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Topological Optimization of Simply Supported Beam for Fused Deposition Modelling Process

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Abstract—*Topology optimization is a strong approach for generating optimal designs. Topology optimization can be described as a distribution of a given amount of material in a specified design domain, which is subjected to certain loading and boundary conditions. But these designs cannot be fabricated using conventional manufacturing technique but with the advent of 3D printing techniques complexity of design is no more a problem. In this paper topology optimization and 3D printing technique is combine. A simply supported beam is considered for applying topology optimization. Topology optimization is performed using the solid isotropic material with penalization (SIMP) technique which is implemented through finite element analysis software ANSYS. The optimized beam is then fabricated using Fused Deposition Modelling printer.*

1. INTRODUCTION

In 3D Printing industry, it is always necessary to reduce printing time and so the amount of material to be fused which is needed without comprising the mechanical strength of the parts. Combining topology optimization method with 3D printing technique could provide a tool for obtaining mechanical parts in which the compromise between mechanical strength and material savings both is achieved. Topology optimization is a strong approach for generating optimal designs. Topology optimization can be described as a distribution of a given amount of material in a specified design domain, which is subjected to certain loading and boundary conditions. Topological optimization solves the problem by distributing a given amount of material in a design domain under a given constraints such as volume, such that the compliance of the structure minimize. Compliance is the property of a material of undergoing elastic deformation. It is equal to the reciprocal of stiffness. Hence by minimizing the compliance stiffness of the structure is maximized. Most often the topology optimized designs are complex in nature which makes it very difficult to manufacture using conventional methods of manufacturing. But with the emergence of 3D Printing techniques complexity of the design is no more a problem for manufacturing, any complex design can be fabricated using 3D printing techniques.

In this paper topology optimization is performed on simply supported beam and fabricated using fused deposition modelling 3D printing process.

2. MATERIAL AND METHOD

2.1 Topology Optimization Approach

The methodology adopted to perform topology optimization is by using the SIMP technique. The Solid Isotropic Material with Penalization method (SIMP) is the penalization scheme or the power law approach. The SIMP method introduces the concept of material density as a non-physical, independent variable. In design, parameterization is x_i taken as the design variable where,x_i = 1 at a point signifies a material region whilex_i = 0 represents void. The design region is meshed into a fixed grid of N finite elements. All elements carry densities that constitute the design variables. The objective is to find an optimal material distribution in the design domain that subjected to some given constraints, leading to minimizing a specified objective function. Each finite element (formed due to meshing) is given an additional property of pseudo-density, $x_i$where 0≤x_i ≥1, which alters the stiffness properties of the material.

$$x_i = \frac{\rho_i}{\rho_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,

ρ_i= Density of the ithelement

ρ_0= Density of the base material

x_i= Pseudo-density of the ith element

The Pseudo-density of each finite element serves as the design variables, and the intermediate values are penalized according to the following scheme:

$E_i = x_i^p E_0$ ……………………….……………(2) Here E_i is the material young modulus of the ith element while E_0 denotes the young modulus of the solid phase material. Through the power law relation, the stiffness of intermediate densities is penalized, so they are not favoured. As a result, the final design consists only of solid and void regions.

One common objective for topological optimization problems is the minimization of the compliance subject to a volume constraint. In this formulation, the goal is to distribute a given amount of material to obtain a structure with maximum stiffness by minimizing compliance. The compliance problem employing the SIMP material model can be written as:

$C(x_i) = f^T u = u^T K u = \sum_{i=1}^{n} x_i^p u_i^T K_i u_i$……..(3)

volume constrained compliance minimization problem can be described mathematically as:

Min $C(x_i) = u^T K u$

V= $\Sigma \; V^T x_i \le V^0$

$0 \le x_{min} \le x_i \le 1$……………………………....(4)Where u and K are the global displacement and stiffness matrix, respectively, V is the maximum volume constraint.

2.2 Fused Deposition Modelling

After performing topology optimization the structure is fabricated using the Fused Deposition Modelling (FDM) 3D printing process. In this process, thermoplastic material is fed from a large coil, through a moving heated extruder head. The molten material is forced out of the nozzle through the extruder and gets deposited on the heated bed layer by layer one over other thus forming the required 3D shape. In the present study Polylactic acid (PLA) material is used. Polylactic acid (PLA) is a thermoplastic aliphatic polyester and also a biodegradable polymer and it is developed from plant starch such as cassava, sugarcane and corn. PLA has interesting mechanical, thermal and optical properties and PLA is best suitable for a wide range of applications such as biomedical, food packaging and PLA based products are increasing rapidly in the market [5]. The mechanical properties of polylactic acid (PLA) are given in Table 1.

Table 1: Mechanical properties of PLA plastic

Material Property	Value
Tensile modulus	2300 MPa
Ultimate Tensile Strength	26.4 MPa
Yield Tensile Strength	35.9 MPa
Poisson's ratio	0.35

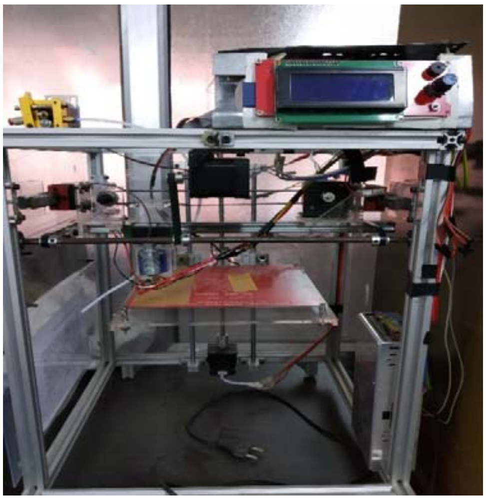

Figure 1: An image of FDM printer

Technical Specification of FDM Printer

Printing area - 200*200mm

Printing speed -150 mm/s

Nozzle diameter- 0.30 mm to 0.50 mm

Minimum layer thickness -100 micron

Extruder temperature limit- 180-250 deg C

Printing bed maximum temperature -50-80 deg C

Filament diameter -1.75 mm

The steps involved in the methodology are shown in the flowchart as illustrated in figure 2.

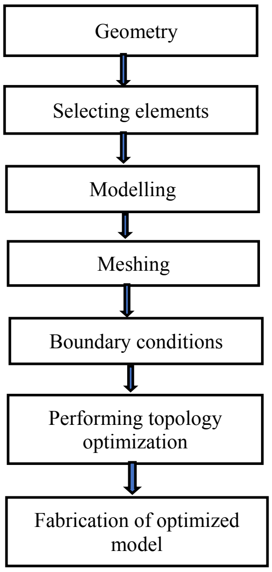

Figure 2: Flowchart of the steps involved in the process

3. SELECTED PROBLEM

The problem is formulated to combine Topology optimization and 3D Printing technique. A Simply supported beam with load at mid-point is considered for performing topology optimization. Objective function is compliance, design variable is pseudo density and state variables are the response of structures that is deflection and von misses stresss. Objected function is subjected to volume constraint and by minimize the compliance, stiffness of beam is maximized. The total volume of the beam is considered as the design area and volume constraints is kept as 50%.Figure. 2 illustrates the boundary conditions for the simply supported beam formulation and Table 2 shows the dimension values of the beam.

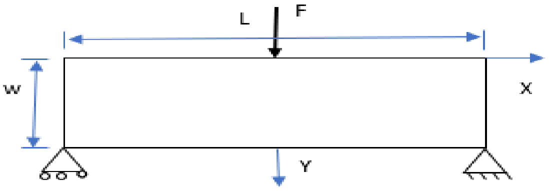

Figure.3. Boundary conditions for Simply Supported Beam Formulation

Table 2: Dimensions of the Simply Supported Beam

Parameters	L (mm)	w (mm)	t (mm)	F (N)
Value	110	20	5	20

4. RESULTS AND DISCUSSIONS

Finite element analysis is carried out on the simply supported beam to see the displacement and stress distribution in the part. The contour plots shown in Figure 4 and Figure 5shows the displacement and von misses stress distribution respectively for the load case in the beam.

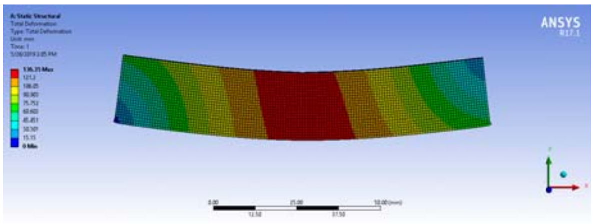

Figure 4: Displacement plot solution for simply supported beam

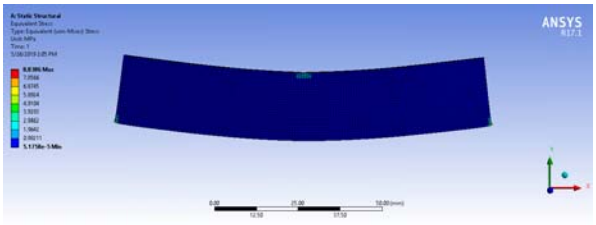

Figure 5: Von-misses stress distribution for simply supported beam

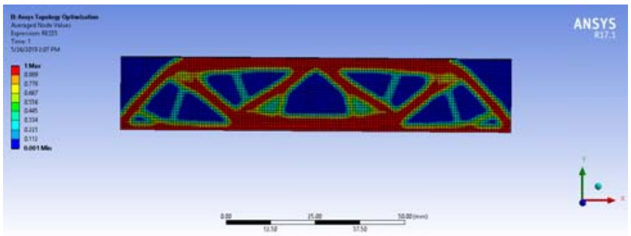

Figure 6: Element density distribution plot for simply supported beam

After performing Topology optimization the Element Density distribution is shown in Figure 6. In the density distribution plot Red color indicates elements with density equal to 1, these are the load bearing elements for the part.The large areas of the part that are shown in blue colorindicates elements with density equal to 0. It is very likely that these areas of the part need material removal as they have negligible effect on the performance of the part and can be neglected from optimized design. The other values of the plot between these two colors (other colors) represent the intermediate density. The intermediate density value is penalized to obtain a practical design using SIMP methodology as they cannot be realized practically into manufacturing.

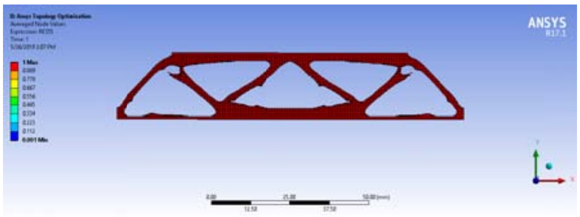

Figure 7: Topology optimized simply supported beam

Figure 8: Topology optimized simply supported beam fabricated using FDM printer

5. CONCLUSION

The Topology optimized designs are very complex and would not be possible to fabricate with the conventional manufacturing process. 3D printing technique such as fused deposition modelling proved to be useful in this aspect with its advantage of fabricating any complex shapes possible. This paper shows an example of the capability of fused deposition modelling 3D printing process by using Topology optimization methods such as Solid Isotropic material with Penalization.

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