Article **Journal of Physiotherapy and Medical Technology**
June, 2023 Vol.7 No.17 6-11

Characterization of composite material specimens manufactured in 3D printing for the construction of a shoulder Rehabilitation Prototype

Caracterización de probetas de material compuesto fabricadas en impresión 3D para construcción de prototipo rehabilitador de hombro

GUANDULAY-ALCÁZAR, Miguel Ángel, FERRER-ALMARAZ, Miguel Ángel, ORTIZ ROA, Arturo and FLORES BALDERAS, Juan Nicolás

Universidad Tecnológica del Suroeste de Guanajuato

ID 1st Author: *Miguel, Guandulay-Alcázar* / **ORC ID**: 0000-0002-8831-9547, **Researcher ID Thomson**: S-6750-2018, **CVU CONAHCYT ID**: 443671

ID 1st Co-author: *Miguel, Ferrer -Almaraz* / **ORC ID**: 0000-0003-4913-4010, **Researcher ID Thomson**: S-6969-2018, **CVU CONAHCYT ID**: 342076

ID 2nd Co-author: *Arturo, Ortiz-Roa* / **ORC ID**: 0000-0003-0543-7810, **Researcher ID Thomson**: S-7642-2018, **CVU CONAHCYT ID**: 947387

ID 3rd Co-author: *Juan, Flores-Balderas* / **ORC ID**: 0000-0002-3097-7504, **Researcher-ID Thomson**: IQW-2569-2023, **CVU CONAHCYT ID**: 632361

DOI: 10.35429/JP.2023.17.7.6.11 Received March 10, 2023; Accepted June 30, 2023

Abstract

The present work seeks to characterize polymer specimens with aluminum and stainless steel reinforcements, using additive manufacturing for their elaboration and thus increase their tensile strength and implement them for industrial, medical and automotive use. The methodology to follow consists of a documentary investigation of related articles and standards such as ASTM D638, where the tensile properties of plastics are specified, continuing with the manufacture of the test tubes in a 3D printer, this according to the corresponding standard., to later carry out stress tests on the universal machine. The contribution of the work developed lies in the increase in the tensile strength of the composite material experienced, resulting for a first test tube an increase of 52.4% in the maximum tensile strength with an aluminum reinforcement, and an increase of 59.1%, this with a steel reinforcement, in the second specimen submitted to tests with aluminum reinforcement an increase of 20.04% was obtained and with the steel reinforcement it was 84.54%.

Test Tube, Polymer, 3D

Resumen

El presente trabajo busca caracterizar probetas de un polímero con refuerzos de aluminio y acero inoxidable, utilizando manufactura aditiva para su elaboración y así aumentar su resistencia a la tensión e implementarlas para uso industrial, médico y automotriz. La metodología a seguir consiste en una investigación documental de artículos relacionados y normas como la ASTM D638, donde se específica las propiedades a la tracción de los plásticos, continuando con la fabricación de las probetas en una impresora 3D, esto de acuerdo a la norma correspondiente, para posteriormente efectuar pruebas de tensión en la máquina universal. La contribución del trabajo desarrollado radica en el aumento de la resistencia a la tracción del material compuesto experimentado resultando para una primera probeta un incremento del 52.4% en la resistencia a la tracción máxima con un refuerzo de aluminio, y un incremento del 59.1%, esto con un refuerzo de acero, en la segunda probeta sometida a pruebas con refuerzo de aluminio se obtuvo un incremento de 20.04% y con el refuerzo de acero fue 84.54%.

Probeta, Polímero, 3D

Citation: GUANDULAY-ALCÁZAR, Miguel Ángel, FERRER-ALMARAZ, Miguel Ángel, ORTIZ ROA, Arturo and FLORES BALDERAS, Juan Nicolás. Characterization of composite material specimens manufactured in 3D printing for the construction of a shoulder Rehabilitation Prototype. Journal of Physiotherapy and Medical Technology. 2023. 7-17: 6-11

* Correspondence to the Author (e-mail: maguandulay@utsoe.edu.mx)
† Researcher contributing as first author

Introduction

The process to carry out the additive manufacturing starts with the geometric modeling of the part in space, using some computer aided design software, such as SolidWorks, then a conversion of the dimensioned model to a coded reading of G commands will be done, that is to establish the necessary instructions to manufacture the part, then by means of a communication system the information is transferred to a processor that generates the additive manufacturing by joining the material layer by layer. The economic reduction of resources and manufacturing time are points in favor of additive manufacturing. The diverse applications that additive manufacturing has nowadays force to develop suitable materials that can give solution to the problems posed by the industry, such as the improvement of the mechanical properties of the same, such as yield strength or tensile strength, the use of bio-based materials is significant.

For example, the use of bioplastic materials, such as PLA or a polymer such as ABS, used in food applications, or in the manufacture of gears, is significant, being in this way the problem to be solved: to have available parts made of a molten polymer material, manufactured by means of a 3D printer, these parts would have to have a tensile strength or ultimate, close to steel or aluminum to be used industrially, for this steel and aluminum materials will be added to the materials already mentioned resulting in a composite material whose mechanical properties should be significantly improved. In addition, additive manufacturing is standardized by ISO/ASTM 52900 [5], which establishes the manufacture of components with 3D printers, in general.

Development

In the realization of the present experimental experimental a PLA (polylactic acid) polymer material will be used, as well as ABS resin in filament form, this due to its malleability and low cost, the ultimate strength of the PLA thermoplastic polymer is between 40 and 60 MPa [2], while the ABS material has a tensile strength between 41 and 45 MPa [3].

The solution to the above problem is to generate a composite material consisting of PLA and ABS, in addition to the addition of other materials, respectively, and to add other materials [4] other materials respectively,

The materials to be added will be: stainless steel and aluminum, due to their cost and accessibility, all of which should improve the mechanical properties of the base material. The materials to be added will be: stainless steel AISI 302, cold rolled, whose tensile strength or ultimate strength is 860 MPa and for aluminum 6061-T6 is 260 MPa [1].

1. Tensile test

In order to perform the tensile test, a specimen will be used A specimen will be used, according to ASTM D638 [4], called: Standardized Test Method for Tensile Properties of Plastics. The specifications of the standardized specimen to perform the tensile tests are shown in Figure 1. The specimens used by this standard are classified by types, as described below.

Type I

Type I specimen is preferably used, and should be used when there is sufficient material with a thickness of 7 mm (0.28 in.).

Type II

This specimen is recommended when the breakage of type I does not occur in its narrow part.

Type III

Type III specimen should be used for all materials with a thickness greater than 7 mm (0.28 in.) but not greater than 14 mm (0.55 in.). In this case, both the width of the narrow parallel section and the head width and overall length are increased so that the specimen thickness is less than the width.

Type IV

Generally used when direct comparisons between materials in different stiffness cases (i.e. non-rigid and semi-rigid) are required.

Type V

If only a small amount of material is available, or if it is not possible to extract a larger specimen from a component, then a type V specimen is used, reduced in all its dimensions with respect to type I. It can be stainless steel and aluminum, this due to its cost and accessibility, all of which should improve the mechanical properties of the base material. The materials to be added will be: stainless steel AISI 302, cold rolled, whose tensile strength or ultimate strength is 860 MPa and for aluminum 6061-T6 is 260 MPa [1].

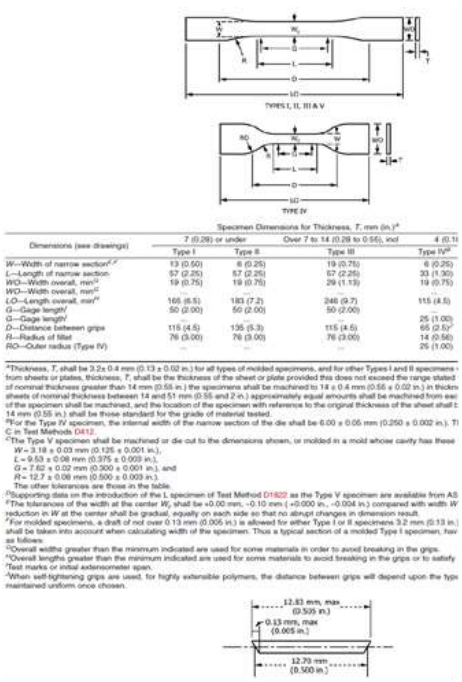

Figure 1 Specifications for standardized specimen, tensile test [4]

2. Additive manufacturing process of the specimens

The specimens were modeled in SolidWorks software, according to the parameters of the type I specimen, with a thickness of 7 mm and 165 mm total length, as well as 13 mm width in the narrowest section and a bending radius of 76 mm. Type I specimens will be manufactured in ABS material and type II in PLA material, the generated designs are saved with STL extension so that in the Digilab 3D Slicer software is converted into a control file for the 3D printer, this file is composed and is called G-Code consisting of G and M commands each with a movement or action assigned, Figure 2 shows an example of the G-Code of one of the specimens manufactured in 3D.

With the combination of these, transformed into a programming language that allows the 3D printer to understand which commands must be executed so that the part can be printed by the layer-by-layer process.

```
M140 S60
M104 S230
M109 S230
G28
G1 Z50.00 F400
G92 E0
G1 F200 E3
G92 E0
M132 X Y Z A
M907 X100 Y100 Z50 A100
;LAYER_COUNT:16
;LAYER:0
M107
M204 S2000
G0 F3000 X-17.671 Y11.3 Z0.3
;TYPE:SKIRT
G1 F1500 X-23.113 Y11.454 E0.27161
G1 X-28.486 Y11.911 E0.54064
G1 X-33.825 Y12.672 E0.8097
G1 X-41.55 Y14.195 E1.20252
G1 X-42.164 Y14.276 E1.23341
G1 X-42.479 Y14.286 E1.24914
```

Figure 1 G-Code sample from one of the specimens

In this same software the additive manufacturing parameters are specified, as described below:

Printing material

PLA and ABS with a diameter of 1.75mm.

Quality

The quality is related to the layer height, higher values produce a faster print with a lower resolution and lower values produce a slower print with a higher resolution, in this case a quality of 0.2 mm was used, the highest and lowest value handled by the DREMEL 3D 45 printer is 0.3 and 0.05 mm respectively.

ISSN 2523-6849

Filling

Adjusts the density for the printing filling, a 100% filling was used, this makes the printed model completely solid, the lower this percentage, the lower the resistance of the material.

Printing temperatura

The printing temperature of the PLA filament, extruder nozzle of 220 °C and the printing bed of 30 °C, for the ABS filament it was 240 °C and 60 °C respectively.

Speed and acceleration

Printing speed was 60 mm/s, displacement speed was 120 mm/s, printing acceleration was 2000 mm/s2 and displacement acceleration was 5000 mm/s2.

Once all the above parameters are defined, Digilab 3D Slicer generates the G-code, which is the programming language used.

The printing of the ABS and PLA specimens, Figure 3, was performed on a DREMEL 3D45 printer, it has a build volume of 9x9.9x5.5 inches (230x150x140mm) with a layer thickness of 50 µm. Type I samples were printed with ABS material and type II with PLA material.

Figure 3 3D printed PLA test tube

3. Implementation of reinforcement to the type I specimen

After the fused deposition modeling (MDF) process of the specimens, the reinforcement was implemented to the specimen, the material used for the reinforcement was aluminum and steel independently, Figure 4. The aluminum and steel sheets were cut with the same dimensions as the 3D printed specimens.

Figure 4 ABS test tube with reinforcement material (aluminum)

4. Tensile tests for the analysis and interpretation of results

Once the specimens were obtained, the tensile tests were performed with a universal machine, the ABS type I specimens were fractured outside the narrowest part of the specimen, see Figure 5, in this case it is recommended to use the type II specimen according to ASTM D638 standard to obtain the most accurate results of the material strength.

Figure 5 Tensile test on a type I specimen, made of ABS material

Since the fracture of the specimen type I was not in the middle part as recommended by the standard, the PLA specimens, type II, were used, in the same way they were reinforced with aluminum and steel independently, using the same process with the specimens reinforced with ABS, type I, to later perform the tension test in the universal machine, figure 6.

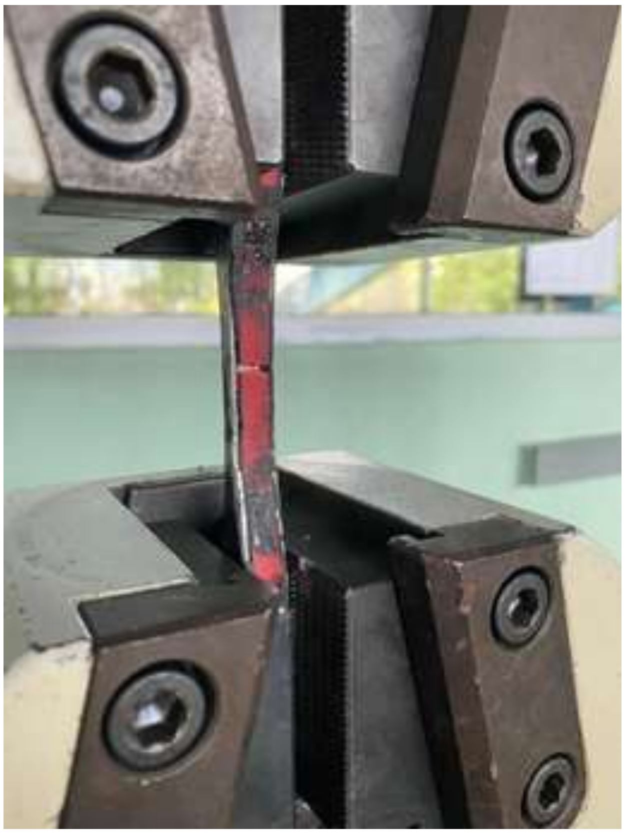

Figure 6 Tensile test on a type II specimen made of PLA material and reinforced with steel

The tests performed for the ABS material type I and PLA material type II specimens were three for each of them, the first was the original specimen without reinforcements, the second was with aluminum reinforcement and the last one with steel reinforcement, in total there were 6 tests, for each of these samples different results were obtained in relation to the tensile strength, i.e. each of them supports different loads, this was to be expected due to the mechanical properties of each material used in the printing of the specimens and the materials used in the reinforcements.

5. Results

As a result of the tensile tests carried out on the specimens manufactured with PLA and ABS both without reinforcement and with Alumina and steel reinforcement respectively, the values obtained are shown below:

Type of test tube	Material	Reinforcement	Tensile Strength, MPa
I	ABS	None	40.6
		Aluminum	61.9
		Steel	64.9
II	PLA	None	41.4
		Aluminum	49.7
		Steel	76.4

Table 1 Tensile test results, type I and II test specimens

6. Conclusions

The results obtained from the tensile tests carried out on ABS and PLA materials with aluminum and steel reinforcements, respectively, show an increase of 34.4% in tensile strength in the case of the ABS specimen with added aluminum and 37.4% increase with added steel % increase in the tensile strength in the case of the ABS specimen with added aluminum, 37.4 % increase with added steel, so the improvements are highly significant. With respect to the PLA material, the addition of aluminum increased the tensile strength by 9.16% and 45.8% with the addition of steel. All of the above is gratifying in the sense of the improvement of the conditions in the properties of the proposed materials, however, the costs of the additional materials to the base material must be considered, which could be a factor in deciding the material to be used.

This can be visualized in the future in a new study that would complement the present one.

This study proves and opens the opportunity to expand the area of application of these composite materials as mechanical elements where they will be subjected to tension or compression forces, as a very particular example in the development of projects focused on the field of bio-mechanics and physiotherapy, in the case of the latter, as future work is contemplated to develop a shoulder rehabilitator prototype, with composite material, having a great advantage in terms of cost and weight, this will make the project competitive and innovative.

7. References

[1] Beer, F. P. (2010). Mecánica de Materiales (5a. ed.). México: McGraw-Hill Interamericana.

[2] Serna C. L, Rodríguez de S. A, Albán A. F. Ácido Poliláctico (PLA): Propiedades y Aplicaciones. inycomp [Internet]. 4 de junio de 2011 [citado 23 de mayo de 2023];5(1):16-2. Disponible en: https://revistaingenieria.univalle.edu.co/index.php/ingenieria_y_competitividad/article/view/2301

[3] Vargas-Henríquez, Lisandro. (2020). Caracterización del ABS utilizado en procesos de manufactura aditiva y el ABS natural. Scientia et Technica. [citado 23 de mayo de 2023];5(1):16-2. Disponible en: https://www.researchgate.net/publication/346254982_Caracterizacion_del_ABS_utilizado_en_procesos_de_manufactura_aditiva_y_el_ABS_natural

[4] ASTM International, ASTM D638-14 Standard test method for tensile properties of plastics (2015).

[5] ISO/ASTM, Additive Manufacturing - General Principies Terminology (ASTM52900), 2015. https://www.iso.org/standard/69669.html

[6] Y. A. Jin, J. Plott, R. Chen, J. Wensman, and A. Shih, “Additive manufacturing of custom orthoses and prostheses - A review,” in Procedia CIRP, 2015, vol.36, pp. 199–204 doi: 10.1016/j.procir.2015.02.125.

[7] D. S. Chae *et al.*, “The functional effect of 3D-printing individualized orthosis for patients with peripheral nerve injuries: Three case reports,” Medicine, vol. 99, no. 16, p. e19791, Apr. 2020, doi:10.1097/MD.0000000000019791.

[8] S. Janzen, K. Stewart, and P. P. Pott, “Low-cost active knee orthoses - A systematic evaluation: Assisted stair climbing and sit-to-stand,” Current Directions in Biomedical Engineering, vol. 4, no. 1, pp. 649–652, Sep. 2018, doi: 10.1515/cdbme-2018-0156.