Mechanical Displacement for 3D Printers’ Parts Using FEM as Inverse Engineering Method in Honduras

Jose Luis Ordoñez Avila¹, Maria Elena Perdomo², Mildred Yanire Rivas Bejarano³, Jose Luis Ordoñez Fernández⁴

¹,²Universidad Tecnológica Centroamericana, UNITEC-Honduras
³,⁴Universidad Nacional Autónoma de Honduras

jlordonez@unitec.edu

Abstract. Plastics industry is growing day by day; the new techniques generated by the fourth industrial revolution, such as additive manufacturing (AM) or better known as 3D printing, make the design and production of plastic products available to all. The aim of this research aims to explore the application of reverse engineering in improving the mechanical displacement in AM. The method used in this paper was the finite element analysis (FEM) applying it to different 3D printing parameters with a grid infill. Then the multiple line regression (MLR) was implemented to determine parameters relation. Finally, the simplex method to improve the parameters to decrease the mechanical displacement in AM. Reverse engineering process for parts that use 0.2 as shell wall and 25% of grid infill can have acceptable mechanical performance to be used in different applications.

1. Introduction
Additive Manufacture (AM) is a new opportunity for new companies in Honduras. These companies base their designs on reverse engineering, measuring, and reviewing different aspects of finished products to develop their prototypes. These micro-enterprises came together to support hospitals in the country with personal protective equipment. In 26 days, they produced over 7400 masks that were delivered throughout the country because of COVID-19. Honduras imported $9.9 billion in 2017, making it the 90th largest importing country in the world. Where the import of plastics represents 12%, which is led by plastic containers, followed by tires and then ethylene polymers in primary forms—importing these plastics from El Salvador, Guatemala, and the United States, many of these products can be manufactured using AM [1].

The creation of AM-oriented companies is necessary for the country, as there is a large market for imported plastic products. These products are often imported because of the skidded workforce found in the country. The major aim of this research is to explore the quality of the AM parts, designed using CAD SolidWorks to measure its mechanical displacements.

2. ABS and PLA

2.1. ABS
The ABS and PLA are the more popular filaments in the country. ABS has high hardness and strength, heat resistance, and corrosion resistance; butadiene affects resistance and toughness [2]. A comparison
with aluminium properties determined that the plastic gear does not present significant deformations; therefore, it can be made of ABS plastic material [3].

CAD / CAM files are used to design parts for different applications; SolidWorks Simulation provides information about stress, displacement, security factor. These variables are useful for plastic injection design; AM has unique characteristics. When AM is used, products are formed without pressure but with similar density and strength properties? ABS plastic has low viscosity, getting non-porous products without internal stresses due to 3D printing [4].

2.2. PLA
The PLA belongs to the family of aliphatic polyester produced by chemical synthesis or carbohydrate fermentation. This polymer is getting demand in tissue engineering applications; it has a porous and three-dimensional structure [5]. In terms of impact strength, the micro-nano-cellulose can provide good toughness. The impact strength of the sample is excellent [6].

The average tensile between a PLA virgin sample and a recycled sample has showed that the tensile strength of recycled PLA is decreased by approximately 11%. The decrease is because of thermal degradation during the injection process [7]. PLA/EBAC blends’ mechanical properties were measured in bending film mode at a constant vibration frequency of 1 Hz, a temperature range of 30-140°C [8].

ABS and PLA have outstanding characteristics; both of them show strength resistance. Strength resistance is important to avoid mechanical displacement. A material with a big mechanical displacement can cause breaking off. Since ABS has better strength than PLA, it was used for the simulations and results.

3. Additive Manufacture 3D Printers Parameters
Desktop 3D printers are quite common; they have different parameters. These parameters determine the mass and time of the printing parts. The parameters that are discussed in this paper are the shell and the infill. All the other parameters Ultimaker Cura recommends for ABS and PLA printing. The quality parameter depends on the layer height, directly affecting the printer speed. The shell also affects the printer speed by configuring the layer width [9]. The infill determines the inside porosity of the part. This porosity may not be useful for chief strength in an industrial application different from plastic injection. It may grow 3D printed components in low volume, design components, and low strength applications [10]. The infill can also have different parameters such as grid, lines, triangles, and others.

There is a lot of application where 3D printers can be used; there are three important areas where it has fit in Honduras. The first one is education, where institutions like IHCETI, UNITEC, UNAH, and others train their students in this area. These institutions apply inverse engineering using metrology as scanners, as shown in figure 1. It must apply 3D scan position concerning the angle of incidence to reduce the said instrumental error in complex elements [11]. AM is also used to develop electronic boards. The platform, working areas, and layout dimensions are advantages of this method [12].

The second application is marketing; small companies design plastic souvenirs to represent different companies’ brands. And finally, for biomedical applications, especially hand prosthesis (figure 2) and plastic spare parts. The physical models manufactured are low-cost 3D printing can be used for medical application after improving the process to achieve dimensional accuracy [13].
4. Methods and simulations
ABS and PLA were introduced in section 2, to compare some of their characteristics. Then in section 3, print parameters as infill and shell were defined. This section describes the simulation methods used to describe the relationship between the print parameters and effort displacement. For the simulations, we used the infill grid, as shown in figure 3. This infill was changed depending on the scenario simulation. These parts are subjected to a force of 50 lbs. The finite element method is used to analyse the reliability of using AM for production. The FEM was configure using the adaptive solution H method. Testing did these simulations in SolidWorks by designing the internal infill that Ultimaker Cura makes to perform ABS. Then, a multiple line regression was used to analyse the relation between the parameters, giving a linear equation. Finally, and the simplex method to improve the equations models gives the shell wall and infill parameters to reduce mechanical displacement.
5. Results

5.1. Simulation results

SOLIDWORKS is powerful in modelling and assembly software [14]. Shell wall and infill were introduced in Ultimaker Cura to get time and mass. Then simulation was performed in using different SolidWorks infill and shell design. We draw the infill grid as shown in figure 3 b, if the infill increases the grid is increase, having more supports for the part. This design uses a triangle mesh, with the h method to improve iterations in the FEM. The parts were held from the bottom and a 50 lb force was applied in the top to calculate the maximum displacement. It is appreciated in table 1 that having a higher frame density (infill) reduces deformation. However, it increases the time, as seen in scenarios 1 and 2. Finally, scenario 3 and 4 shows the width of the wall surrounding the part is increased the time rises in a smaller proportion. However, the deformation is not reduced, as with a density of 20%. Scenario 3 is the most expensive in terms of time and mass.

Table 1. Scenarios displacement due to 50 lbs

| Scenario | Shell wall (mm) | Infill (%) | Time (min) | Mass (g) | displacement (mm) | displacement animation |
|----------|----------------|------------|------------|----------|-------------------|------------------------|
| 1        | 0.8            | 20%        | 217        | 38       | 0.0091            |                        |
| 2        | 0.8            | 10%        | 168        | 27       | 0.0184            |                        |
| 3        | 1.6            | 20%        | 252        | 41       | 0.0080            |                        |
| 4        | 1.6            | 10%        | 204        | 30       | 0.0148            |                        |
5.2. *Multiple line regression analysis*

The mechanical displacement of AM is because of the infill and the shell width. The multiple line regression (MLR) gives us how this parameter relationship can improve to reduce the displacement. The surface graph gives table 2 as the results of the multiple line regression. The multiple correlation coefficient is 0.989, which shows a strong relationship between the parameters. The coefficient R2 shows a 93.5% of reliability, and the typical error is small, just 0.00125.

| **Table 2. Regression statistics** |
|----------------------------------|
| **Description**                  |
| Multiple correlation coefficient | 0.98907262 |
| Coefficient R²                   | 0.97826465 |
| Coefficient R² adjusted          | 0.93479395 |
| Typical error                    | 0.00125    |

![Surface Graph](image)

**Figure 4** Surface graph

The displacement d is now determined by equations 1, 2, and 3. \(x_1\) is the shell wall, and \(x_2\) is the infill. Now the parameter with more effect in the mechanical displacement is the infill, so it compares to the displacement of a part design for plastic injection manufacturing. The displacement calculated in SolidWorks by FEM was 0.0022 mm; for a printer, the parameters infill 100%. The goal for this equation is 85% of 0.0022 mm. The simplex method was used to solve the equations model. As the result, the improve parameters are \(x_1 = 0.2\) and \(x_2 = 0.25\). The estimated time for printing increases to 300 min and 48 g.

\[
d = 0.0282 - 0.00294x_1 - 0.081x_2 \quad (1)
\]
\[
0.8 < x_1 < 2.4 \quad (2)
\]
\[
0.1 < x_2 < 0.25 \quad (3)
\]

6. Conclusion

We have calculated the additive manufacture parameters that improve the mechanical displacement for 3D printing parts. This calculation has been performed using FEM, MLR, and simplex as methods to perform 93.4% of reliability. Parts that use 0.2 as shell wall and 25% of grid infill can have acceptable mechanical performance to be used in biomedical applications. Using this parameter for 3D printing gives a better performance to mechanical applications in which the mechanical displacement is an issue.

7. References

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