Article
Journal of Mechanical Engineering
December, 2022 Vol.6 No.18 21-28

Design and manufacture of a splint prototype for the upper extremities of the human body

Diseño y fabricación de prototipo de férula para extremidad superior del cuerpo humano

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DOI: 10.35429/JME.2022.18.6.21.28 Received: September 30, 2022; Accepted: December 20, 2022

Abstract

The article presented below shows the process carried out for the elaboration of a splint prototype and the techniques used for its elaboration, the design is carried out with the solidworks software, the designs with the most optimal forms that confer a greater resistance are analyzed. to the prototype, the configuration of the laminating software and the correct orientation for its manufacture are shown. A review of the optimal materials for its manufacture is made, such as PLA, PETG and ABS. For the printing of the prototype, an Ender 3 pro model 3D printing machine will be used, while the Simplify 3D program will be used for the configuration of the printer, which will allow us to configure temperature parameters, such as the extruder temperature, temperature of bed, layer height, printing speed, filling percentage among others.

Splint, Design, ABS, 3D printing

Resumen

El artículo presentado a continuación muestra el proceso llevado a cabo para la elaboración de un prototipo de férula y las técnicas empleadas para su elaboración, el diseño se realiza con el software solidworks, se analizan los diseños con las formas mas óptimas que confieran una mayor resistencia al prototipo, se muestra la configuración del software de laminado y la orientación correcta para su fabricación. Se hace un repaso de los materiales óptimos para su fabricación, como es PLA, PETG y ABS. Para la impresión del prototipo se empleará una máquina de impresión 3D modelo Ender 3 pro mientras que para la configuración de la impresora se hará uso de el programa Simplify 3D, el cual nos permitirá configurar parámetros de temperatura, como la temperatura de extrusor, temperatura de cama, altura de capa, velocidad de impresión, porcentaje de relleno entre otros.

Férula, Diseño, ABS, Impresión 3D

Citation: LICONA-GONZALEZ, Marlon, IBARRA-ROBLES, Gabriel Ted, MENTLE-GALINDO, Margarita, BLAS-SANCHEZ, Luis Ángel. Design and manufacture of a splint prototype for the upper extremities of the human body. Journal of Mechanical Engineering. 2022. 6-18: 21-28

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Introduction

A splint is an equipment that is incorporated externally to the body and provides containment, postural correction or deviation, as appropriate. It keeps the body segments in physiological position to perform activities, i.e. aligned, and at the same time allows control of the patient's involuntary movements. [9]

Many of the models that are on sale are not considered entirely practical due to their structure because they tend to be heavy, uncomfortable or very invasive, and many prostheses are rejected because they do not have an aesthetic that the patient considers acceptable [1].

Currently there are different types of injuries, the most common are fractures and/or dislocations. However, the clinical and rehabilitation methods to treat these types of problems have not changed much.

Currently, with the development of new technologies we seek to provide solutions, making use of design software, additive technology equipment, lamination software, 3D scanners, electronics and stress simulation software for the study of materials. This project focuses on the design and development of splints and prostheses that facilitate the user a comfortable rehabilitation without having to limit their mobility.

The variable designs of 3D printed splints allow the establishment of a series of very diverse objectives that help to improve the quality of life of people [4].

Method

Conventional splints, especially those made of plaster, are the most used for the treatment of injuries due to their low cost, but they have a main problem since the user loses strength, mobility and muscle reduction, because they are completely sealed and without ventilation. For the user it tends to be annoying to use this type of splints, since they generate a higher body temperature, sweating and itching in the affected area, having also a greater care in contact with water.

Figure 1 Conventional plaster ferrule
Source: OrthoInfo (October 2022)

The digitized splinting process is promising for the benefit of both clinicians and their patients, provided that future research and investment can overcome the current limitations [5]. For the realization of this work we seek to make an optimal design to subsequently 3D print it by previously making an analysis of the most suitable materials and analyze and the properties of each of them.

The use of additive technology commonly known as 3D printing is not new, but it is only now that with the cheapening of this technology is seeking to provide solutions to problems in different areas ranging from engineering, architecture, medicine etc.

3D printing as a clinical practice is too rare to study and there are no specialized tools for clinical manufacturing practices [3]. Although it is known that 3D printing has been with us for more than 35 years, many are unaware of its use and how interesting this technology can be to find solutions to everyday problems.

Materials

In the market there are several types of plastic materials to be used in the world of 3D printing, among them are the following:

- Pla
- Petg
- Abs
- Nylon
- Carbon Fiber
- Tpu

Each of these materials has particular characteristics, such as:

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- Flexibility
- Durability
- Chemical Resistance
- Resistance to high temperatures
- Rigidity

For this work, three materials are contemplated, Petg, Abs and Pla: Petg, Abs and Pla, however, ABS confers a higher resistance in terms of stresses such as bending and torsion, these stresses are key for the application of the splint.

SolidWorks software will be used for the development of the splint prototype. We will work together with a physiotherapist specialist to evaluate the preliminary design to ensure that it does not affect the strength of the splint once printed and that it has sufficient ventilation for the user.

The design takes into account three variables for the thickness of the splint ranging from 2mm, 3mm, 4mm, for the first design and printing test will be made three bracelets which are intended to analyze the strength of the material which in this case will be ABS, the length of the bracelets is 10cm with a crescent of 12.5cm.

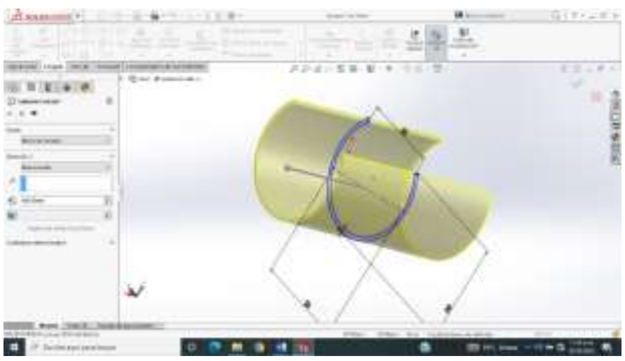

Figure 2 2 mm thick bracelet
Source: Author's contribution (October 2022)

For this first bracelet design a rounding will be applied on the 4 corners with a radius of 20mm.

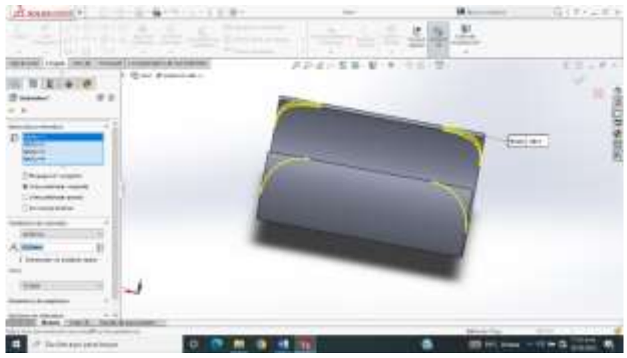

Figure 3 Rounding applied
Source: Author's contribution (October 2022)

Shapes will be inserted to cut-extrude giving only measurements to the holes that will be used as fasteners, subsequently cut and extruded.

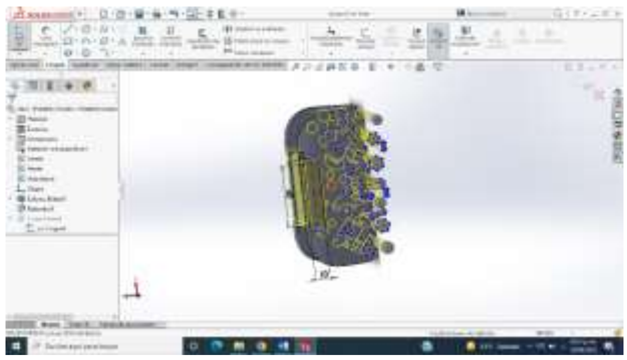

Figure 4 2mm bracelet with extruded shapes
Source: Author contribution (October 2022)

In order to know what would be the ideal thickness, the three bracelets were printed, taking into account the following parameters to configure in the 3D printer:

- Layer height
- Filling percentage
- Temperature
- Speed
- Addition

Based on the above mentioned points, the parameters are as follows:

Parameter	Indicator
Layer height	0.2mm
Percentage of filler	100%
Temperature	235°C
Speed	60 mm/s
Addendum	Balsa

Table 1 Printing Parameters
Source: Author's contribution (October 2022)

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Once the designs have been finalized and the optimal printing parameters have been analyzed, we proceed to the configuration of the stl, using the Simplify 3D program.

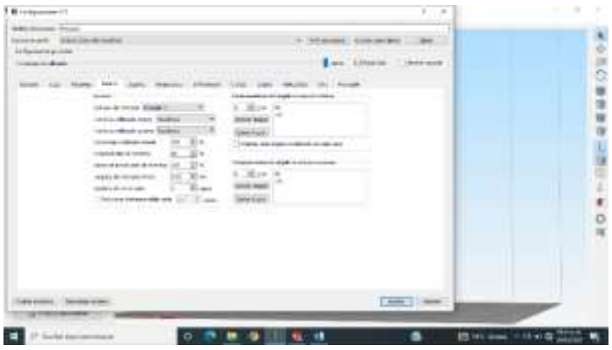

Figure 5 Simplify 3D interface
Source: Author's contribution (October 2022)

Each of the parameters must be entered manually to the laminator, it should be taken into account that if one of the parameters that were set were to change in the laminator, this could cause problems and cause the part once printed to have imperfections and its mechanical properties to decrease. Once the parameters are configured, we proceed to run a simulation of the print in the Simplify 3D program in order to know the following data:

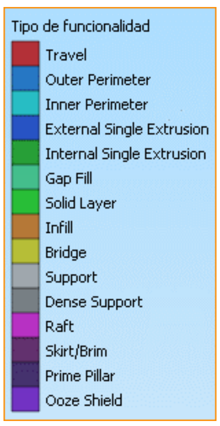

Figure 6 Laminator Color Code
Source: Author's contribution (October 2022)

The simulation run in the laminator shows how the part will be laminated depending on the orientation given, thanks to this we will have an approximate of the time used for printing, as well as the length of the filament needed and its weight.

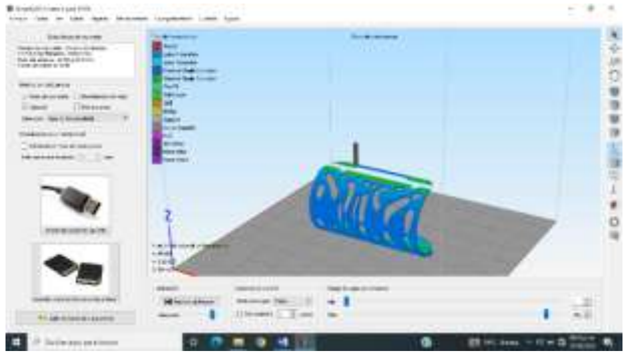

Figure 7 Bracelet Printing Simulation.
Source: Author's contribution (October 2022)

This first bracelet, which has a thickness of 2mm will have a printing time of 2hr 22 min, this time and other data vary depending on the thickness of each one of them, below is a table with the different values obtained in the simulation.

Thickness	Weather	Filament length in meters	Weight
2mm	2hr 22 min	10.2 m	12.56 gr
3mm	3hr 05 min	12.4 m	14.99 gr
4mm	3hr 58 min	14.1 m	16.42 gr

Table 2 Values Obtained in the Simulation
Source: Author's contribution (October 2022)

Once each of the parameters are configured, we proceed to laminate the part, for this work we will use an Ender 3 PRO 3D printer, which has a printing area of 230mm x 230mm x 250mm, these parts will be printed taking into account the parameters presented in Table 1.

Figure 8 Printing of the 2mm cuff on Ender 3 PRO printer
Source: Author's contribution (October 2022)

With the three bracelets printed, we proceed to analyze each one in terms of its resistance and the flexibility needed to open the bracelet so that it can fit correctly in the shape of the forearm.

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Figure 9 Bracelets of Different Thicknesses
Source: Author's contribution (October 2022)

The cuff with the best results in terms of sufficient opening flexibility was the 3 mm cuff. The following table shows the problems detected in the other cuffs according to the manual bending and compression tests.

Part	Problem
2mm bracelet	Excessive flexibility and easy breakage
4mm bracelet	Lack of flexibility, a greater force is required for opening, which may lead to deformation in the medium term.

Table 3 Problems by Bracelet
Source: Author's contribution (October 2022)

Having already determined the optimal thickness, we proceed to the complete design of the forearm splint, this design will take into account the thickness of 3mm and the shapes will be circular, following the same pattern as the bracelets, the splint will have a height of 20cm.

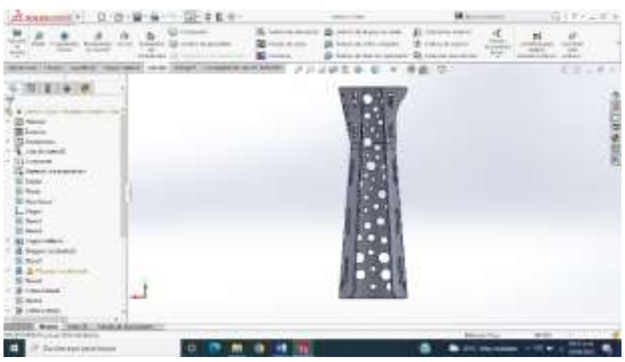

Figure 10 Version 1 splint with circular patterns
Source: Author's contribution (October 2022)

With the design of the first version we proceed to laminate the splint in the Simplify program, the approximate time for the printing of the splint is 6 hr 30 min.

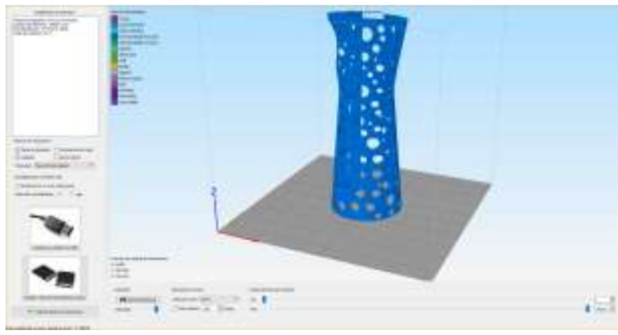

Figure 11 Simulated lamination of Ferrule Version 1
Source: Author's contribution (October 2022)

The configuration used for the ferrule lamination is as follows:

Parameter	Indicator
Layer height	0.15mm
Percentage of filler	100%
Temperature	235°C
Speed	50 mm/s
Addendum	Balsa

Table 4 Impression Parameters Splint V1
Source: Author's contribution (October 2022)

With these parameters we proceed to print this first version of the splint which has as main purpose, to evaluate the design and ergonomics, the total printing time for this version of the splint was 8 hr 23 min,

Problem presented in Version 1

The main problem detected in this first version is the weight which is 200gr, the second problem presented are the shapes of the splint, which are circular and there is not enough space between each one of them which presents the inconvenience that the circles are joined and these minimize its resistance, the third problem are the spaces to secure the splint to the forearm, these spaces are very thin and presented breakages when the securing tapes were placed.

Figure 12 Splint Version 1 Printed
Source: Author's contribution (October 2022)

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Figure 13 Ferrule Version 1 problems presented
Source: Author's contribution (October 2022)

After this first version and having obtained the first results, a second version of the splint is analyzed and designed, where the aim is to reduce the weight and improve the patterns of the splint, as well as to increase its resistance.

It should never be forgotten that it is the model that is studied and analyzed, and not the real system. From this it is taken into account that the model has to reproduce the behavior of the system in those aspects that are relevant [2].

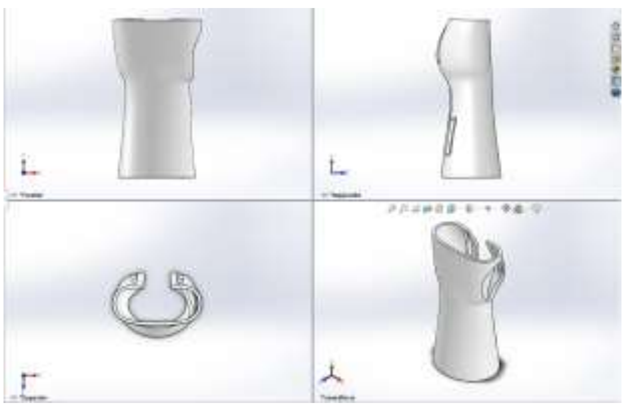

Figure 14 Ferrule Design Version 2
Source: Author's contribution (October 2022)

In order to perform the tests to the design of the splint, the Von Mises analysis was performed with the purpose of demonstrating the stress to which the splint will be subjected with a load of 6N, in this way it can be determined which area of the part is susceptible to suffer a permanent deformation without being able to recover its original shape, complementing this analysis with the displacement and unit deformation analysis.

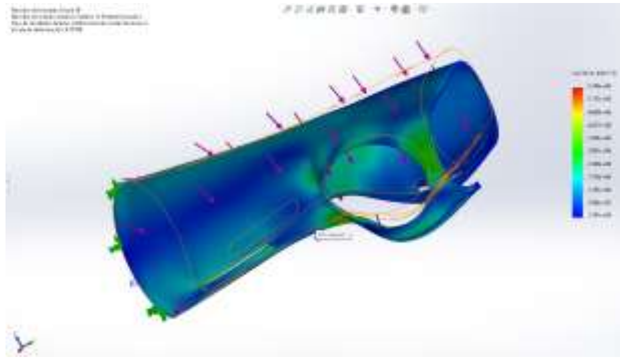

Figure 15 Von Mises analysis
Source: Author's contribution (October 2022)

A displacement analysis was performed with the main objective of showing how many millimeters the splint can be displaced when it is subjected to a load of 6N, resulting in a displacement of 1.891e +00 as shown in Figure 16. This displacement would take place in the lower part of the splint, which is the part most exposed to stress since people regularly rest this part of the body on an object.

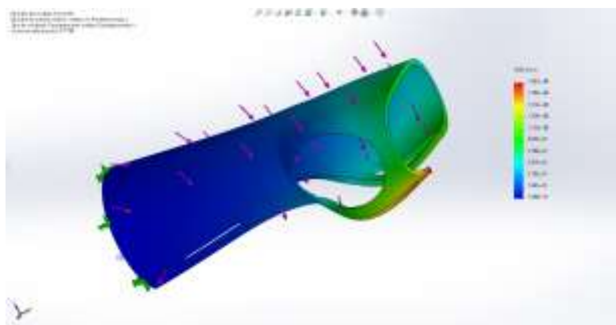

Figure 16 Von Mises analysis
Source: Author's contribution (October 2022)

The design was optimized by reducing the mass percentage by 40% (Figure 17) with respect to the mass of the design in Figure 10, resulting in the optimized design in Figure 18.

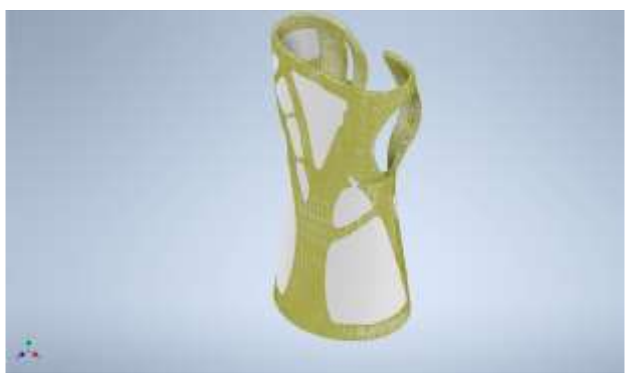

Figure 17 Generative design reducing 40% of the mass
Source: Author's contribution (October 2022)

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Figure 18 Final result of Version 2 splint for impression
Source: Author's contribution (October 2022)

Once the design is concluded and having simulated the different tests, we proceed to the printing of the version 2 splint, for this version the same parameters of table 4 will be used since these presented optimal results for version 1. The approximate printing time for version 2 is 5 hours and 23 minutes with an approximate weight of 53.35 gr, which shows a considerable decrease with respect to the previous design.

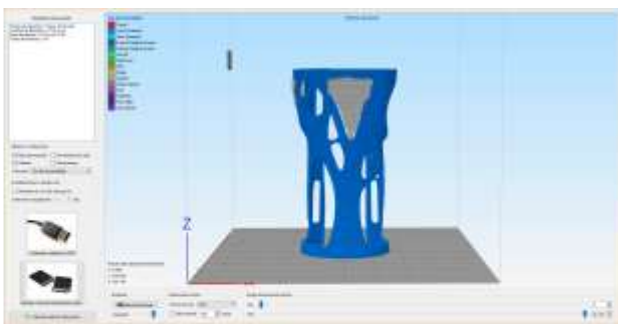

Figure 19 Simulation of Splint Printing Version 2
Source: Author's contribution (October 2022)

Once the printer was configured, we proceeded to print the part, the actual printing time was 5 hours 20 minutes.

Figure 20 Splint Version 2 Printed
Source: Author's contribution (October 2022)

Once the splint is printed, it is placed, and then it will be analyzed with a physiotherapist to evaluate the ergonomics and possible improvements that the splint could have. This work is the first part of three that are scheduled, it is intended to improve the design in the future having already obtained results with a patient, among the future improvements is the placement of electronic devices that can stimulate the patient so that he does not lose mobility. All this will be published in subsequent works.

Conclusion

Designing and manufacturing a piece that is going to be used for the recovery or rehabilitation of a person is a great challenge because it involves an adequate selection of materials, an optimized design that will lead to greater comfort. This first prototype gives us an idea of what can be improved in terms of design and the most appropriate parameters. Likewise, thanks to these tests we are taking into account the implementation of electronic devices that favor the rehabilitation of the user in a much shorter time.

Acknowledgement

This work was carried out with the sponsorship of the Universidad Tecnológica de Xicotepec de Júarez for the Industrial Maintenance and Petroleum career. We are grateful for the support provided.

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