ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 3, June 2022, pp.334-340

Characterization of fatigue properties of 3D printed polylactic acid

Hind B. Ali [1], Dalia R. Alazawi [2]
[1] Materials Engineering Department, University of Technology, Iraq
[2] Materials Engineering Department, University of Technology, Iraq

ABSTRACT

The goal of this research is to determine how tiredness behavior may be measured (PLA). A To A variety of technical data sets were S-N curves were chosen and statistically re-analyzed. as described in the following section, to generate a negative reference value reverse slope also an improved tolerance limit of 106 2 failure cycles. The average effect of stress on fatigue can be indicated via administering the highest level of stress achievable during the cycle, according to experimental data examined after treatment. Furthermore stress/strength study may be effectively performed until the printing orientation seems to possess minimal influence on PLA's general tiredness behavior. carried out via taking the printing orientation into account. A homogeneous, linearly elastic polymer is described. When acceptable experimental findings are not available, the paper explains how to conduct a fatigue evaluation (with a survival probability better than 95%). The study demonstrates how to do so via utilizing standard fatigue curves with a negative-inverse regression of 5.5 and a tolerance limit (2 106 cycles to failure) equivalent to 10% of the material's maximum σ_t.

Keywords: Fatigue strength, 3D printing, polylactic acid, Fused deposition modelling

Corresponding Author:

Hind B. Ali
Materials Engineering Department
University of Technology
Baghdad, Iraq
E-mail: 130047@uotechnology.edu.iq

1. Introduction

3D printing is an example of additive manufacturing, which converts a digital design into a real thing. Lasers are utilized to fuse materials such as liquid or powdered plastic, metal, or cement together in thin layers. Industrial productivity has already been increased via the usage of 3D printing technology since its debut [1]. Whether this technology is effectively utilized in big manufacturing processes, it has the potential to disrupt both industrial logistics and inventory management [2]. The present rates of 3D printing are insufficient for large-scale production. However, using 3D printing technology, this process has sped up the fabrication of prototype components and devices, as well as the tooling required to produce those parts. It is extremely beneficial to small-scale companies since it decreases production costs while also reducing product time-to-market [3]. The present rates of 3D printing are insufficient for large-scale production. However, using 3D printing technology, this process has sped up the fabrication of prototype components and devices, as well as the tooling required to produce those parts. It is extremely beneficial to small-scale companies since it decreases production costs while also reducing product time-to-market [4]. Fundamental principles. A CAD application, even a simple digital camera & photogrammetry software may be utilized to create 3D models. to create prototypes for 3D printing [5]. The process of manually modeling geometric data of 3D computer graphics may be compared to fine arts like sculpting in many ways [6] and [7]. When you scan an item, digital data about its look and feel is captured, which may then be utilized to generate a reliable digital representation of the thing. Following the modeling process, the CAD file must be converted to an STL file for use in 3D modeling and printing software [8]. When printing a 3D model from an STL file, care must be taken to guarantee the model is error-free [9, 10]. It is required to verify a 3D model built from an STL file for errors prior to printing. Then g code from the simulation software will got to printer as X, Y, Z points to printed in [11].

1. Rapid prototype
2. Layering steps on 3 axes

3. Final product

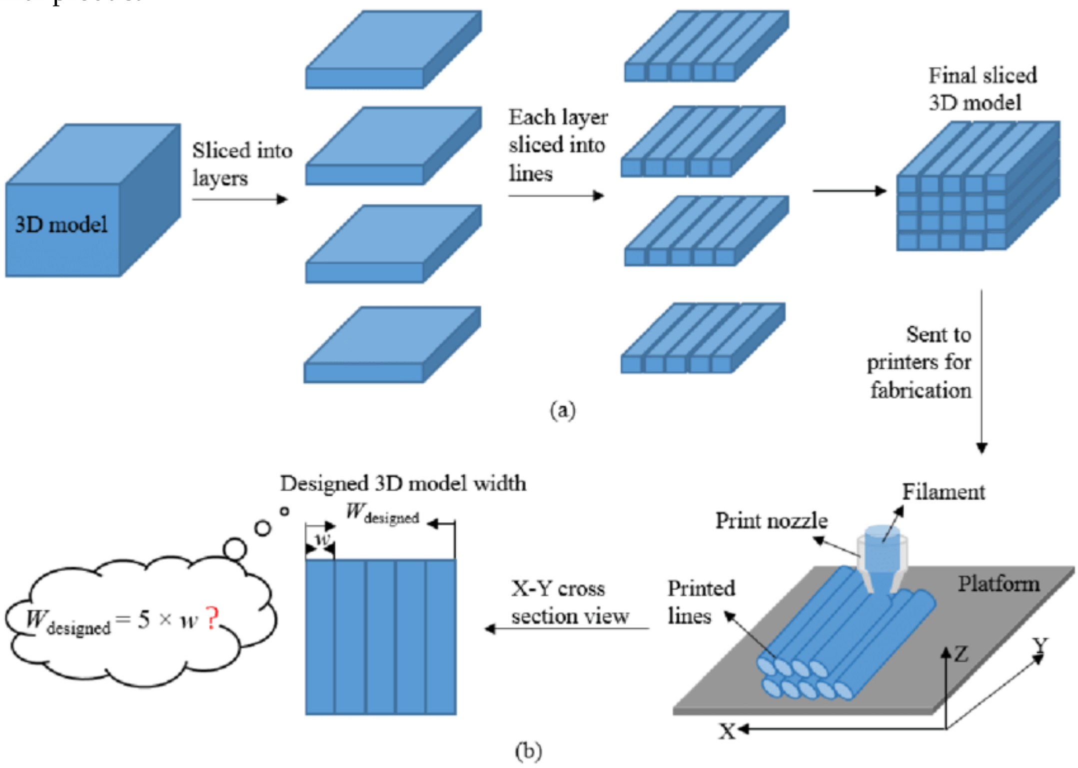

Figure 1. Main process stages common to most RP systems

1.1. 3D printing

Building a model using contemporary methodologies can take anything from a few hours to several days, depending on the strategy utilized and the size and complexity of the models being built, among other factors [12] and [13].

- full three-dimensional printing
- The approach is analogous to the process via which ink or toner is fused to paper in a printer.
- At each point in the horizontal cross section where solid material is desired, a liquid or powder solidifies or binds together.
- Layering via models during the design of new parts
- Complex parts to manufacture
- Final product to sale

2. Materials and methods

PLA is a biopolymer, which means it degrades spontaneously over time. PLA is manufactured using sustainable energy sources such as sugar cane and maize starch. In addition to 3D printing, this material is frequently utilized in canning, packaging, plastic cups, and plastic water bottles. Because it is made from plants, it is more environmentally friendly than ABS [14, 15]. PLA has a higher surface hardness as well as brittleness. As a result, it is more prone to breaking when twisted. Models made of this material can be cut, sanded, cooled, painted, and joined together with adhesives; however, these models cannot be treated with acetone to increase the smoothness of the final surfaces[16, 17]. Bubbles and spurs appear at the extrusion nozzle when PLA wires are exposed to air for an extended length of time. This has the potential to clog the nozzle and reduce the surface quality of the product. The item may also show signs of staining and discoloration. Although hot air may be utilized to dry wet PLA wires, heating can alter the crystallization rate of the material as well as the thermal properties of the wires, which can affect the printing temperature [18]. PLA has a tendency to jam (or clog) the printer's nozzle because it is more viscous and swells more when melted. To avoid clogging the nozzle, we recommend that you strictly adhere to the printer manufacturer's recommendations [19, 20]. Because holographic layers frequently do not shrink when cooled, seam warping and breaking are not a worry, and the holographic print may be removed from the print surface more simply than with ABS[21]. This material does not require a heated surface (though employing it appropriately might increase the quality of the resultant shape), nor does it require the printer to be enclosed (but, again, may give better results). We propose wrapping the print surface with masking tape to increase the degree of adherence (also known as paint tape). PLA is biodegradable since it is made up of plant components. Because it takes heat to break down, it might be utilized in organic fertilizers for cities but not in home garden fertilizers [22].

Table 1. conditions for PLA

Nozzle temp.	230 – 270 C
Table Bed temp.	30 - 70 C, optimum 40 C
Printing isolated	Glass and griding silicon

Strategies of Minnesota, USA, pioneered FDM. It's extruded from a small nozzle onto a platform, creating a semi-liquid thread of material Via moving in an X-Y plane, this nozzle places a thin layer of filament on the surface of the part. Each extruded layer adheres to the one before it, forming a solid structure. The platform is then lowered in reference to the nozzle, and the subsequent slice of the component is deposited on top of the prior slice.. [23] When the portion is finished, the support structures are separated from it, as seen in Figures 2 and 3. We utilize a WINBO 3D PRINTER with a single nozzle model WB.CL.V03 which shown in figure 4.

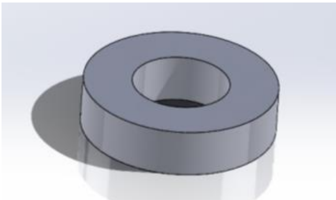

Figure 2. Model 1 fatigue sample

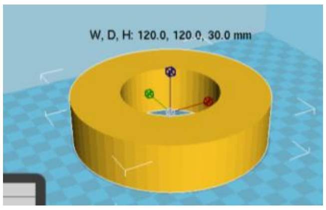

Figure 3. Software modeling

Figure 4. Schematic of fused deposition modelling

2.1. Fatigue strength

Static and fatigue mechanical properties of PLA are effect via the following factors: infill % also nozzle size as well as the manufacturing orientation and filling pattern, feeding speed and manufacturing speed of the extruders. Another important factor is the temperature at which the container is filled. AM polymer products' mechanical behavior is greatly influenced via the thickness of the shell, which serves as a parametric retaining wall. When a new layer is added to a 3D-printed object, the printer develops the shells as the first structural components. As a general rule of thumb, the shell thickness should be multiplied via the best practice in AM manufacturing PLA products. Static strength is also affected via the thickness of the layers. In general, PLA is brittle, with ductility changing with printing speed. For design reasons, PLA may be treated as an isotropic, homogeneous, linear-elastic material. It has been shown via extensive testing that factors like as infill density, nozzle diameter, & printing speed all have a significant effect on total fatigue strength. A lack of time-consuming and costly experimental procedures makes it difficult to discover and evaluate mutual connections and effects. Via conducting a systematic experiment, it is possible to evaluate the influence of various manufacturing parameters on the mechanical properties of PLA. Here, we're going to focus on fatigue in order to get some ideas for constructing PLA that can withstand cyclic stress. Reversed (i.e., R=minimum/maximum=-1) axial force applied to PLA specimens manufactured via the commercial 3D printer WINBO 3D PRINTER was studied. A flat construction plate with 100% infill was utilized to create the examples. Layer thickness was 0.4mm; shell thickness was 0.8mm; and print speed was 40m/s for the bulk material of the specimens, as shown in the figures below.

2.2. Model attempted

2.2.1. First attempt

Dimensions: X= 120 Millimeter, Y = 120 Millimeter, Z = 30 Millimeter. the characteristic of this sample are with big scale directly, Low layers capacity, and Greater layer height. While the structure represented that the Material distributes according to increase of fan speed, Medium Layers mesh and Big scale for more efficiency to fatigue test as shown in figure 5.

Figure 2. Shape of Sample 1

2.2.2. Second attempt

Dimensions: X= 120 Millimeter, Y = 120 Millimeter, Z = 30 Millimeter. the characteristic of sample Modify last attempt, Close fan, High feed speed, and Successful printing as shown in figure 6. While the structure is Material distribute according to increase of fan speed, Medium Layers mesh, and big scale for more efficiency to fatigue test.

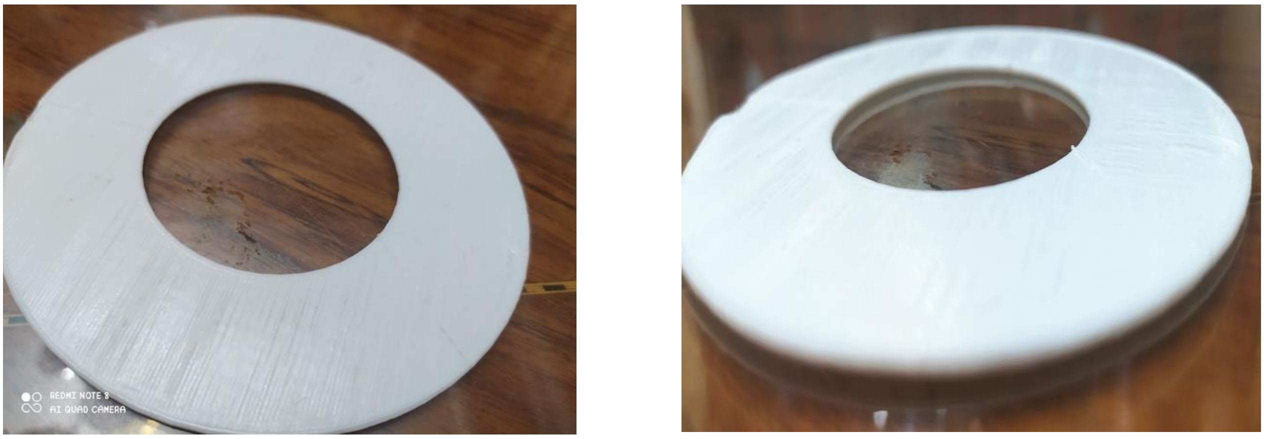

Figure 3. Shape of Sample 2

3. Results and discussion

The tests' outcomes were assessed collectively via dividing the σ_{max} via the σ_{UTS} of the material. There was a 99.9% chance of survival and a 1.0% chance for design considerations in the normalization technique shown in

Figure 7. Figure 7 seems to support the assumption that PLA's total fatigue strength is nearly linked to its static strength, with max appropriately representing the mean stress effects when normalizing the data.
Figure 7 shows the results of the tests, and the following is a references S-N curve for fatigue PLA design with 100% in fill:

$k=5.5$ ……………………………………………………………..………………..(1)

$\sigma_{MAX}=0.1\cdot\sigma_{UTS}$ at $N_0=2\cdot10^6$ cycles to failure for $P_S\geq95\%$..................................(2)

The test is simulated as the relationship between stress on the model and failure cycles, and based on previous assessments, it is the correct test that could be made on. The findings are shown and analyzed as an S-N curve to show tiredness across the run out via Zita of the working test [24].

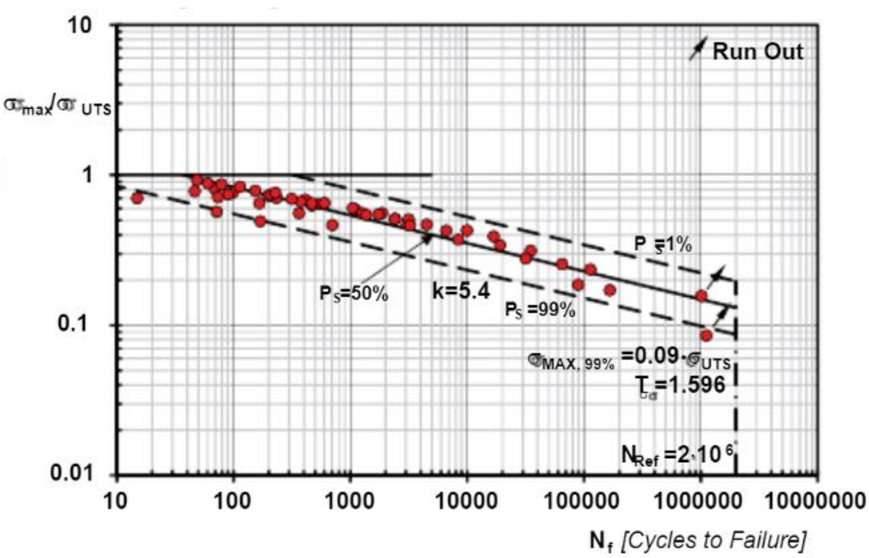

Figure 4. Design fatigue curves normalized (for an infill level equivalent to 100 percent)

To conclude the present analysis, a sequences of fatigue outcomes obtained exams traditional PLA are matched to the information acquired tests PLA in Figure 8's S-N chart. This figure illustrates that common PLA has somewhat higher fatigue strength than PLA, with experimenter outcomes from testing conventional PLA remaining within the referenced scatters range, as shown in Figure 8. This illustrates that, when it comes to PLA,, AM may produce components with fatigue performance comparable to that of older, well-established methods [25].

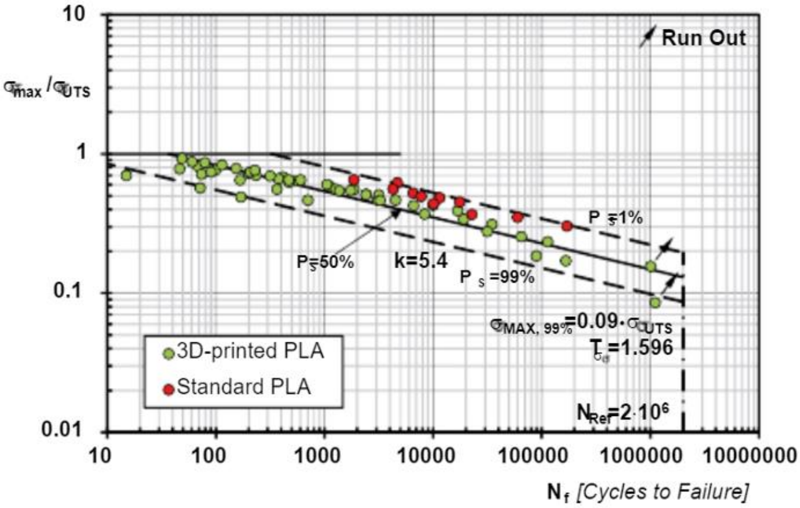

Figure 5. Fatigue strength of standard PLA vs. fatigue strength of AM PLA

4. Conclusion

As a consequence of using the aforementioned standards, the data in the graph below has been normalized. A scatter band was developed with a survival probability (PS) ranging from 99% to 1% due to design constraints.

Experimenting with a standardization method resulted in a lower figure for T. This lends credence to the hypothesis that AM The fatigue life of PLA is determined via its static strength, with the mean stress effects playing an important influence. PLA fatigue may be assessed via using the cycle's highest stress level to accomplish a critical function. PLA components may be developed to survive fatigue utilizing references designed curve with a negative reverse slope (k) of 5.5 & a fatigue limit (calculated in term of σ_{max} & extrapolated to 2.106 cycles to failure), (for PS95%). Using conventional and well-established production methods, PLA maintains the same fatigue properties. It functions as an inherently notched material, reducing the total fatigue strength of the material when it has less than 100% filling

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

Funding information

No funding was received from any financial organization to conduct this research

References

[1] M. F. Afrose, S. H. Masood, P. Iovenitti, M. Nikzad, and I. Sbarski, "Effects of part build orientations on fatigue behaviour of FDM-processed PLA material," *Progress in Additive Manufacturing,* vol. 1, no. 1-2, pp. 21-28, 2015.

[2] B. Durakovic, "Design for additive manufacturing: Benefits, trends and challenges," *Periodicals of Engineering and Natural Sciences (PEN),* vol. 6, no. 2, 2018.

[3] R. D. Averett, M. L. Realff, K. Jacob, M. Cakmak, and B. Yalcin, "The mechanical behavior of poly(lactic acid) unreinforced and nanocomposite films subjected to monotonic and fatigue loading conditions," *Journal of Composite Materials,* vol. 45, no. 26, pp. 2717-2726, 2011.

[4] D. D. S. A.-F. Dr. Hussain J.M AL-Alkawi, Ahmed Adnan AL-Qaisy, "Effect of Plasma Peening on Mechanical Properties and Fatigue life of AL-Alloys 6061-T6," *Engineering & Technology Journal,* vol. 33part A, no. 7, pp. 1667-1679, 2015.

[5] L. S. A. A. Ahmed "Additively Manufactured PLA under static loading: strength/cracking behaviour vs. deposition angle," presented at the XXIV Italian Group of Fracture Conference, 2017.

[6] I. Al Zamzami and L. Susmel, "On the accuracy of nominal, structural, and local stress based approaches in designing aluminium welded joints against fatigue," *International Journal of Fatigue,* vol. 101, pp. 137-158, 2017.

[7] F. V. Andrei Gorelov1 "3D printed solder masks for printed circuit boards," *Periodicals of Engineering and Natural Sciences,* vol. 9, no. 4, pp. 443-441, 2021.

[8] O. H. E. a. L. Susmel, "On the fatigue strength of 3D-printed polylactide (PLA)," *Procedia Structural Integrity* vol. 9, pp. 29-36, 2018.

[9] M. W. Todd Letcher "MATERIAL PROPERTY TESTING OF 3D-PRINTED SPECIMEN IN PLA ON AN ENTRY-LEVEL 3D PRINTER," in *International Mechanical Engineering Congress and Exposition IMECE2014*, 2014, November 14-20, 2014, Montreal, Quebec, Canada

[10] Y. S. Mezaal and S. F. Abdulkareem, "Affine cipher cryptanalysis using genetic algorithms," *JP Journal of Algebra, Number Theory Applications,* vol. 39, no. 5, pp. 785-802, 2017.

[11] J. M. Chacón, M. A. Caminero, E. García-Plaza, and P. J. Núñez, "Additive manufacturing of PLA structures using fused deposition modelling: Effect of process parameters on mechanical properties and their optimal selection," *Materials & Design,* vol. 124, pp. 143-157, 2017.

[12] N. S. A. M.S. Abdu_Lateef, A.G. Mohammed, "Prediction of Fatigue Life of Fiber Glass Reinforced Composite (FGRC) using Artificial Neural Network," *Engineering and Technology Journal,* vol. 35, Part A, no. 4, 2017.

[13] O. M. Ajka Aljilji, Hazim Bašić, Nedžad Prazina, "Mechanical properties of dried fruit packaging materials," *Periodicals of Engineering and Natural Sciences,* vol. 8, no. 4, pp. 2547-2552, 2020.

[14] C. B. O. Jadallah, H. Askes and L. Susmel, "Microstructural length scale parameters to model the high-cycle fatigue behaviour of notched plain concrete," *International Journal of Fatigue,* vol. 82, pp. 708-720, 2017.

[15] H. Salim, S. H. Abbood, M. Rahim, and A. M.Alaidi, "DR-LL Gan: Diabetic Retinopathy lesions synthesis using Generative Adversarial Network," *International journal of online and biomedical engineering,* vol. 18, no. 3, 2022.
[16] J. A. T.-R. R. Jerez-Mesaa, J. Llumà-Fuentesa, G. Gomez-Grasb, and D. Puiga, "Fatigue lifespan study of PLA parts obtained by additive Manufacturing " *Procedia Manufacturing* vol. 13, pp. 872-879, 2017.
[17] S. A. Shandal, Y. S. Mezaal, M. F. Mosleh, and M. A. Kadim, "Miniaturized wideband microstrip antenna for recent wireless applications," *Advanced Electromagnetics,* vol. 7, no. 5, pp. 7-13, 2018.
[18] A. Lanzotti, D. Eujin Pei, M. Grasso, G. Staiano, and M. Martorelli, "The impact of process parameters on mechanical properties of parts fabricated in PLA with an open-source 3-D printer," *Rapid Prototyping Journal,* vol. 21, no. 5, pp. 604-617, 2015.
[19] S. Oudah, H. Al-Attraqchi, and N. Nassir, "The Effect of Process Parameters on the Compression Property of Acrylonitrile Butadiene Styrene Produced by 3D Printer," *Engineering and Technology Journal,* vol. 40, no. 1, pp. 189-194, 2022.
[20] R. A. Azeez, M. K. Abdul-Hussein, M. S. Mahdi, and H. T. S. ALRikabi, "Design a system for an approved video copyright over cloud based on biometric iris and random walk generator using watermark technique," *Periodicals of Engineering Natural Sciences,* vol. 10, no. 1, pp. 178-187, 2022.
[21] H. B. Ali, "Effect Of Reinforced by Coconut Fiber Core on The Mechanical Properties for Un-Saturated Polyester Matrix Composite Material," *Engineering and Technology Journal,* vol. 17 part A, no. 31, pp. 292-296, 2013.
[22] M. R. Khosravani, F. Berto, M. R. Ayatollahi, and T. Reinicke, "Characterization of 3D-printed PLA parts with different raster orientations and printing speeds," *Sci Rep,* vol. 12, no. 1, p. 1016, Jan 19 2022.
[23] A. P. a. D. Hodzic, "Mechanical properties comparison of PLA, tough PLA and PC 3D printed materials with infill structure – Influence of infill pattern on tensile mechanical properties," *IOP Conf. Series: Materials Science and Engineering,* vol. 1208, 2019.
[24] I. M. Al-Sudani, S. A. Al-Rabii, and D. S. Al-Fattal, "The Effects of Anodizing Process on the Corrosion rate and Fatigue Life of Aluminum Alloy 7075-T73," *Engineering and Technology Journal,* vol. 38, no. 1, pp. 34-42, 2020.
[25] I. Sedighi, M. R. Ayatollahi, B. Bahrami, M. A. Pérez-Martínez, and A. A. Garcia-Granada, "Mechanical behavior of an additively manufactured poly-carbonate specimen: tensile, flexural and mode I fracture properties," *Rapid Prototyping Journal,* vol. 26, no. 2, pp. 267-277, 2019.