Finite Element Analysis on Vacuum Chamber for Vacuum-Assisted FDM System

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ABSTRACT – Additive manufacturing (AM) is a rapidly expanding technology in several industrial sectors. This paper reviews the finite element analysis (FEA) for a designed vacuum chamber model to be applied in fused deposition modeling (FDM). The static analysis is executed using SolidWorks Simulation to identify potential failures when input pressure is applied. The analysis is vital to ensure the chamber is safe before it is manufactured. Value of von Mises stress, deflection, and safety factor was identified. However, the von Mises stress is higher than yield strength, and the safety factor value is less than one, representing the failure mode of the model.

1. INTRODUCTION

Additive manufacturing (AM) is one of the methods to construct visualization models for products as they are generated. Exact models are produced with the help of material extrusion to represent the conceptual design. AM is utilized to reduce time and cost, human engagement, and product development. However, according to Bhuvanesh Kumar and Sathiya [1], dimensional inaccuracy, poor surface quality, and reinforcement distribution are some challenges in additive manufacturing's final part. Due to the layered nature of the printing process, the staircase effect is the main reason for low surface quality, and consequently, this also affects the mechanical properties. As a result, it will increase post-processing.

However, post-processing will require time, high cost, and is hazardous for some processes [2]. The vacuum system is said to be helpful in terms of improving surface quality. According to Maidin [3], vacuum-assisted FDM is useful because it creates a low-pressure environment for the FDM process. The air density molecules were less than the one atmospheric state, making the convection of heat energy harder to take place. This eliminates the rapid cooling that can lead to stress and distortion. When the layer bonding is improved, the surface quality of the product will increase, hence improving the mechanical properties of FDM parts [4].

In this paper, the design modeling for a vacuum chamber was made and analyzed by finite element analysis (FEA). The FEA aims to identify the model's issues in buckling, stress, and deformation. These analyses are essential as it shows the potential failure of the modeling before the fabrication process takes place.

2. METHODOLOGY

2.1 *Material selection of vacuum chamber*

The material for the chamber needs to be transparent so it can be see-through. High strength and high stiffness material are required to withstand the vacuum pressure as the input pressure increases. However, of all the properties the material provides, it has to be lightweight. The material chosen to fabricate this chamber is Acrylic. The properties of acrylic are tabulated in Table 1.

Table 1 Properties of Acrylic

PROPERTIES	VALUE
Elastic Modulus	3000 Mpa
Poisson's Ratio	0.35 N/A
Shear Modulus	890 Mpa
Mass Density	1200 kg/m^3
Tensile Strength	73 Mpa
Yield Strength	45 Mpa
Thermal Expansion Coefficient	5.2e-05/K
Thermal Conductivity	0.21 W/(m.K)
Specific Heat	1500 (J/kg.K)

2.2 *Design of vacuum chamber*

The chamber is 500mm in length, 700mm in width, and 800mm in height, made from acrylic material of 20mm thickness. Figure 1 shows the isometric view of the vacuum chamber with its dimension. One of the walls has 2 holes to attach the pressure release valve, and vacuum pressure valve. The chamber was designed with 2 doors to access the printing bed and filament areas of the 3D printer. The doors will be attached with the door latch to ensure it is fitted to the frame as it closes, and hinges to ease the opening and closing. There will also be a rubber gasket seal at both doors to ensure the doors is fully tight to the frame.

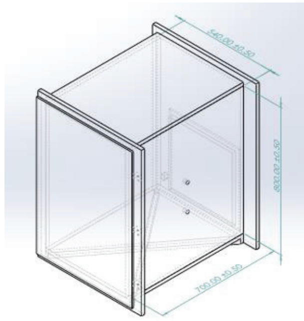

Figure 1 500x700x800mm Vacuum chamber design

3. RESULTS AND DISCUSSION

Simulation of static analysis was made towards the designed chamber model to identify its deformation and strength. The simulation was executed using SolidWorks software. Figure 2 shows the Von Mises stress with the maximum value of 5.195e2Pa, highlighted in the red circle. However, von Mises stress is higher than the Yield strength of 4.500e1Pa (Table 1). This can cause deflection towards the model. The value is high at the red circle because the body's frames are stacked together, causing compressive force exerted on the structure.

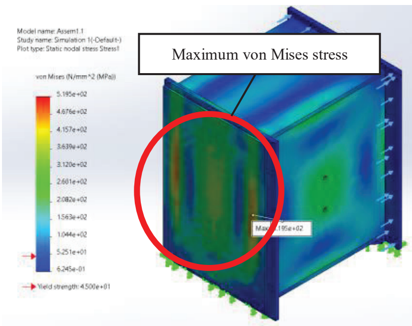

Figure 2 Von Mises stress result of the chamber

A displacement simulation was conducted to ensure the acceptable deflection of the chamber walls from their original place. Figure 3 shows the displacement simulation of the chamber. The maximum displacement is in the red region, where the wall experiences 32.38 mm deflections. Due to the less or no support in the middle area of the chamber, it is easy to deflect and hence, it is the weakest point of the chamber.

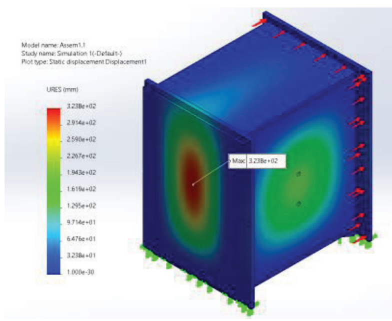

Figure 3 Displacement result of the chamber

The chamber's safety factor was determined by the formula shown in Equation (1). The calculation is essential to prevent the designed model from undergoing any failure mode. From the equation, the minimum safety factor is 0.086, indicating the model is in failure mode as the value is less than 1. As a countermeasure, an improvement in design needs to be developed.

$$\frac{Von\ Mises\ stress}{Yield\ strength} < 1 \qquad (1)$$

4. CONCLUSION

Finite element analysis (FEA) of the chamber was conducted using SolidWorks Simulation to ensure the chamber is in a safe, solid, and stiff condition before being used physically. FEA is crucial, mainly when the input pressure or force is applied. From the simulation, the result of von Mises stress shows a higher value than the yield strength value, and this was due to the compressive force between the wall. The maximum displacement value identified by the analysis was at the weakest point in the middle of the wall, with a value of 32.38mm. In addition, the model's safety factor of 0.086 indicates that the chamber fails to meet the safety factor. Thus, a new design of the chamber model with less potential deflection and stress will be required. The pressure input with the chamber's capacity will also need to be ideal.

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