Topology Optimization for Additive Manufacturing as an Enabler for T shaped Joint

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Abstract - *The additive manufacturing is gradually becoming popular worldwide as corona virus pandemic stalled various manufacturing units. The demand for design and 3D printing of components at home increased drastically. The current research is intended to minimize the mass of T shaped joint by using lattice structure and topological optimization tool. The CAD model of T shaped joint is developed in Creo design software and fatigue life assessment is conducted using ANSYS FEA software. The stresses, deformation, safety factor of generic and optimized design is evaluated on the basis of these mentioned parameters. The findings have shown that topological optimization method is best as compared to lattice structure method for weight minimization.*

Key Words: *ANSYS, Additive Manufacturing, Topological Optimization*

1.INTRODUCTION

Additive Manufacturing (AM) refers to a group of methods and technologies that create arbitrarily complex three-dimensional structures through the sequential layer wise addition of materials in selected regions corresponding to digital slices of a computer-generated model. AM (also known as 3D printing) has potential to revolutionize the manufacturing industry and convert digital data into prototype (physical component). AM is becoming quite popular in various industries like electronics, automotive, jewelry design, dentistry. As compared to conventional manufacturing process the additive manufacturing offers higher design flexibility and customization. As the material is added layer by layer, the need of mould is replaced which was expensive and time consuming also. The additive manufacturing has higher dimensional accuracy and takes lesser time and thereby is best technique for rapid prototyping.

1.1 OBJECTIVES

The current research investigates the application of lattice structures in mass minimization of T shaped joint. The CAD modelling of joint is done in Creo design software. The fatigue life assessment is conducted on generic and optimized design using ANSYS FEA to determine the effect of lattice structures on fatigue life parameters. The comparison of lattice structure design is then made with generic design and topologically optimized design.

2.REVIEW OF LITERATURE

Gebisa, A et al. [1] has conducted topological optimization of jet engine bracket using additive manufacturing. The topological optimization is very potent method for mass minimization which reduces manufacturing time, cost and material required. **Gschweitl, M et al. [2]** has worked on mass minimization of spaceflight components using topological optimization tools. The component worked is engine support structure of lunar launch vehicle. The process highlighted the feasibility of additive manufacturing tool for designing and fabrication of flight hardware considering the above situation monitoring.

Panesar A et al. [3] has discussed about DFAM (Design for Additive Manufacturing) and compared the procedures and standards against DFM (design for manufacturing). The application of DFAM in academia is also contemplated. **Kirkman-Brown et al. [4]** has also discussed about integration of CAD and CAM with additive manufacturing. The topological optimization tool can be very beneficial in future research works and to process a CAM program that allows the temporal design of a fabrication parameter which gives a new method of the design of additive manufacturing materials. **Nirish and Rajendra et al. [5]** has evaluated the various techniques and advantages of additive manufacturing technique against subtractive manufacturing. The waste minimization, design alteration, design flexibility and topological optimization are some of the key advantages. The researcher also discussed the present and future topology optimization method for additive manufacturing. The laser beam is used in DMLS/SLM and the electron beam is used in EBM. The consumption of energy is more in EBM so that titanium alloy is best for fabrication EBM. The researcher shows the different kinds of Metal 3D printing methods and in the space industry, they need lightweight materials. The methods will fabricate the new designs, processes, and materials according to their requirements. **Dapogny et al. [6]** explained and analyzed the properties of materials which are manufactured by additive manufacturing methods, and also investigated the given facilities. The researcher emphasizing the material extrusion methods which are required for explained the properties of materials which are depending on the trajectory followed using the machine pieces of equipment at the time of assembly. The researchers took benefit of AM methods for constructing characteristics. Lastly, several experiments are doing in 2D to explain the important points.

3. METHODOLOGY

The imported CAD model is checked for any geometric errors like surface patches, edge errors and other facet errors etc. The model is then repaired and freed from any geometric errors. The dimensions of T shape joint is taken from literature [7].

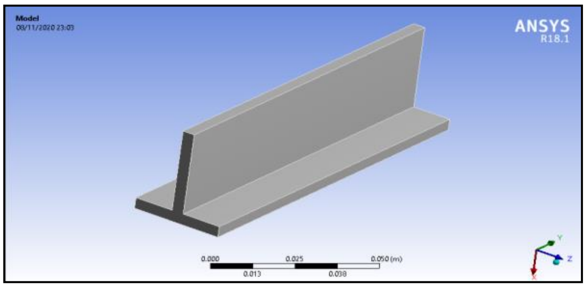

Figure 1: Imported CAD model of T shape joint in ANSYS design modeler

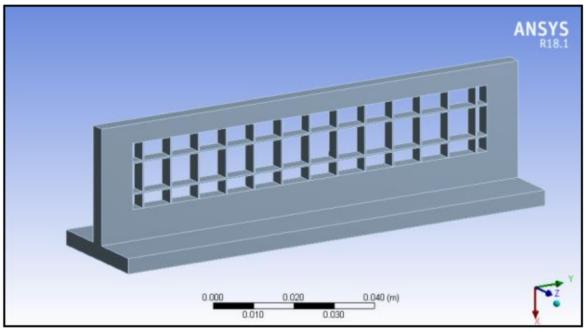

Figure 2: Imported CAD model of T shape joint with 50% scale density

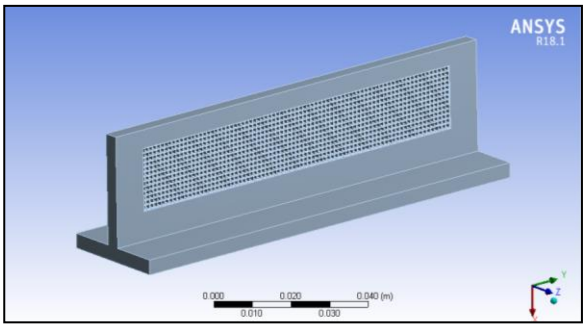

Figure 3: Imported CAD model of T shape joint with 40% scale density

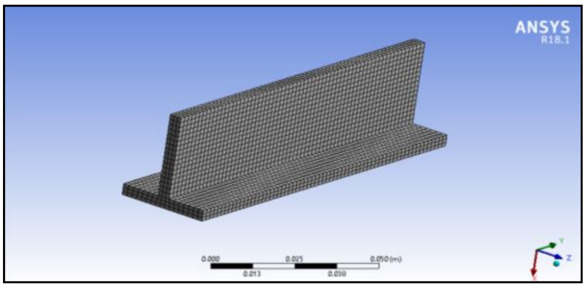

Figure 4: Meshed model of T shape joint

The T shape joint (without any lattice) is meshed using brick shape. The brick shape meshing is possible due to topological consistency and absence of any complex shapes. The number of elements. generated is 6630 and number of nodes generated is 34246.

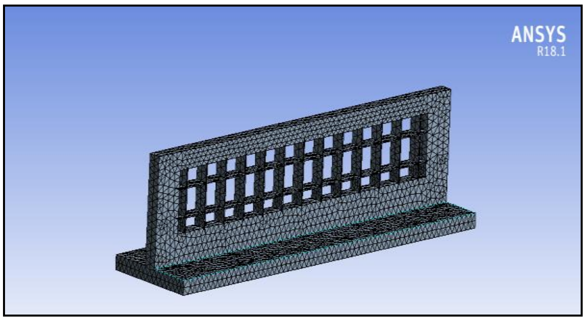

Figure 5: Meshed model of T shape joint with 50% scale density

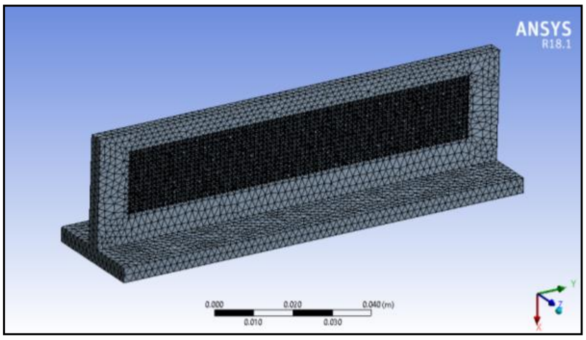

Figure 6: Meshed model of T shape joint with 40% scale density

The T shape joint (having lattice structure) is meshed using tetrahedral elements as shown in figure 4.13 and figure 4.14. The mesh density is higher at lattice structure and is lower on other regions.

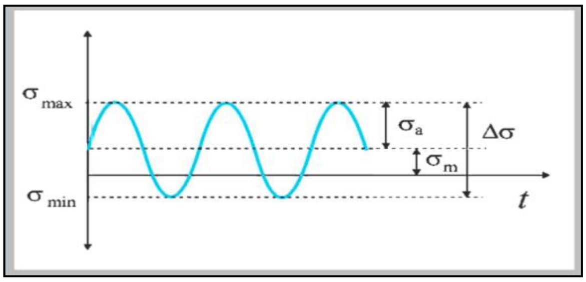

Figure 7: Fully reversed load cycle

For the fatigue analysis, the load applied is of constant amplitude with fully reversed loading as shown in figure 7 above. The stress life approach is used for fatigue life determination.

Stress range: $\Delta\sigma = \sigma_{max} - \sigma_{min}$ (1)

Stress amplitude: $\sigma_a = \frac{1}{2}(\sigma_{max} - \sigma_{min})$ (2)

Mean stress: $\sigma_a = \frac{1}{2}(\sigma_{max} + \sigma_{min})$ (3)

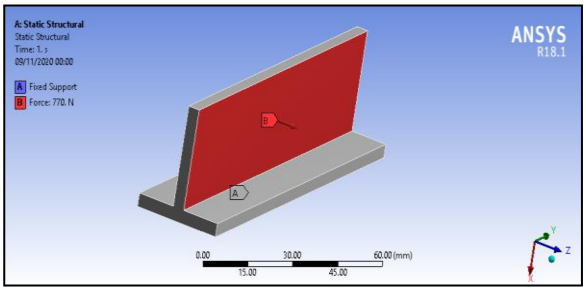

Figure 8: Loads and boundary condition on T shaped joint

The bottom face of T shaped joint is applied with fixed support and side surface is applied with force of 770N as shown by red colored surface. The force is later converted in to cyclic load for fatigue life analysis. The applied load is taken from literature.

4. RESULTS AND DISCUSSION

The following section discusses the results obtained using T shaped joint with generic design.

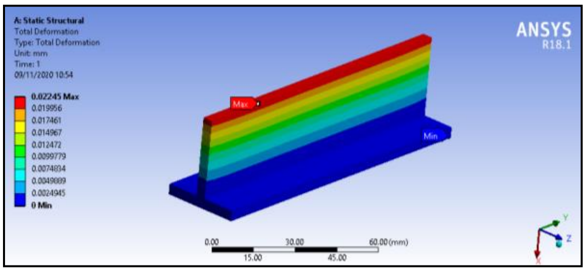

Figure 9: Deformation plot of generic design

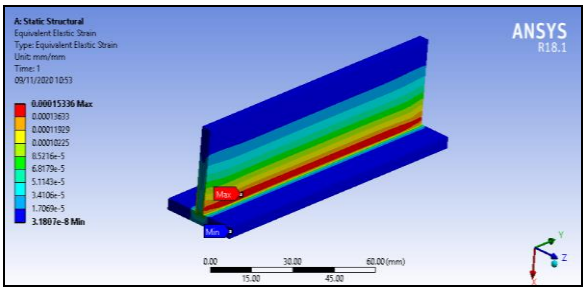

Figure 10: Equivalent elastic strain plot of generic design

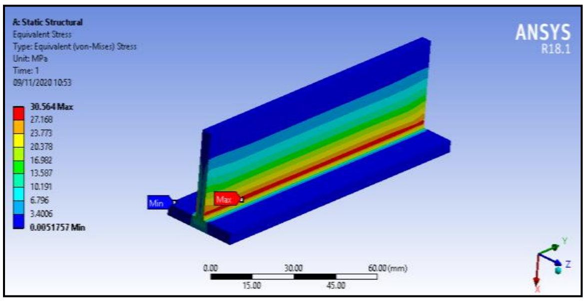

Figure 11: Equivalent stress plot of generic design

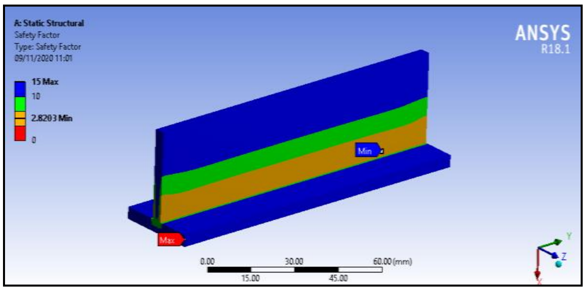

Figure 12: Safety factor plot of generic design

The deformation, equivalent elastic strain, equivalent stress and safety factor are evaluated for generic design of T shape. The maximum deformation of magnitude .02mm is observed on topmost end of T shape joint as shown in figure 9 above. The maximum equivalent strain and equivalent stress is observed on the intersection region of vertical and horizontal member as shown in figure 10 and figure 11 respectively. The safety factor obtained generic design for T shaped joint is 2.82. The minimum safety factor is observed on regions of lower stresses.

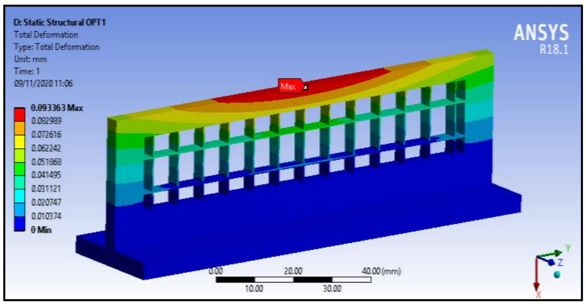

Figure 13: Deformation plot with lattice structure at 50% scale

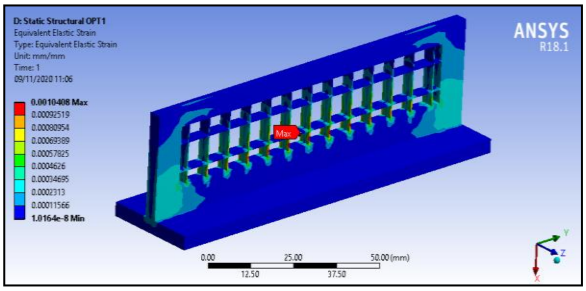

Figure 14: Equivalent elastic strain plot with lattice structure at 50% scale

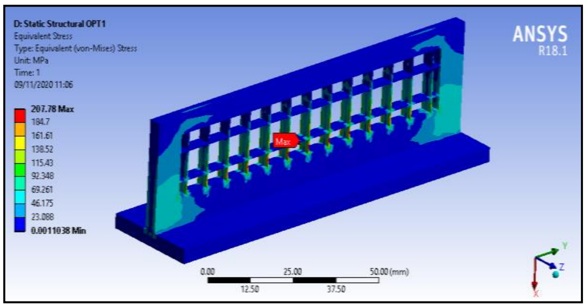

Figure 15: Equivalent stress plot with lattice structure at 50% scale

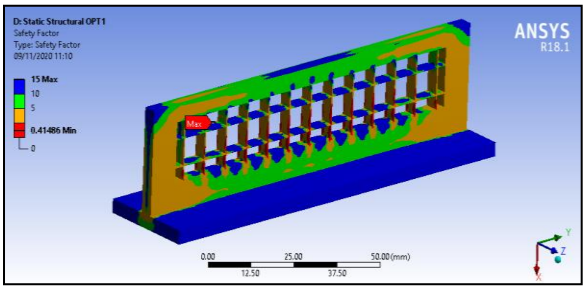

Figure 16: Safety factor plot with lattice structure at 50% scale

The deformation plot obtained for T shape joint with lattice structure of 50% scale density is shown in figure 13 above. The plot shows an increase in magnitude as compared to generic design of T shape. The deformation is non uniform and maximum deformation at located at top central portion of vertical member. The max equivalent stress, equivalent elastic strain is located on same location i.e., 7th grid of lattice. The safety factor of lattice structure design significantly decreased to .41 as against 2.8 for generic design. T shape joint is optimized using topological optimization tool as shown in figure 17 below. The mass retention percentage set for optimization is 70.

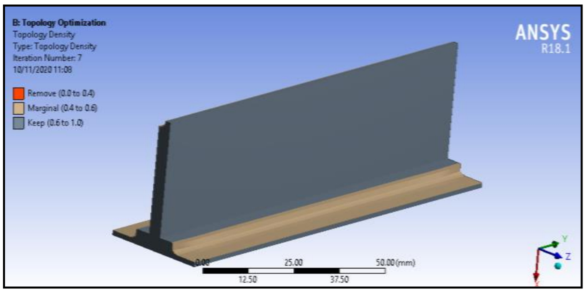

Figure 17: Topological optimization

The results obtained from topological optimization is shown in figure 17 above. The plot shows higher mass reduction for base (region with light brown color) while retaining higher thickness at the joint location. The topologically optimized geometry is analyzed under same loading conditions to determine stresses and deformation.

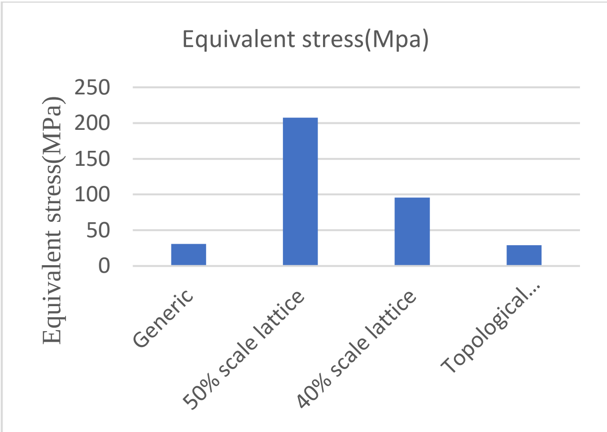

Figure 18: Equivalent stress comparison plot

The equivalent stress comparison plot shows that maximum equivalent stress is observed with 50% scale lattice structure followed by 40% scale lattice and minimum equivalent stress is observed with topological optimization tool.

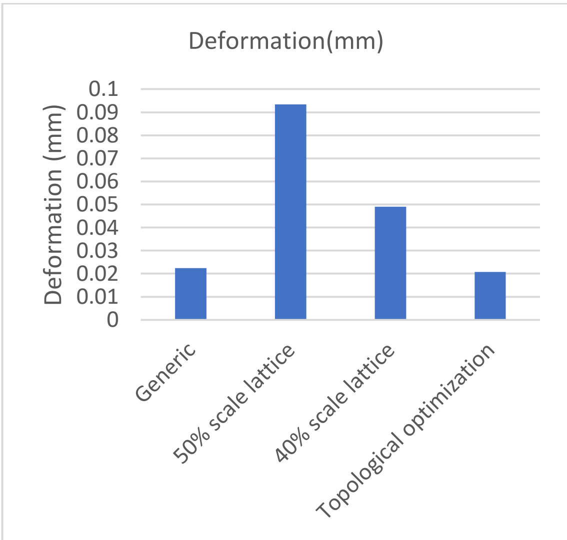

Figure 19: Deformation comparison plot

The deformation comparison plot shows that maximum deformation is observed with 50% scale lattice structure followed by 40% scale lattice and minimum deformation is observed with topological optimization tool.

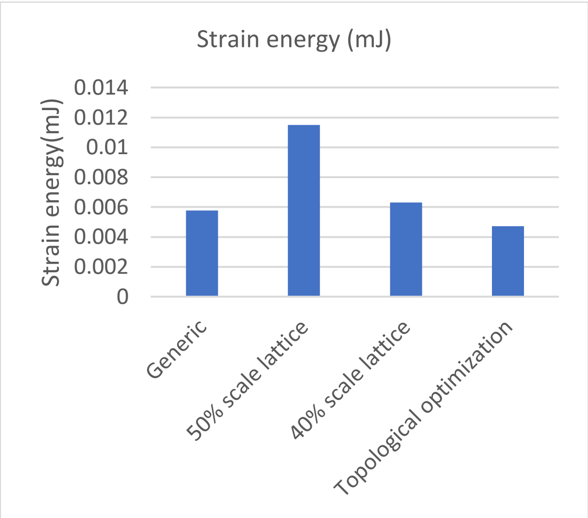

Figure 20: Strain energy comparison plot

The strain energy comparison plot shows that maximum strain energy is absorbed with 50% scale lattice structure followed by 40% scale lattice and minimum strain energy is absorbed with topological optimization tool.

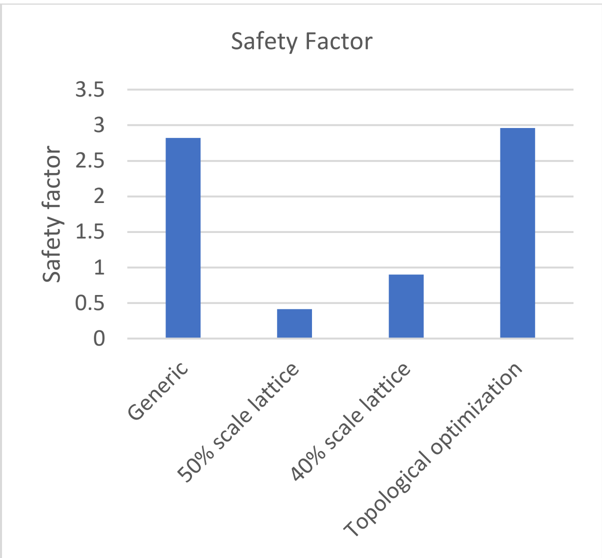

Figure 21: Safety factor comparison plot

The safety factor comparison plot shows that maximum safety factor is observed using topological optimization tool and minimum safety factor is observed using 50% lattice structure.

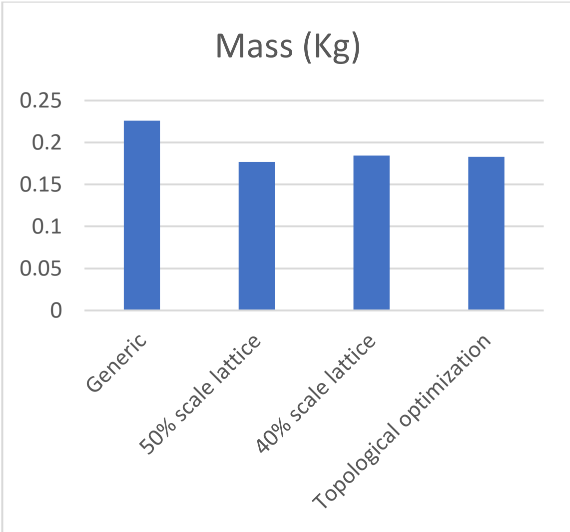

Figure 22: Mass comparison plot

The mass comparison plot shows that 50% scale lattice structure model has minimum mass as compared to 40% scale lattice structure.

5. CONCLUSION

Although significant mass reduction is achievable using lattice structure but the strength and fatigue life of component is affected. The location of maximum stress also changes with incorporation of lattice structure. Therefore, weight minimization of any component should be carefully done so as to have minimum effect on strength and safety factor. The topological optimization technique can be used to identify possible regions of mass reduction.

1. For T shape joint, the mass T shape joint with lattice design is .17684Kg and in generic design is .22608Kg mm which is nearly 21.7% less.
2. For T shape joint, the safety factor with lattice design (50% scale) is .414 and in generic design is 2.8 which is nearly 85% less.
3. For T shape joint, the safety factor with lattice design (40% scale) is .9 and in generic design is 2.8 which is nearly 68% less.

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