International Journal of Mechanical Engineering

The Effect of Water on Mechanical Properties of 3D Printed Materials (St-PLA, PLA+, PLA and ABS)

Mohammed Hazim[1,)], **Dr. Sadiq J. Hamandi** [2*)]
1,2) Biomedical Engineering Department, Al-Nahrain University, Baghdad-Iraq.

Abstract:
The aim of this research is to test the effect of water on the mechanical properties of the most popular 3D printed materials specially ABS & PLA, and compare the new generation of PLA (PLA+ & ST-PLA) with standard type of PLA, to ensure the different of mechanical properties, this helps to select the better material for applications that been affected with wetting surfaces, like prosthetic parts, The test starts with tensile test and then immerse the samples in water and made another tensile test, then compare the results, the results show a little effect on material elasticity for ABS, PLA with different its generations shows more effect by water.

Keywords: 3D printer, 3D print material, mechanical properties, ASTM, PLA & ABS.

1. Introduction

Materials used in mechanical applications must be provided flexibility or strength and range of motion, its must capable to transmit normal loads depend on the type of applications, for structurally the material should be durable and has long life time. Polymers are primary made from covalent linkage of small molecular size monomers to made high molecular weight compounds [1], Polymers are occupy the major position in the bearings field, the aim of this research is to test the effect of water on the most popular 3D printing materials (ABS & PLA), and compare the different types of PLA (PLA+ & ST-PLA) with stander PLA, This helps to ensure the material can capable with applications that work at wet environments or it fails specially for prosthetic parts.

2. Tensile Test

The tensile tests results are help to selecting the better materials for different engineering applications. Tensile properties frequently are included in material specifications to ensure quality of the material and its qualification for the needed application. When develop of new materials tensile properties often are measured, so that materials with different types and with different fabrication processes can be compared. Finally, the behavior of the material under forms of different loading can be predicted by tensile properties.[2]

The strength of the material that works on it can be measured by the necessary stress that can cause noticeable plastic deformation or the highest stress load can apply on the material without fail. These measures help to detect of the strength of the material that needs to use, with proper care (in the form of safety factors), in engineering design. Also, the other important thing is the material's ductility which is a measure of the maximum material deformation before failure. Rarely is ductility combined directly in design [3], to ensure quality and toughness it must be included in material properties . Low ductility in a tensile test means the material has low resistance to fracture under other forms of loading [2].

Tensile Specimens: The typical tensile specimen is shown in **Figure (1)**. It has expanded ends or shoulders to help better gripping. The major part of the specimen is the gage section. The cross-sectional area of it is reduced relative to that of the remainder of the specimen so that deformation or failure occurs [4].

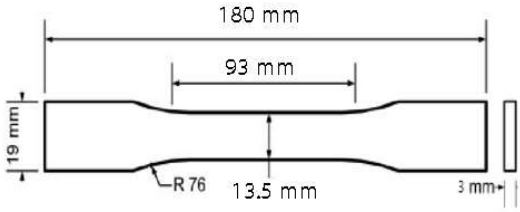

Figure (1) ASTM D638 Tensile Test Specimen

3. Procedure

The procedure started with 3D modeling based on ASTM D638 with AutoCAD, then the final model was exported as STL file, the second step was adding the exported file at slicer software, the Repetier-Host was used for slice the model and prepare it for 3D print as shown in **Figure (2).**

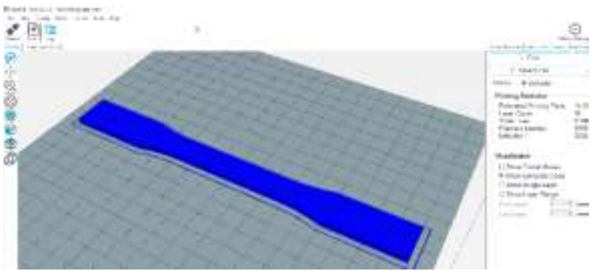

Figure (2) Repetier-Host slicing software

The final file was sent to 3D printer for printing, the model was printed as a solid without any internal grid, it was used layer precision at 0.2mm and nozzle temperature at 225ºC for (PLA, PLA+ and ST-PLA) and 235ºC for ABS.

The final results were three samples of every materials for every test, this helped to take an average result for every material to ensure the accuracy.

The device model that used for the test was **Testometric M500** [5] as shown in **Figure (3).**

Figure (3) Testometric M500

The final result from the device is row data on a note file then all data transformed to excel sheet, the calculations were made in excel file as shown in **Figure (4-a)**, the raw data that enter in to the excel file have not equal numbers of row that cause discard some data when take an average for calculated result, the solution for this problem is by using interpolation technique by **Origin** software as shown in **Figure (4-b)**, it simply draws the curve from entered data then resampling the curve as number of data that needed, then transferred the interpolated data to excel file to complete the calculations, then the final curves was drawn.

Figure (4-a) Excel sheet

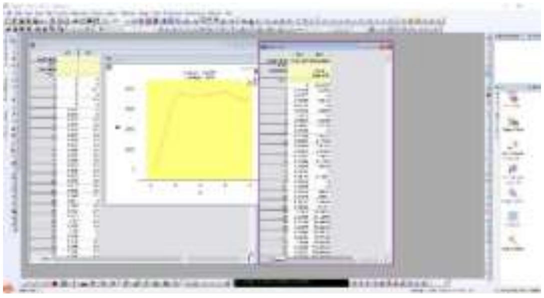

Figure (4-b) Origin software

The second test was the water effect, it starts by 3D printing the same samples and taking the weight for all of them, then immersing the samples in water as shown in **Figure (5)** for every 24 hours. The samples were removed from water and reweighted as shown at **Figure (6)**.

Figure (5) Samples at water

Figure (6) Electronic Balance

The weight of samples slightly increases because of absorbing of water, this process remains till day six so that the weight remain constant. The tests continue for eighteen days then stops.

The second prosses is to drying the samples by adding them in side oven with temperature less than 60ºC because PLA become ductile at this temperature, the temperature fixed at 40ºC, the lab oven was used for drying prosses shown at **Figure (7).**

Figure (7) Lab Oven (Binder)

Then the sample reweighted. The cycle of drying and reweight prosses were repeated till the weights of samples return to the same weight before poring them at water. Finally, the tensile test was made to ensure if any mechanical changes was happened, and the result shown in **Table (1)**.

Table (1): Weight of samples in the water **(g)**

Days	ABS	PLA	PLA+	ST-PLA
0	9.4536	11.5432	11.3752	11.4327
1	9.6944	11.6538	11.4021	11.5323
2	9.6959	11.6840	11.4327	11.5532
3	9.6543	11.7018	11.4895	11.4680
5	9.6833	11.7112	11.5020	11.5258
6	9.6884	11.7182	11.5163	11.6028
7	9.6995	11.7180	11.5276	11.6070
9	9.7250	11.7187	11.5170	11.6158
11	9.8001	11.7215	11.5358	11.6201
12	9.8402	11.7280	11.3397	11.6222
13	9.8604	11.7275	11.3378	11.6218
15	9.8600	11.7285	11.3365	11.6221
18	9.8602	11.7281	11.5370	11.6220

4. Results & Discussions

The tensile tests for (ABS, PLA, PLA+ and ST-PLA) materials show the force peak for ST-PLA around 2470N and for PLA+ is 1470N and for stander PLA is 1622N and for the last ABS is 1769N, the tensile curve for every material was shown in **Figure (8)**

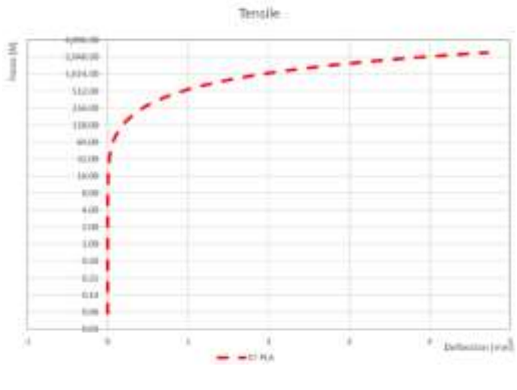

Figure (8-a): ST-PLA Tensile

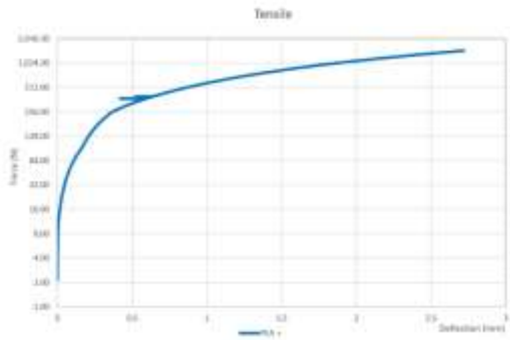

Figure (8-b): PLA+ Tensile

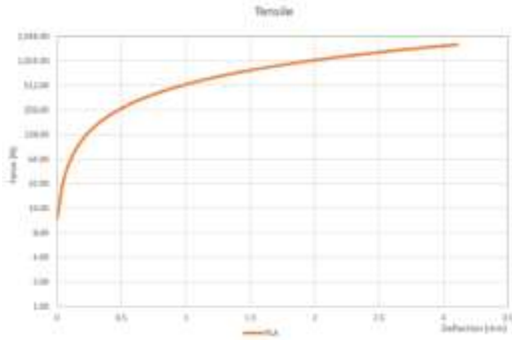

Figure (8-c): PLA Tensile

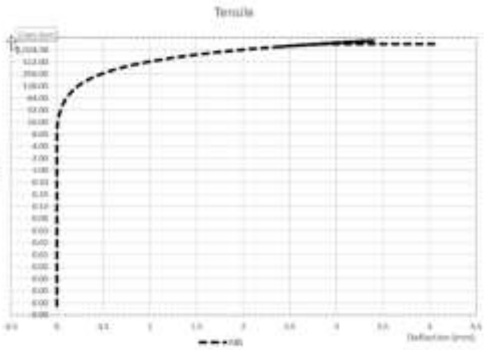

Figure (8- d): ABS Tensile

As shown from **Figure (8),** every material has different ultimate tensile strength but the ST-PLA has the highest one, the final comparison curve is shown in **Figure (9)** for all materials, the material has close article behavior at elastic region that why the curves is overlaps but the significant results were shown in **Table (2).**

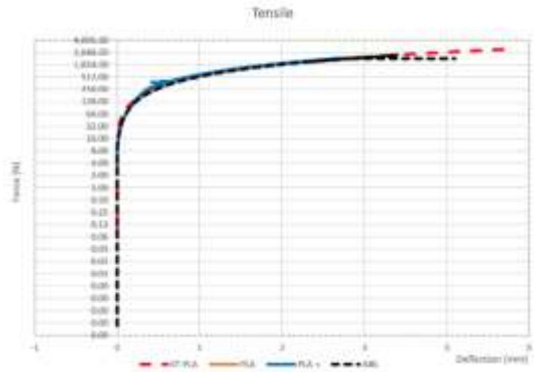

Figure (9): Tensile **test**

The results of the wetting tests show that the ST-PLA ultimate tensile strength of deflection was dropped, but all the declaration appear at the plastic region deflection. They decrease around 25%. After six day it becomes stable to the end of the test time at 18 days as shown in **Figure (10)**, but in the elastic region there is no noticeable effect.

For other type of PLA, it shows 31% drop for deflection at plastic region, and for PLA+ the drop is around 21%. At the elastic region there is no noticeable effect for deflection or tensile strength, the result is shown in **Table (2)**.

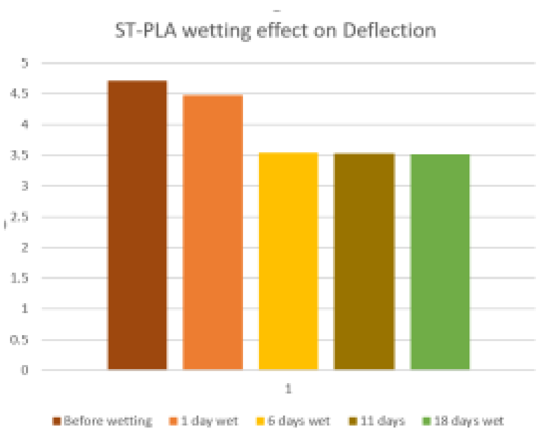

Figure (10): ST-PLA VS ST-PLA wet

Table (2): Results of tensile tests

Materials	Yield strength	Deflection (mm)				
		Before wetting	1 - day wetting	6 - day wetting	11 - days wetting	18 - days wetting
ABS	1527	4.21	5.65	4.78	4.85	4.91
ST-PLA	2086	4.72	4.47	3.53	3.51	3.51
PLA+	1676	2.72	2.71	2.54	2.12	2.15
PLA	2091	3.1	2.95	2.22	2.09	2.12

The same test was made on ABS as shown in **Figure (11)**, the results show no stable effect by the water, this because ABS is not a biodegradable material [6] and at the first time the elasticity has little increase then drop, but the change is very little in the plastic region.

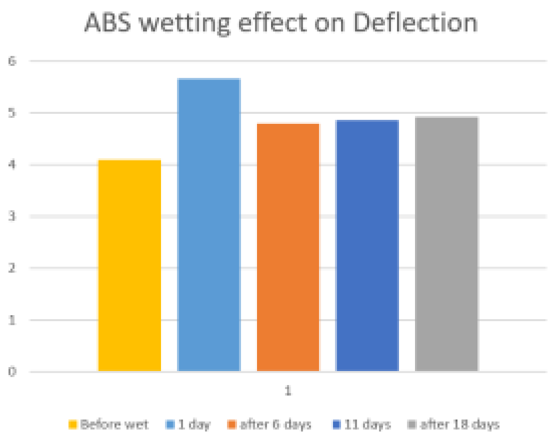

Figure (11): ABS VS ABS wet

The final results shown that ABS has not a big effected by water, that's mean it is suitable for application that works in wet environment, with notice that the ABS is toxicity [6]. Spatially due printing and the complexity of printing, all types of PLA can be used. For applications that need a material has higher yield strength, PLA or ST-PLA are very good choices. There is no matter of environment that choose a wet or not, because the effect of water happened at the plastic region and most applications work at the elastic region.

7. References:

[1] A. I. Shamki and S. J. Abass, “Friction and Wear Testing of Lubricated Joint Implant Material using AMTI Ortho-POD,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 757, no. 1, pp. 10–19, 2020, doi: 10.1088/1757-899X/757/1/012048.

[2] T. Testing, “Introduction to Tensile Testing,” pp. 1–13, 2004.

[3] P. Wenjea and J. Tseng, “Chapter 3 : Tensile Testing Tensile-testing Machine,” pp. 1–10, 2010.

[4] J. L. Koenig *et al.*, “NOTICE : This standard has either been superseded and replaced by a new version or discontinued . Contact ASTM International (www.astm.org) for the latest information . Standard Test Method for Tensile Properties of Plastics 1,” vol. 12, no. 2, pp. 1–8, 2004, [Online]. Available: www.radford.edu/~biol-web/stats/standarderrorcalc.pdf%5Cnhttps://books.google.com/books?id=6J6Vv3l6GvQC&pgis=1.

[5] R. I. Abed, S. J. Abbass, and W. A. Alsaadan, “Testing mechanical behaviour of bone-plate construct,” *2020 3rd Int. Conf. Eng. Technol. its Appl. IICETA 2020*, pp. 220–225, 2020, doi: 10.1109/IICETA50496.2020.9318943.

[6] “5 reasons why abs needs to go away,” *https://all3dp.com*. 3D printing expert, [Online]. Available: https://all3dp.com/5-reasons-why-abs-needs-to-go-away/.