REPIQUE REVISTA DE CIENCIAS SOCIALES
e-ISSN: 2550-6676

Vol. 5 Núm. 1
Enero – Junio 2023
e-ISSN: 2550-6676
pp 100-125

# Optimization of the manufacturing process by 3D printing of the glass lift handle in Chevrolet Aveo Family

Ember Zumba-Novay*
Alex Merizalde-Salas*

## Abstract

The objective of this research is to provide an alternative solution through 3D printing of the handle of the glass elevator of the Chevrolet Aveo vehicle, which was simulated and evaluated in Inspire software where its mechanical properties were verified prior to printing. The 3D printing process was performed, and the weights of the original and optimized handle were compared with Inspire and Simsolid software, respectively. In addition, the displacements, safety factor, and deformation analysis of the original and optimized handle were compared. The study was based on the multi-criteria and COPRAS methods, to compare materials selected as the best alternatives to replace the original (PLA, PC and PVC). The results showed that the most suitable material to replace the original is PLA because it has excellent mechanical and physical characteristics. Through Inspire it was possible to change the original design of the handle, obtaining an optimized proposal with a 2.7% lower weight, in addition, the 3D

* Escuela Superior Politecnica de Chimborazo, Ent. 1 ESPOCH, Panamerican Highway South km 1 ½, 060155, Riobamba, Ecuador. ezumba@espoch.edu.ec https://orcid.org/0000-0002-2121-8418
* Carlos Cisneros Technological Institute, La Paz 07-56 & Mexico, 060110, Riobamba, Ecuador. alex.merizalde@itscarloscisneros.edu.ec, https://orcid.org/0000-0002-0469-5079

**Como citar APA:** Zumba-Novay, E., Merizalde-Salas, A. (2023) Optimization of the manufacturing process by 3D printing of the glass lift handle in Chevrolet Aveo Family. *Repique*, 5(1), 100-125

printing time is reduced by 8.3% compared to the original model. With the present study it can be mentioned that the PLA alternative material is ideal to replace the original ABC-PC, and the benefits of the analysis contribute to have an alternative to industrial production in the world of vehicles.

**Keywords:** Optimization, 3D printing, simulation, mechanical analysis, vehicle handle.

## *Optimización del proceso de fabricación mediante impresión 3D de la manilla del ascensor de cristal del Chevrolet Aveo Family*

### Resumen

El presente trabajo de investigación tiene como objetivo brindar una alternativa de solución a través de la impresión 3D de la manija del elevador de vidrio del vehículo Chevrolet Aveo, la cual fue simulada y evaluada en el software Inspire donde se verificó sus propiedades mecánicas previo a la impresión. Se realizó el proceso de impresión 3D y se compararon los pesos del mango original y optimizado con el software Inspire y Simsolid, respectivamente. Además, se compararon los análisis de desplazamientos, factor de seguridad y deformación del mango original y optimizado. El estudio se basó en los métodos multicriterio y COPRAS, para comparar materiales seleccionados como las mejores alternativas para reemplazar el original (PLA, PC y PVC). Los resultados mostraron que el material más adecuado para reemplazar el original es el PLA debido a que presenta excelentes características mecánicas y físicas. A través de Inspire se logró cambiar el diseño original del mango, obteniendo una propuesta optimizada con un 2,7% menos de peso, además, el tiempo de impresión 3D se reduce en un 8,3% respecto al modelo original. Con el presente estudio se puede mencionar que el material alternativo PLA es ideal para reemplazar el ABC-PC original, y los

beneficios del análisis contribuyen a tener una alternativa de producción industrial en el mundo de los vehículos.

**Palabras Clave:** Optimización, impresión 3D, simulación, análisis mecánico, manejo de vehículos.

**Received :** 03-09-2022

**Approved:** 22-11-2022

## INTRODUCTION

The 3D printing process, also known as additive manufacturing, has been investigated for over 20 years with applications in aerospace, automotive, architecture and medical treatment (Goh et al. 2017). The most used printing technologies for polymer resin include ink jet printing (Choi et al. 2017), fused deposition modeling (Ngo et al. 2018), digital light printing (Mu et al. 2017), stereolithographic printing (Yan & Gu 1996), and laser-assisted laminated object fabrication (Parandoush et al. 2017).

Nowadays, the industrial sector is closely related to technology, where additive manufacturing, 3D printing process, and computer aided design and manufacturing [CAD] play an essential role in the computer systems (Li et al. 2020), which involves the design and manufacture of products. In advanced engineering, CAD has revolutionized the 21st century as an important tool to help solve problems in the industrial sector efficiently and with reliable results (Li et al. 2020). Analysis and simulation are important when mass producing products in the industrial sector, as it helps to reduce environmental pollution. Today, the automotive sector has become one of the most important industries of the modern era; its status lies in the social and economic effect it causes (Pereira y Romero 2017).

To meet the quality standards and challenges in modern manufacturing processes, industries must select the best available design, process planning, machine tool, materials, welding process, inspection system, etc., as the choice of the right alternative is affected by various attributes, the decision-making process is not an easy task. In recent years, there have been many changes and innovations in manufacturing (Makhesana 2015). Many of the latest technologies, such as robotics, flexible manufacturing systems, rapid prototyping, etc., have been developed by today's manufacturing (Ding et al. 2004). Decision-makers in the industry must consider various characteristics of the alternative, such as economics, aesthetics, serviceability, technical details, etc., and, based on this, it is possible to select the appropriate alternative (Hwang 2012).

The multi-criteria method and the COPRAS method used in the automotive industry are analytical tools of great utility and potential in engineering processes (Roy 1996). This interweaving of multi-criteria and systemic approaches can be addressed both at the conceptual level and at the operational level of concrete actions (Abu et al. 2021). The multi-criteria method is an assessment and operational decision support approach for dealing with complex problems that offer high uncertainty, conflicting objectives, different forms of data and information, multiple interests and perspectives, and an evolution of complex systems (Kumar et al. 2017). While the COPRAS method selects the best decision alternatives considering ideal and worst-case solutions, in a step-by-step ranking and evaluation of the alternatives in terms of their importance and degree of usefulness (Chérrez-Troya et al. 2018). The use of both methods helps to identify the materials that present better properties for 3D designs and printing, taking into account that there is a wide range of materials that can be used in many areas of the automotive industry (Haruna, Shafiq, & Montasir 2021).

In Ecuador, the Chevrolet Aveo Family is one of the common vehicles sold in the market. The handle of the glass elevator of this vehicle is constructed of plastic material and the cost in the domestic market is around 12 dollars. However, this plastic material is not resistant enough to impacts or any type of damage. The handles of the glass elevators are frequently changed after a certain period of time, principally due to wear on the inside of the coupling presenting damage, breakdown or failure at the time of fulfilling its function of displacement (Zumba 2021).

Today, composite materials provide weight reduction and thermal and chemical resistance to weathering, which has driven the development of new thermoplastic materials for the automotive industry, both in interior and exterior components. This provides a new style to vehicle parts (Patil, Patel, & Purohit 2017). Selected materials have been used as the best alternatives to replace the original among them we have PLA, PC and PVC (Rahman & Brazel 2004).

Due to the high variability of manufacturing parameters, the integration of simulation tools such as finite element analysis with fused filament manufacturing is particularly attractive for designing 3D printed products and analyzing the mechanics of complex geometries (Ali, Batai, & Sarbassov 2019).

This article analyzes the simulation of 3D printing that is performed in the Inspire software because printing 3D designs is talking about the process of manufacturing and creating parts and objects, i.e. using the three-dimensional x, y, z plane where these variables are the height, length and width from a digital model of the design that is built using computer software and then will be printed (Bordignon, Iglesias, & Hahn 2018).

Depending on the industry or business in which the 3D printer is going to be used, the material will vary, since each one has different properties that will determine the final appearance of the solid (Chango 2021). A large portion of printers use a filament of thermoplastic material, which during printing comes out of the extruder melted and then hardens as it cools (Mazzanti, Malagutti, & Mollica 2019). The most common are ABS and PLA, which is why they are the most used for the present article. PLA is a thermoplastic material of natural origin; it has good characteristics. Printing with this material is faster, although the solids obtained do not present much resistance, as ABS vs PLA can be analyzed it can be mentioned that for our analysis we could select the ABS material for presenting better properties as far as it has to do with hardness and resistance (Mazzanti et al. 2019).

Therefore, the main objective of this study is to optimize the 3D printing manufacturing process of the handle of the Chevrolet Aveo Family vehicle glass lifter for the improvement of mechanical properties. Specifically, the 3D design of the glass lifter of the Chevrolet Aveo Family vehicle was carried out by using Inspire software for the simulation of the mechanical behavior with the PLA alternative material. The 3D printing process and the comparison of the weights between the original handle and the optimized handle are shown, as well as their displacement, safety factor and deformation analysis between both handles.

## METODOLOGY

The methodology visualizes according to Table 1 the properties of the most appropriate materials for printing the handle, according to reports of several authors (Santos & Paganotti 2019), where the PLA material was used in this article.

**Table 1.** *Physical, mechanical, and thermal properties of materials for elevator handle*

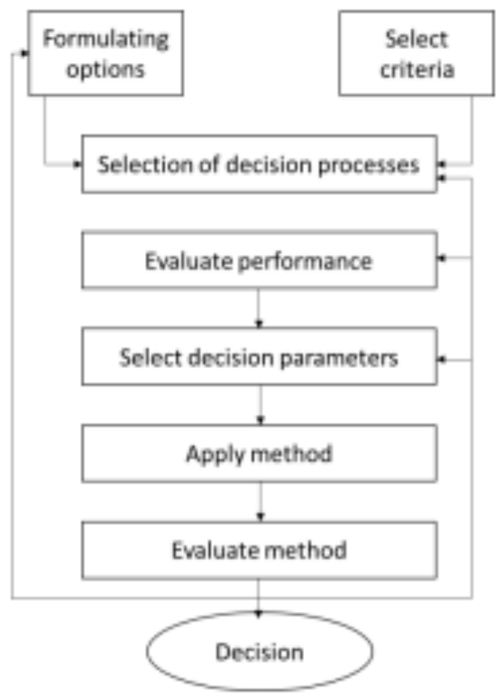
| Properties | Characteristics | PC-ABS | PC | PLA | PVC |
|---|---|---|---|---|---|
| **Cost** | 4 Kg-1 | 10 | 7.5 | 8.0 | 6.9 |
| **Physics** | Density [g cc-1] | 1.1 | 1.0 | 1.3 | 1.3 |
| | MFI [gr 10min-1] | 10 | 11 | 23 | 20 |
| **Mechanics** | Tensile strength (MPa) | 45 | 20 | 20 | 30 |
| | Elongation at break (%) | 100 | 110 | 6 | 210 |
| | Elastic modulus in tension (GPa) | 2.3 | 2.1 | 3.5 | 2.87 |
| | Bending resistance (MPa) | 80 | 34 | 80 | 84 |
| | Impact resistance (J/M) | 587 | 600 | 600 | 800 |
| **Thermal** | Vicat Temperature (°C) | 129 | 103 | 60 | 92 |

With the list of materials and their referential properties, we proceeded to perform the multi-criteria method and the COPRAS method to select the material that will be the alternative to 3D print the handle of the Chevrolet Aveo's window lift.

Multi-criteria method

To apply the multi-criteria method, different steps were proposed and established to improve the decision-making process to select the best and most appropriate material to allow the design and printing of the Chevrolet Aveo's window lift handle, as shown in Fig. 1.

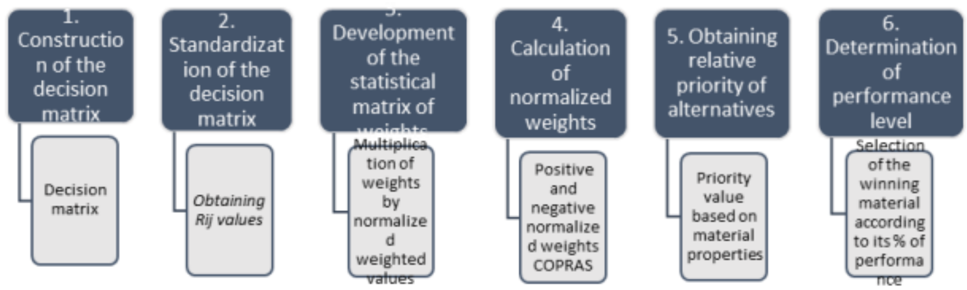
***Figuere 1.*** Model for decision making based on the multi-criteria method




COPRAS Method

The COPRAS method helps to select the best values that guide to the ideal results. In order to apply the COPRAS method correctly, the following steps should be followed as suggested by (Chérrez-Troya et al. 2018), as shown in Fig. 2.

*Figure 2.* Steps to apply the COPRAS method




According to Fig. 2, the first step is developed from the decision matrix, from which the same normalized matrix of the COPRAS method was used. In step 2, the normalized decision matrix was defined, based on equation 1.

$$R_{ij} = \frac{\alpha_{ij}}{\sum_{i=1}^{m} \alpha_{ij}}$$
(1)

Where, $R_{ij}$is the normalized decision matrix, aij is the value of each criterion In the third step, equation 2 is applied:

$$V_{IJ} = (w_I)(r_{Ij})$$
(2)

Where, $V_{IJ}$ is the standardized weight matrix, $w_i$ is the weights of each criterion, and $r_{Ij}$ is the normalized matrix values.

In step 4, weight will be given to each criterion according to the property compared to the property to be achieved, with equations 3 and 4.

$$S_{+i} = \sum_{j=1}^{m} S_{+ij}$$
(3)

$S_{-i} = \sum_{j=1}^{m} V_{+ij}$
(4)

Where, $S_{+i}$ is the negative normalized weight, $V_{+ij}$is the sum of the weights of each positive criterion, and S-i is the sum of the weights of each negative criterion normalized matrix values In the step 5, a degree of satisfaction is sought for each alternative applying the equation 5.

$Q_i = S_{+i} + \frac{\sum_{j=1}^{m} S_{-i}}{S_{-i}\sum_{j=1}^{m}\frac{1}{S-1}}$
(5)

Where, $Q_i$ is the relative priority.

In step 6, it is proposed to compare the qualities of each alternative material looking for the most efficient by percentage applying the equation 6.

$u_i = \frac{Q_i}{Q_{max}} * 100$
(6)

Where, $U_i$ is the performance, $V_{+ij}$ is the máximum priority.

In the final step, 7. The one material with the highest value is considered as the best option. These methods (Multicriteria and COPRAS) have been considered for the correct selection of the material according to the characteristics of the original material to fulfill the function for which it was designed.

Simulation and parameters of 3D Printing with PLA material

To perform the simulation of the Chevrolet Aveo Family vehicle's glass lift handle, 3D modeling was performed based on the selection of the winning material according to the COPRAS method, based on the best physical, and mechanical, properties of the PVC, PLA, and PC materials. The 3D simulation of the glass lift handle of the Chevrolet Aveo Family vehicle was performed using Cura Software, version 4.6.1.

According to Qamar et al. (2022), there is a better tensile mechanical behavior of 3D printed elements when they have 100% filler. Based on Camargo et al. (2019) refers that 3D printed parts subjected to bending loads give better results with 100% infill and honeycomb type. Considering these considerations, a dynamic printing quality was established with which layers of 0.16mm height and 0.84 mm thickness were generated from the initial and final layers of the handle, as well as a printing speed of 60mm/s. Once the filling parameters were defined, the printing simulation was executed.

Considering the use of the same printing parameters previously established, the possibility of carrying out the 3D printing of the original design handle using PLA was considered, thus starting with the importation and positioning of the geometries. To establish a comparison between the printing processes of the original and optimized handle, the same printing parameters such as speed, percentage, and type of filling, among others, were used. Once all the parameters were established, the simulation of the 3D printing process was executed, where the supports for all the surfaces were generated and the software calculates the printing time.

The handle optimization process was carried out in Inspire software, starting with the elimination of the internal reinforcements of the original model and increasing the amount of material in the middle section of the handle in such a way that the software can eliminate material until an adequate design is obtained for the loads to which the geometry is exposed. Once all the optimization parameters on the geometry of the handle were defined, the execution was carried out under the default parameters established by the software prioritizing 30% of the use of the available material. Once the optimization process is finished, the ideal amount of material calculated by the software is important for the element to withstand the loads to which it is exposed.

Once the geometry of the optimized handle was obtained, the structural analysis was carried out considering the same conditions regarding loads and movement restrictions described above, however, for this analysis it is necessary to specify PLA as construction material; the software library does not contain this material, so to define it was necessary to enter properties such as the modulus of elasticity, density, and Poisson's coefficient. After the material was created, it was added to the library and for the analysis it was assigned to the whole handle.

## RESULTS

In Fig. 3(a), the upper part of the optimized proposal with the new design is observed once the 3D printing of the element is finished. The other part of the 3D printing process is shown in Fig. 3(b), where the handle and the base of the handle are observed, in addition to the supports that were generated.

*Figure 3.* (a) Top view of 3D printed optimized middle part and (b) 3D printed handle and base

(a) (b)

After removing the brackets on all the printed elements and assembling the components, the proposed optimized 3D printed Chevrolet Aveo family vehicle window lift handle was obtained. Fig. 4a shows the original design handle 3D printed using PLA and Fig. 4b shows the optimized 3D printed handle.

*Figure 4.* (a) Top view of the 3D printed optimized middle part and (b) 3D printed optimized handle

(a)

(b)

The Cura software was able to establish the differences between the printing of the original design handle and the optimized proposal, analyzed under the same printing parameters, only differing in its geometry. Table 2 summarizes the main differences, where once the simulation of the 3D printing process was executed, the Cura software took a printing time of 7 hours and 26 minutes using 17.96 m of PLA material.

**Table 2.** *Differences between original and optimized handle 3D printing*

| Design | Printing material | Printing time | Quantity of material used |
|---|---|---|---|
| **Original** | PLA | 7 hours and 26 minutes | 17.96 m |
| **Optimized** | PLA | 6 hours 49 minutes | 17.84 m |

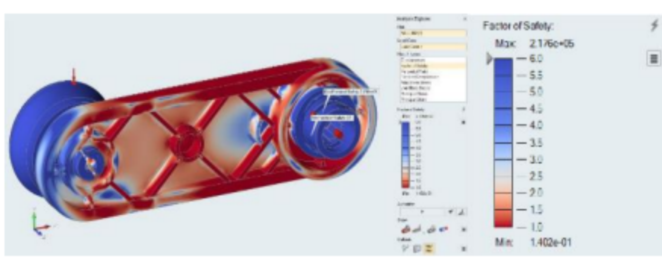
## Weights between original and optimized design handle

Using SimSolid software, the weight of the original and the optimized design handle was 22.2 gr and 21.6 gr, respectively. The optimization process resulted in a 0.6 g reduction in the weight of the element.

## Displacements in the original handle

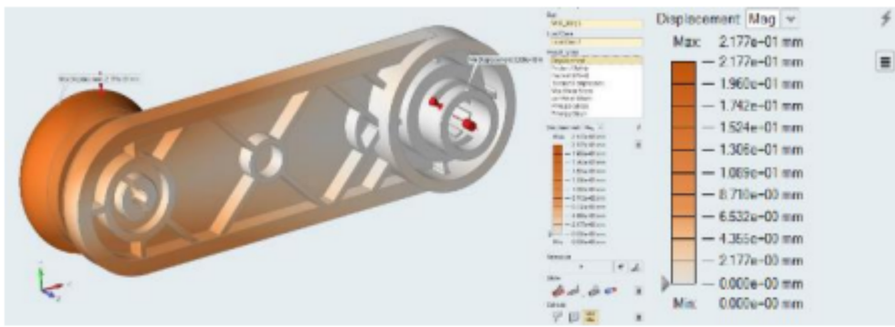
The applied load of 70 kg generates a maximum deformation in the handle of 21.77 mm in the handle grip area, in Fig. 5, these results and the distribution of the values along the entire geometry can be observed.

***Figure 5.*** Displacement at the original handle at 70kg load



On the other hand, figure 6a shows the maximum displacement that occurs in the handle when the horizontal pulling force is applied, where it shows a value of 7 mm, while Fig. 6b shows a value of 4 mm when the load is applied vertically, in both cases it is presented in the section where the load is applied.

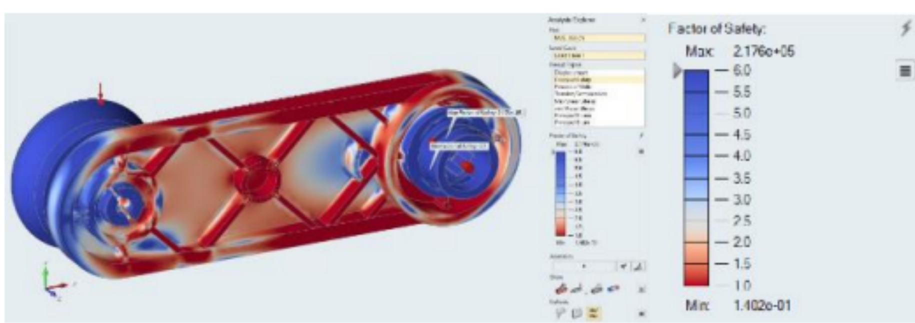
*Figure 6.* Maximum (a) displacement in the handle horizontally and (b) vertically




Safety factor on the original handle

The stresses produced by the 70 kg load result in the safety coefficients shown in figure 7, where the lowest value obtained is 0.14; therefore, the areas painted in red show excessive structural resistance stresses.

*Figure 7.* Safety coefficient for 70 kg load on the original handle



From the structural analysis it is obtained that the minimum safety factor for the simulation considering the vertical and horizontal pulling load is 1.1, however, in Fig. 8a it can be observed that when the load is applied horizontally, the ends of the central section of the handle are the most exposed parts, while in Fig. 8b when the vertical load is applied, the reinforcements of the central section are the elements that support the greatest stress. The minimum value of the safety factor occurs in the reinforcements at the base of the handle.

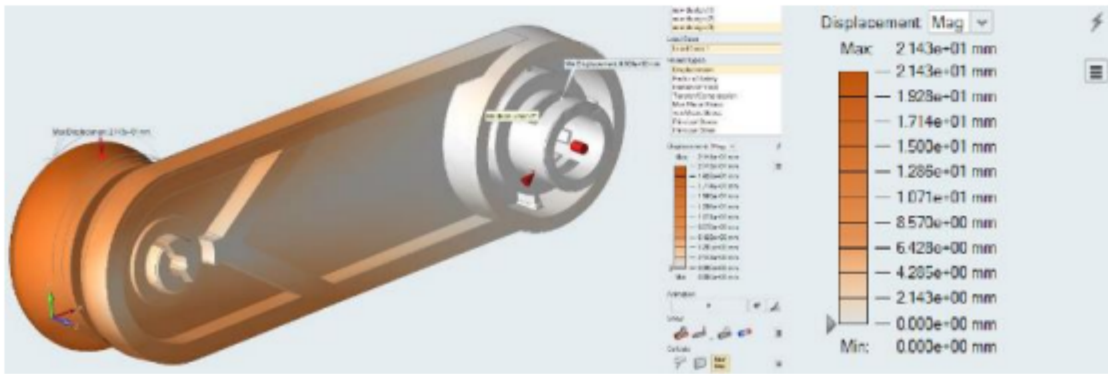
*Figure 8.* Safety factor in original handle


(a)


Optimized handle displacements

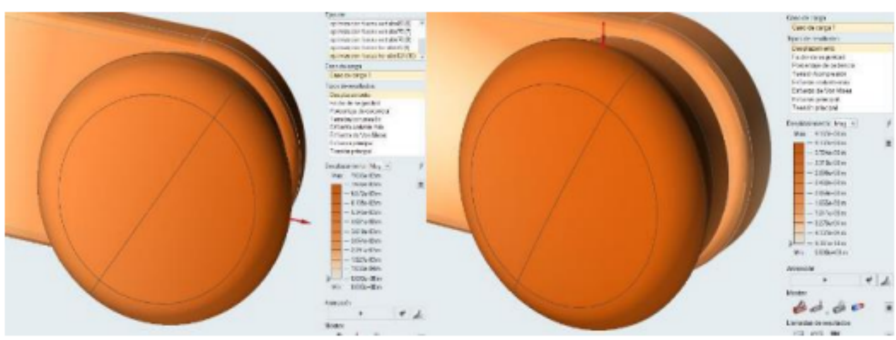
The analysis with 70kg produces a deformation in the handle of 21.43 mm at the grip which is the place where the force is applied and as it approaches the support base these values decrease as shown in Fig. 9.

*Figure 9.* Deformation in the optimized handle under the 70 kg load




When applying the horizontal load the optimized handle undergoes a displacement of 7.63 mm, as shown in Fig. 10a, while in Fig. 10b, when applying the vertical load, a maximum deformation of 4.14 mm is recorded.

*Figure 10.* Displacement in the (a) horizontal and (b) vertical the optimized handle



Optimized handle safety factor

The minimum value of the safety factor generated by the 70 kg load on the handle is 0.14 and these are present in the entire optimized section and support, as shown in Fig. 11.

***Figure 11***. Safety factor in the optimized handle for the 70kg load.

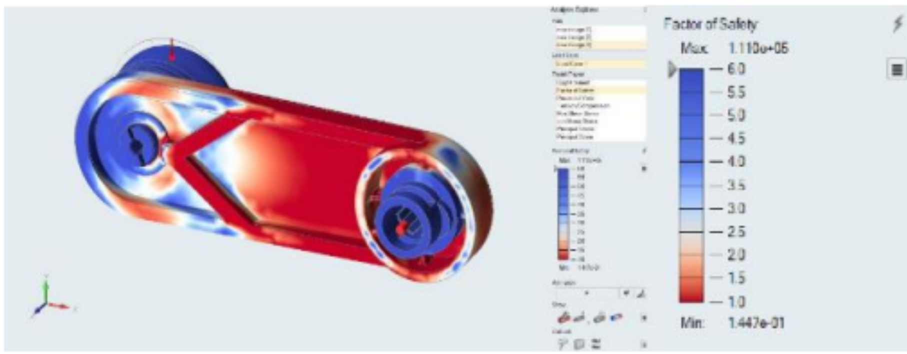



Fig. 12a shows the distribution of the values of the safety factor in the optimized handle when applying the horizontal pulling load, the lowest value is 1.3 and is in the upper part at the height of the grip area, the elements that remain in tension are the ends of the middle section of the handle. On the other hand, Fig. 12b, shows the results of the safety factor in the handle when applying the vertical load, it is observed that greater stresses are produced at the base of the handle, thus generating a minimum safety factor of 1.06 and slight stresses in the middle area of the handle that are supported by the internal reinforcements.

**Figure 12.** (a) Distribution of the values of the safety factor in the optimized handle (b) when applying the load

(a)

(b)

Deformation analysis between the original and optimized handles

Because of the excessive application of the 70 kg load, a plastic deformation of the elements occurs, which is reflected in the values shown in Table 3.

**Table 3.** *Deformation under 70 kg load*

| Analysis | Maximum deformation (mm) Force 70 kg | Critical zone |
|---|---|---|
| Original handle | 21.77 | Base |
| Original handle | 21.43 | Base |

The deformation produced in the models because of the average applied pulling loads is shown in Table 4, as can be seen from the values, there is no significant change in the analyzed results.

**Table 4.** *Deformation in the original and optimized handles (maximum deformation)*

| Analysis | Horizontal force | Vertical force |
|---|---|---|
| Original handle | 7.7 | 4.2 |
| Optimized handle | 7.6 | 4.1 |

## CONCLUSIONS

The application of the multi-criteria method and the Copra's method facilitates the selection of the winning alternative material that can replace the original material, resulting in a maximum value of 100% to PLA for the manufacture of the handle of the window lift for the Chevrolet Aveo Family vehicle. PLA is a biodegradable material that presents excellent mechanical, physical and thermal properties to be able to develop the manufacture of automotive accessories, allowing fast and immediate alternatives in the national markets.

The optimization process resulted in a change in the geometric design of the original handle, distributing in a better way the amount of material and the reinforcements in the middle part of the handle, allowing to support in a more efficient way the loads that act on the element.

It was verified that the weight of the optimized handle is 2.3% lower compared to the original design, this value represents a significant advance considering that this type of elements used in the automotive area constitute a wide field of study with the purpose of lightening the weight of vehicles and improving their efficiency.

It was determined that the mechanical behavior of the optimized handle under horizontal load, which generates traction, produces a 3.3% reduction in the stresses generated in comparison with the original handle, while the opposite happens with vertical load, since the stress increases by 17.9%; however, its location changes towards the base of the handle where the stress is distributed in a better way since this area has more reinforcements. It was determined that the deformation decreases 1.2% in the optimized handle, a value that represents an imperceptible variation.

In general terms, the analysis of the mechanical behavior of both handles is similar; however, the added value of the proposal generated in this work is the process of obtaining it through 3D printing, since this manufacturing method allows customizing the element according to the user's taste if the geometry developed here is respected.

The appropriate use of engineering software allows to have simulations close to reality, reducing manufacturing costs that were used for the analysis, through Autodesk Inventor the design of the handle of the glass elevator of the Chevrolet Aveo family vehicle was built, through the Inspire software is optimized and simulations are performed for their respective analysis.

After performing the respective evaluation analysis with the different methods mentioned above in this research, it can be indicated that they all have potential properties that would allow them to be used in industrial manufacturing, for this reason it is important to perform future research with PC and PVC materials. After manufacturing by 3D printing, the surface finish of the auto part can be improved through sanding, puttying, and painting, thus obtaining a product of excellent quality.

Based on the research, it is also recommended that a comparison be made between the plastic injection molding manufacturing process and the additive manufacturing process for the manufacture of auto parts that do not require mass production.

## REFERENCES

Abu, S., Fakhariya I., Sainab F., & Imad A. (2021). Integration of Failure Mode, Effects, and Criticality Analysis with Multi-Criteria Decision-Making in Engineering Applications: Part I – Manufacturing Industry. Engineering Failure Analysis 122:105264. doi: 10.1016/j.engfailanal.2021.105264.

Ali, H., Shaheidula, B., & Dastan, S. (2019). 3D printing: a critical review of current development and future prospects. Rapid Prototyping Journal 25(6):1108-26. doi: 10.1108/RPJ-11-2018-0293.

Bordignon, F., Iglesias, A., & Ángela, H. 2018. Diseño e impresión de objetos 3D: una guía de apoyo a escuelas. UNIPE Editorial Universitaria.

Camargo, C., Álisson, R., Machado, E., & Erickson, F. (2019). Mechanical Properties of PLA-Graphene Filament for FDM 3D Printing. The International Journal of Advanced Manufacturing Technology 103(5):2423- 43. doi: 10.1007/s00170-019-03532-5.

Chango, C. (2021). Diseño y ensamblaje de una cabeza humanoide controlada por servomotores. Instituto Superior Tecnológico Vida Nueva, Quito, Ecuador.

Chérrez-Troya, M., Martínez-Gómez, J., Peralta-Zurita, D., Llanes-Cedeño, E. (2018). Métodos multicriterio aplicados en la selección de un material para discos de freno. Ingenius. Revista de Ciencia y Tecnología (20):83-95. doi: 10.17163/ings.n20.2018.08.

Choi, M., Heo, J., Choi, D., Hwangbo, S., & Hong, J. (2017). Inkjet Printing Based Layer-by-Layer Assembly Capable of Composite Patterning of Multilayered Nanofilms. Macromolecular Materials and Engineering 302(12):1700332. doi: 10.1002/mame.201700332.

Ding, Y., Lan, H., Hong, J., & Wu, D. (2004). An Integrated Manufacturing System for Rapid Tooling Based on Rapid Prototyping. Robotics and ComputerIntegrated Manufacturing 20(4):281-88. doi: 10.1016/j.rcim.2003.10.010.

Goh, G., Agarwala, G., Goh, V., Dikshit, S., Sing L., & Yeong, W. (2017). Additive Manufacturing in Unmanned Aerial Vehicles (UAVs): Challenges and Potential. Aerospace Science and Technology 63:140-51. doi: 10.1016/j.ast.2016.12.019.

Haruna, A., Shafiq, N., & Montasir, O. (2021). Building Information Modelling Application for Developing Sustainable Building (Multi Criteria Decision Making Approach). Ain Shams

Engineering Journal 12(1):293-302. doi: 10.1016/j.asej.2020.06.006.

Hwang, S. (2012). Upcoming Tipping Points in Automobile Industry Based on Agent-Based Modeling. Procedia Computer Science 8:93-99. doi: 10.1016/j.procs.2012.01.019.

Kumar, A., Sah, B., Singh, A., Deng, Y., He, X., Kumar, P., & Bansal, R. (2017). A Review of Multi Criteria Decision Making (MCDM) towards Sustainable Renewable Energy Development. Renewable and Sustainable Energy Reviews 69:596-609. doi: 10.1016/j.rser.2016.11.191.

Li, L., Zheng, Y., Yang, M., Leng, J., Cheng, Z., Xie, Y., Jiang, P., & Ma, Y. (2020). A Survey of Feature Modeling Methods: Historical Evolution and New Development. Robotics and Computer-Integrated Manufacturing 61:101851. doi: 10.1016/j.rcim.2019.101851.

Makhesana, M. (2015). Application of improved complex proportional assessment (COPRAS) method for rapid prototyping system selection. Rapid Prototyping Journal 21:671-74. doi: 10.1108/RPJ03-2014-0027.

Mazzanti, V., Malagutti, L., & Mollica, F. (2019). FDM 3D Printing of Polymers Containing Natural Fillers: A Review of Their Mechanical Properties. Polymers 11(7):1094. doi: 10.3390/polym11071094.

Mu, Q., Wang, L., Dunn, C., Kuang, X., Duan, F., Zhang, Z., Qi, H., & Wang, T. (2017). Digital Light Processing 3D Printing of Conductive Complex Structures. Additive Manufacturing 18:74-83. doi: 10.1016/j.addma.2017.08.011.

Ngo, T., Kashani, A., Imbalzano, G., Nguyen, K., & Hui, D. (2018). Additive Manufacturing (3D Printing): A Review of Materials, Methods, Applications and Challenges. Composites Part B: Engineering 143:172-96. doi: 10.1016/j.compositesb.2018.02.012.

Parandoush, P., Tucker, L., Zhou, C., & Lin, D. (2017). Laser Assisted Additive Manufacturing of Continuous Fiber Reinforced Thermoplastic Composites. Materials & Design 131:186-95. doi: 10.1016/j.matdes.2017.06.013.

Patil, A, Patel, A., & Purohit, R. (2017). An Overview of Polymeric Materials for Automotive Applications. Materials Today: Proceedings 4(2, Part A):3807- 3815. doi: 10.1016/j.matpr.2017.02.278.

Pereira, A., & Romero, F. (2017). A Review of the Meanings and the Implications of the Industry 4.0 Concept. Procedia Manufacturing 13:1206-1214. doi: 10.1016/j.promfg.2017.09.032.

Qamar, M., Mishra, G., Mishra, S., & Sharma, R. (2022). Effect of Infill Pattern and Infill Density on Mechanical Behaviour of FDM 3D Printed Parts- a Current Review. Materials Today: Proceedings 62:100-108. doi: 10.1016/j.matpr.2022.02.310.

Rahman, M., & Brazel, C. (2004). The Plasticizer Market: An Assessment of Traditional Plasticizers and Research Trends to Meet New Challenges. Progress in Polymer Science 29(12):1223-48. doi: 10.1016/j.progpolymsci.2004.10.001.

Roy, B. (1996). Multicriteria Methodology for Decision Aiding. Springer Science & Business Media.

Santos, I., & Paganotti, J. (2019). The innovative process in the automotive industry: an analysis of the great ABC region automotive cluster. Gestão e Regionalidade 35(105): 200-217. doi.org/10.13037/GR.VOL35N105.5303

Yan, X., & Gu, P. (1996). A Review of Rapid Prototyping Technologies and Systems. Computer-Aided Design 28(4):307-318. doi: 10.1016/0010- 4485(95)00035-6.

Zumba, E. (2021). Optimización en el proceso de fabricación por impresión 3D de la manija del elevador de vidrios del vehículo Chevrolet Aveo Family para la mejora de propiedades mecánicas y térmicas. UISEK, Quito, Ecuador.