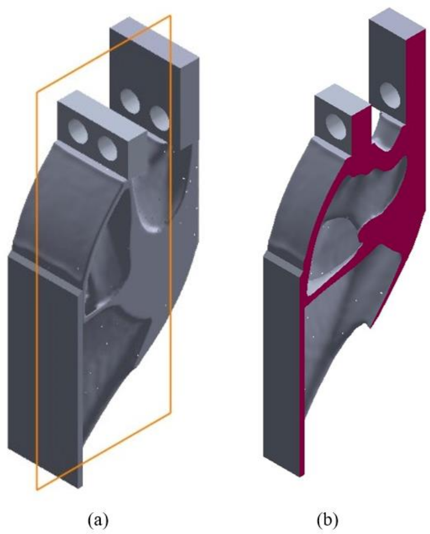


Figure 7. CAD Isometric view of the finger (a) and a cutaway view (b).

Table 2. Comparison between the original parts and the new proposed AM design.

	Material	Mass [g]	Aperture [mm]	Closing [mm]	Cost * [R$]
Original	Aluminum 6060	143.50	74.97	14.97	10931.40
New AM Design	HP MJF PA12	49.00	89.00	29.00	1282.00

Note: **Without transport/shipping costs.*

Once the fingers were printed, they were placed on the robotic arm and tests were made. They showed that the printed fingers withstand the forces applied to them. Also, no visible plastic deformation due to the tests was seen on the parts after tests.

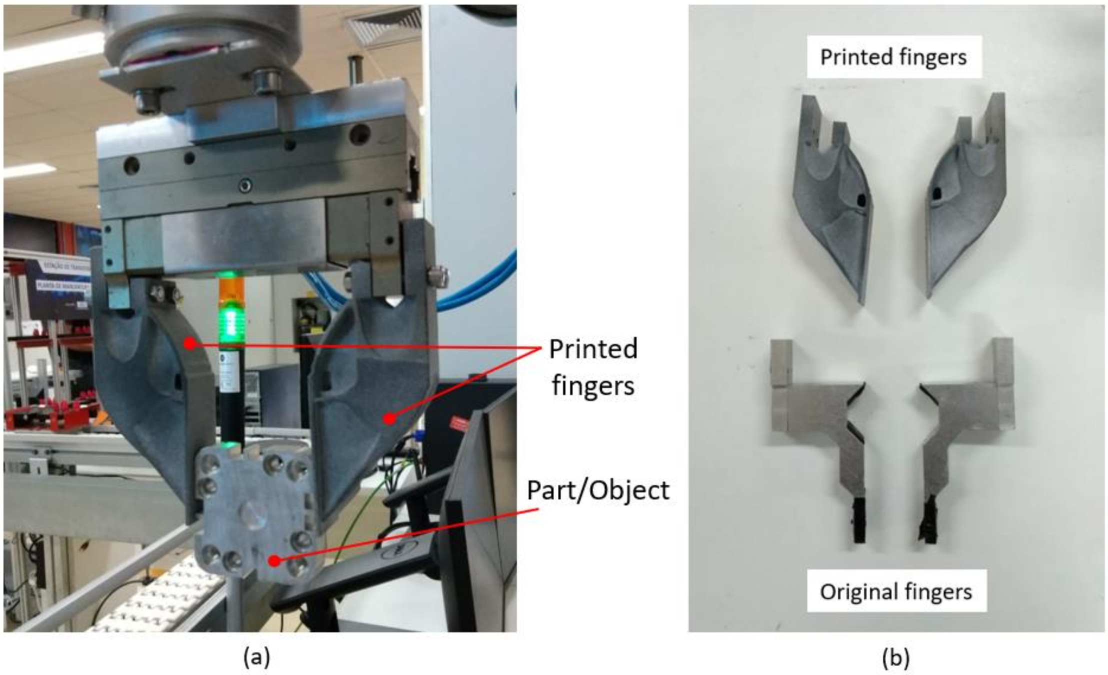


Figure 8. Printed fingers holding an object (a) and comparative between printed and original fingers (b).

4. CONCLUSION

It is possible to conclude that additive manufacturing and the material adopted have a high potential to generate a part with good quality and strength, meeting the project requirements. In addition, the designed part is economically viable, since the price of its manufacture is lower than that of conventional methods, considering the supply of the part by its original manufacturer. The printed parts should also be tested for a longer time, performing its function several times in the transfer station of the laboratory's advanced manufacturing plant. Finally, other works in this line of research can be done, seeking to design and manufacture robot grippers with different applications. Even articulated grippers can be obtained using additive manufacturing. In addition, a study on built-in damping surfaces on the finger’s grippers to reduce the impact can be done, to maximize the lifespan of the component.

5. ACKNOWLEDGEMENTS

The authors would like to thank the support of the company HP Brasil Indústria e Comércio de Equipamentos Eletrônicos Ltda, Altair do Brasil and SENAI CIMATEC. Altair Brasil provided educational licenses of Altair Inspire. This project was funded by HP Brasil using resources based on Law #8.248 of 1982 (Informatics Law).

6. REFERENCES

AMANDO, José A. Diaz e SOARES, João E.; 2022. *O BRAÇO ROBÓTICO COMO FERRAMENTA INTERDISCIPLINAR*. Mostra Nacional de Robótica. Vitória da Conquista. <http://sistemaolimpo.org/midias/uploads/7cd05ca2e7bf2981ca931606c94c33d9.pdf>.

AUTOMATION WORLD. 2022. *End-of-Arm Tooling Grasps Broadening Demands*. Automation World <https://www.automationworld.com/factory/robotics/article/13318758/endofarm-tooling-grasps-broadening-demands>.

DILBEROGLU, Ugur M; GHAREHPAPAGH, Bahar; YAMAN, Ulas e DOLEN, Melik. 2017. *The role of additive manufacturing in the era of Industry 4.0*. 27Th International Conference On Flexible Automation And Intelligent Manufacturing. Modena.

ERHARD, Gunter. 2006. *Designing with plastics*. Munich. Hanser Publications.

GEBISA, A W; LEMU, H G. 2017. *A case study on topology optimized design for additive manufacturing*. First Conference of Computational Methods in Offshore Technology. Stavanger, https://doi.org/10.1088/1757-899X/276/1/012026 .

GUO, Binbin; XU, Zhiyao; LUO, Xue e BAI, Jiaming. 2021 *A detailed evaluation of surface, thermal, and flammable properties of polyamide 12/glass beads composites fabricated by multi jet fusion.* Virtual And Physical Prototyping. Shenzhen. https://doi.org/10.1080/17452759.2021.1899463.

HIBBELER, Russell Charles. 2015. *Resistência dos materiais*. 7.ed. ed. São Paulo: Pearson Prentice Hall.

HP. 2022. *HP 3D Printing materials for the HP Jet Fusion 5200 Series 3D Printing Solution.* <https://h20195.www2.hp.com/v2/GetDocument.aspx?docname=4AA7-7084ENW>.

INÁCIO, Danilo; DROZDA, Fabiano Oscar; SILVA, Wiliam de Assis; MARQUES, Marcos Augusto Mendes e SELEME, Robson. 2020. *A importância da manufatura aditiva como tecnologia digital para a indústria 4.0: uma revisão sistemática*. Revista Competitividade e Sustentabilidade - Comsus. Cascavel.

O'CONNOR, Heather J.; DICKSON, Andrew N.; DOWLING, Denis P. 2018. *Evaluation of the mechanical performance of polymer parts fabricated using a production scale multi jet fusion printing process*. Additive Manufacturing.

ROGGIA, Leandro; FUENTES, Rodrigo Cardozo. 2016. *Automação Industrial.* Santa Maria: E-Tec Brasil. <https://schunk.com/us_en/gripping-systems/product/2743-0303070-kgg-140-60/>.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.