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Analysis on Lighweighting Approach Topology Optimization Design for Additive Manufacturing (DfAM)

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Abstract: In order to produce a lightweight and high-performance configuration that are difficult to achieve with traditional concepts, topology optimization was developed as an advanced structural design technique. Earlier topology optimization developments considered traditional manufacturing methods with limitations in the processing of complex geometries. However, with the emergence of additive manufacturing technologies, the technology that builds a part layer on a layer directly from the part's three-dimensional (3D) model data, it is no longer a problem to produce complex shape geometry in order to reduce the weight. The analysis from the study enable to determine the analysis on lighweighting approach topology optimization design for Additive Manufacturing (DfAM) while maintaining its overall performance. The mechanical properties can be determined by using Altair Inspire 2019 where the software can design the model and use Finite Element Method to solve the analysis. The weight that being reduce from the original model which is 60 percent above. There are three types of topology optimization that being applied which is Topology, Latticing and Combination of Topology and Lattice. It is found that by reduce its weight and volume by topology which is 80% reduction with safety factor of 1.2 meanwhile latticing 88.79% reduction with safety factor of 2 and combination of topology and lattice 92.39% mass reduction with safety factor of 1.7 which show all model still can fulfil its mechanical properties and maintain its overall performance.

Keywords: Topology Optimization, Lattice, Lighweighting, Additive Manufacturing

1. Introduction

Additive manufacturing uses computer-aided - design (CAD) data tools or 3D object scanners to direct hardware into specific geometric forms to deposit material, layer upon layer. Additive manufacturing (AM), also referred to as 3D printing has evolved greatly over the last three decades, emerging from the mere application in prototyping, it has now indisputably established its position as

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a viable fabrication alternative for end-use parts. This applies to a wide range of industries including medical engineering [1], automotive [2], aerospace [3], and consumer products. Increased emphasis on sustainable transportation and the pursuit for greater efficiency i.e., lower energy consumption, has driven the research into identifying lightweight and robust designs.

Topology optimization (TO) and latticing have emerged as the two major light-weighting strategies, best exploiting the design freedoms offered by AM. A rigorous approach, improving the specific stiffness, whereas the latter can be considered as a design approach for weight-reduction in parts that usually have a high safety factor similar to holes introduced in structural members such as ribs in an aircraft), which has been widely adopted as a common design practice in today's AM-specific software.

The lattice structure is an attractive material for many design applications because of its excellent properties including light-weighting, high specific strength, and stiffness, dissipate heat, and so on [4]. However, lattice structure as another type of cellular material is different from foams and honeycombs, more like bone structure and the difference of structure mainly lies in unit cell topology and scale, and properties [4]. Engineers may use overlapping, interlocking shapes that are partly hollow instead of 3D printing a solid block of plastic or metal. As these lattices are constructed right, the mechanical properties of a component can be significantly strengthened, making it lighter and stronger.

In Additive Manufacturing cost is important in produce a product. The most usual Additive Manufacturing process takes a lot of cost in making a product due to the fully solid structure which uses a large of material and causes a lot of weight. The process of making a product also takes a lot of time to fully design the product. There is a certain complicated geometry and flexible types in the conventional additive manufacturing process that is impossible and costs a lot of money to manufacture. This study will focus on simulating topology optimization and latticing of the lightweight approaches to the product to minimize the volume and material used to simplify the geometry and reduce the weight of the part while retaining its overall efficiency.

This study is a focus on the Analysis of Lightweighting Approach Topology Optimization Design for Additive Manufacturing (DfAM). The implementation of this study was developed using S.M.A.R.T. SMART is an acronym for Specific, Measurable, Achievable, Realistic, and Timely philosophy. There are 3 objectives that need to be achieved in this study which is

i. To simulate the lightweight approaches topology optimization and latticing.
ii. To minimize the total weight with a distribution of materials that maximize the stiffness.
iii. To optimize outer geometry and corresponding stresses distribution and realize weight savings 3d printed parts while ensuring the same structural performance as the original parts.

2. Materials and Methods

This section will discuss the methodology used to achieve the objective of the Analysis on Lighweighting Approach Topology Optimization Design for Additive Manufacturing (DfAM). The approach of this analysis begins with a flowchart where the flowchart is used for the correct project flow. The development of the design system and development process was included in the Methodology. For Quantitative method is a theoretical calculation and collection of the data from FEA analysis for each design that has been topology optimized. In design development process include the list of process for the procedure to topology optimized a product and list of models that will be topology optimized.

The second component of the methodology is the analysis of topology-optimized model performance results. The performance of the design was measured by its parameters using Altair Inspire.

2.1 Materials

The model is Door Support which material will set as Material Aluminium (2024-T3/T6/T8). The loading condition that is set is a static linear load of 1000N in the Y-axis and 2000N in the Z-axis that applied. The mass of the model is 1.477kg and volume of 533200mm^3 with Tensile strength of 2.728x10^8 Pa and safety factor 4.6 the weight that is needed to reduce is more than 60%.

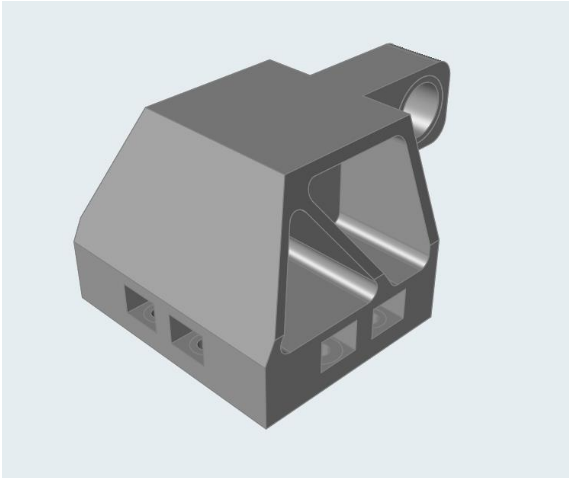

Figure 1: Model Door Support

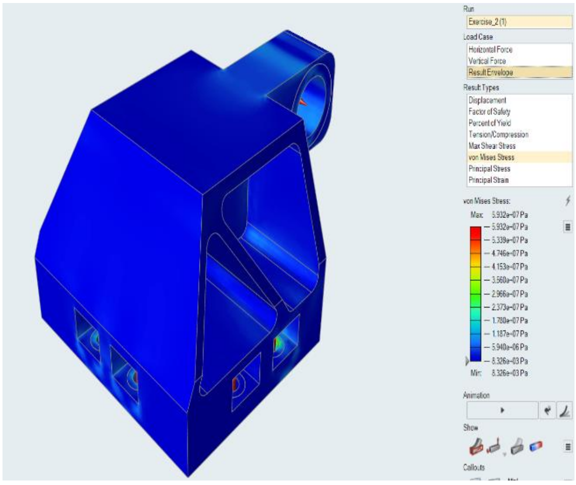

Figure 2: FEA of Model

2.2 Methods

The method that is used in this research to collect data is Quantitative Method. Objective measurements and statistical, mathematical, or numerical interpretation of data obtained by surveys, questionnaires, and surveys or by analyzing pre-existing statistical data using computational techniques are emphasized through the quantitative method. To get the data, I use the FEA instrument to get the parameter to determine its overall performance which is the data of its mechanical properties using Altair Inspire. Figure 2 shows the flowchart of the process of this study.

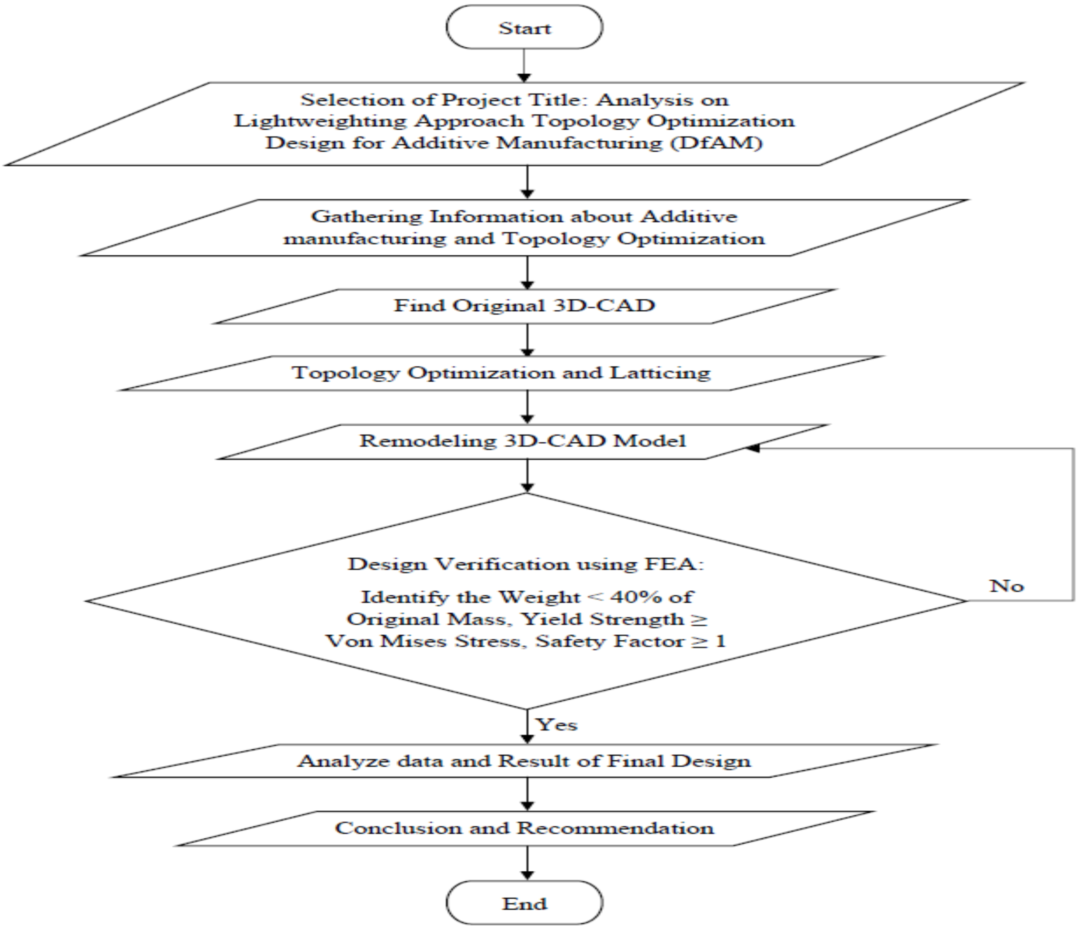

Figure 3: Flowchart

3. Results and Discussion

The result is a tentative that has been achieved for chapter 4 Results and Discussion. Calculation and measurement of the mechanical properties of the model after topology optimization are the developments that have been made. Every mechanical property was included in the assessment. From the test outcome, the final design verification may be carried out. The first step that needs to be done is to evaluate the properties data that being collect from the FEA of the topology model.

3.1 Results

The result is based on the Altair Inspire 2019 design and simulation, there have 2 designs that applying topology optimization and latticing which both designs fulfill the requirement while reducing the mass consumption which more than 80 percent. The figure below shows the design and FEA results for both designs.

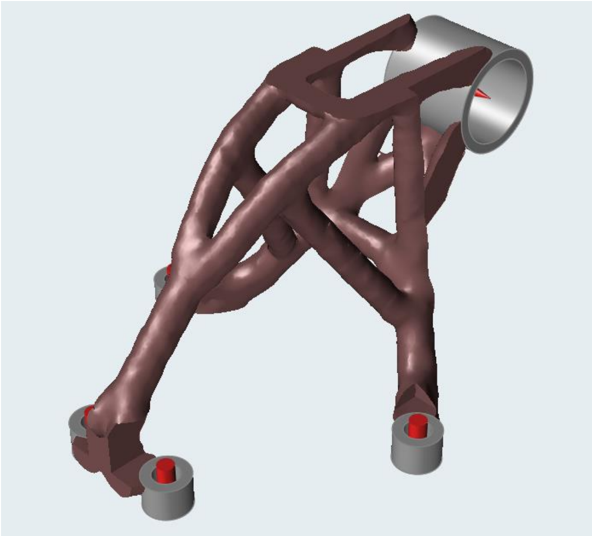

Figure 4: Topology Model

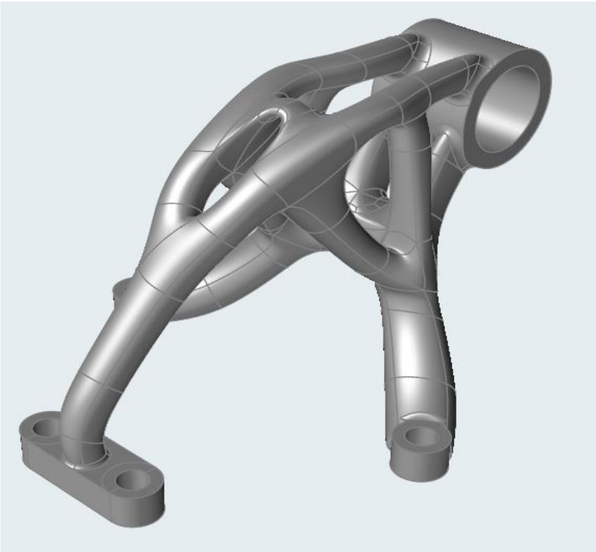

Figure 5: Finalize Design Topology Model

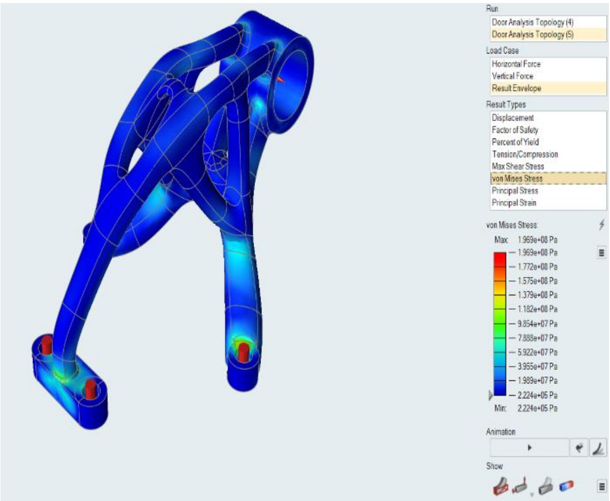

Figure 6: FEA of Topology Final Design

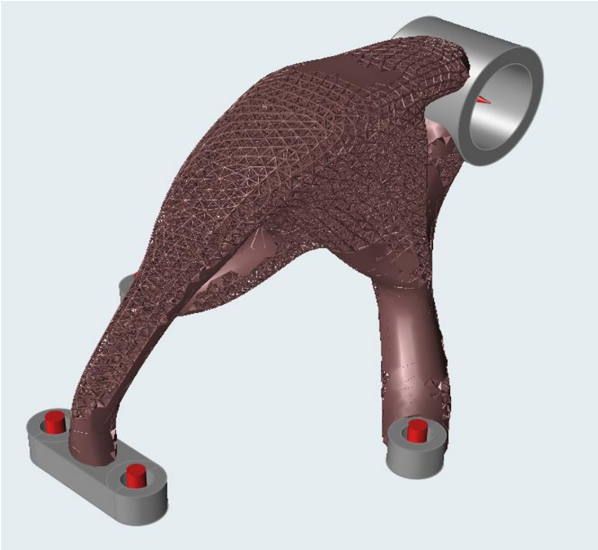

Figure 7: Lattice Design Model

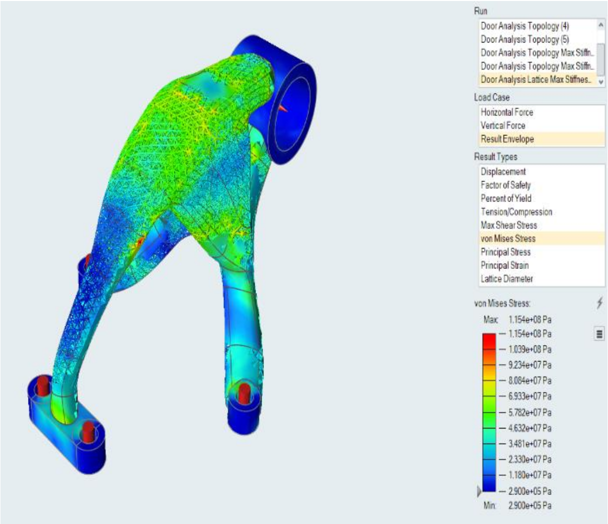

Figure 8: FEA of Lattice Design

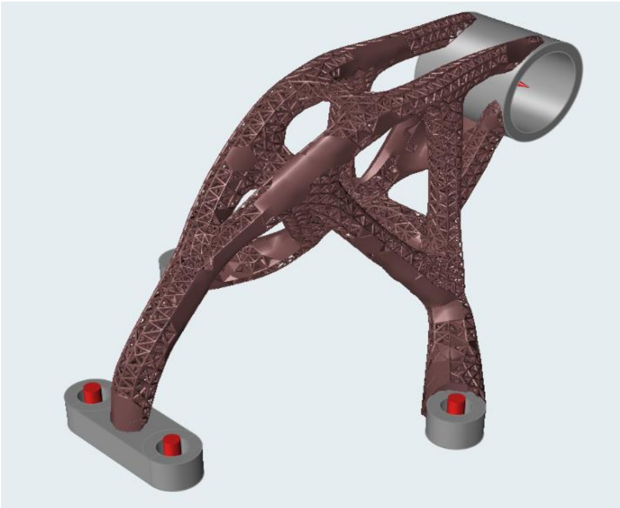

Figure 9: Combination Topology and Lattice Model

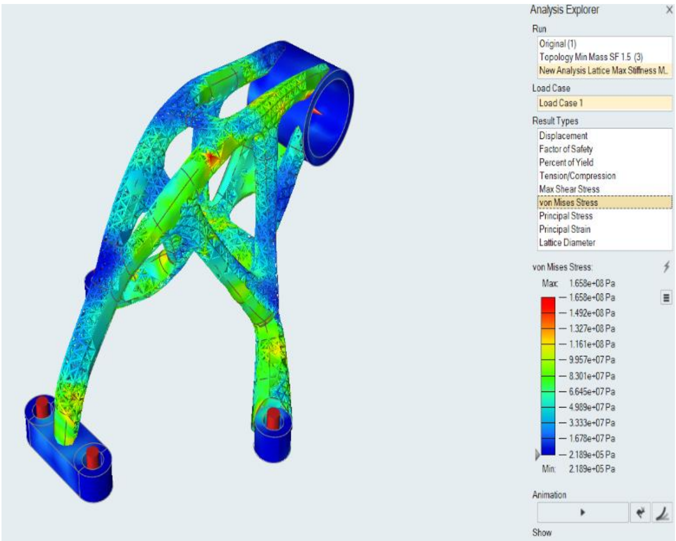

Figure 10: FEA of combination Topology and Lattice Model

After collecting the Properties data from FEA. The next process is design calculation and evaluation which determines is the topology optimization can lightweight the model while maintaining its overall performance. From the FEA the data are being collected and list in table 1.

Table 1: Mechanical Properties

Model	Weight(g)	Volume (mm^3)	Yield Strength ($N.m^{-2}$)	Safety Factor
Original Model	1477	533200	$2.728x10^8$	4.6
Topology Model	263.5	95122	$1.969x10^8$	1.2
Latice Model	135.36	48341	$2.308x10^8$	2
Combination Topology and Lattice Model	112.3	40550	$1.658x10^8$	1.7

3.2 Discussions

From Table 1 the result is as predicted the weight of the model after topology and lattice decrease more than 60 percent from its original weight which fulfills the objective of this study. In the weighted model after topology optimization which 263.5g the mass reduction was 82 percent with a volume of 35122mm^3 meanwhile for latticing the loss of weight was higher than topology which is 180.36g and mass reduction 88.79 percent because of Latticing with 48341mm^3. However, with combination of Topology and Latticing the model manage to reduce 92.39 percent mass reduction with mass of 112.3g and volume 40550mm^3.

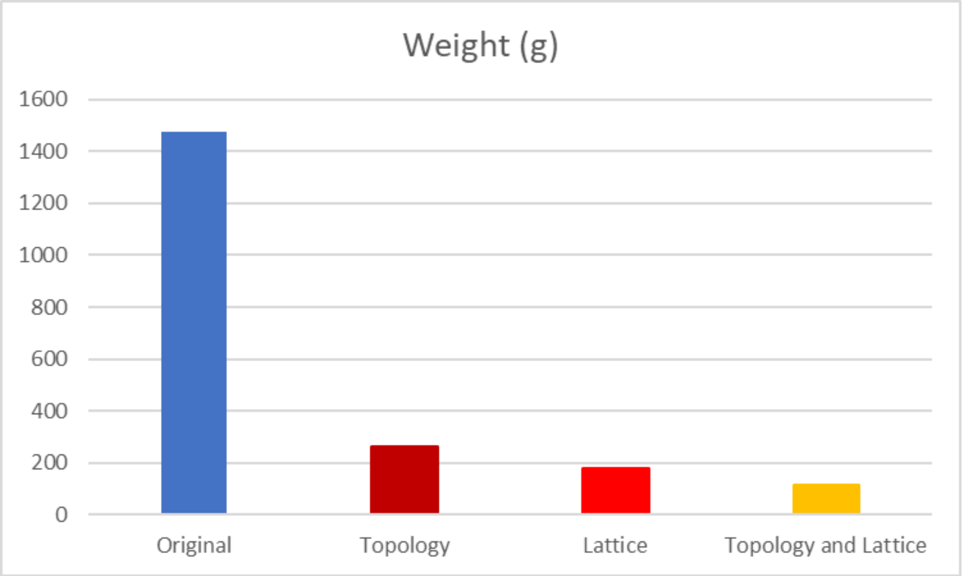

Figure 11: Graph Weight of Model

From the data shown in Table 1, the result shows the Finite Element Analysis of the model after topology and latticing. The equivalent (Von-Mises) stress showed the model material behavior when force is applied whether the material will fracture or not. The mechanical properties of the model can be seen in Table 4.1.

From the FEA result showed in Figure 2, the maximum equivalent stress of the model is 5.932×10^{7} Pa meanwhile its maximum allowable stress is 2.728×10^{8} Pa which makes the safety factor of the model is 4.6.

For the FEA of the topology model based on Figure 6, the maximum equivalent stress is 1.640×10^{8} Pa due to the less material that is applied and its maximum allowable stress is 1.969×10^{8} Pa which makes the safety factor of the topology model is 1.2 and fulfills its performance without fatigue.

From Figure 8, the Lattice model has maximum equivalent stress of 1.154×10^{8} Pa with the lattice structure that makes the model mass reduction for 90 percent have maximum allowable stress of 2.308×10^{8} Pa. Surprisingly with the lower than topology weight and volume it capable with the safety factor of 2 which show that lattice structure capable of reducing the most weight while maintaining its overall performance because of the distribution of load from the lattice structure.

For Figure 10, the combination of topology and lattice model has the lowest weight with maximum equivalent stress of 9.752×10^{7} Pa with lattice structure and topology design that makes the model with highest mass reduction that have maximum allowable stress of 1.658×10^{8}Pa. As expected with combination of topology and lattice structure makes the model with the lowest weight and volume due to distribution of load from the lattice structure with topology design with safety factor of 1.7.

4. Conclusion

By By the end of the result, the objective of the study is achieved. The design of the model is created using Altair Inspire and being tested the FEA also using Altair Inspire. The design that being using the Topology and Lattice approach which all designs reduce more than 80 percent of mass and volume consumption. The material that been applied was Aluminium and there have set two type condition of force Vertical and Lateral force which is 2000N and 1000N.

The result shows all designs manage to reduce their weight and volume by more than 80 percent while maintaining their overall performance. The mass of the Topology model is 263.5g with volume 95122mm^3, Lattice model is 180.36g with volume 48341mm^3 and combination of Topology and Lattice is 112.3g with volume of 40550mm^3. To determine the required performance of the all models, Finite Element Analysis in Altair Inspire has been used to determine its overall performance based on Von-mises Stress, Yield Strength, and Safety factor. The maximum Von-mises stress for the Topology model is 1.640x10^8 Pa and 1.969x10^8 Pa yield strength which concludes the safety factor is 1.2 which makes the design is verified to maintain its overall performance.

For the Lattice model, the maximum Von-mises stress value is 9.737x10^7 Pa and 2.308x10^8 Pa yield strength which concludes the safety factor is 2 this shows that the design fulfills its overall performance while its weight is 12 percent from the original mass.

Lastly, for combination of topology and lattice model, the Von-mises stress value is 9.572x10^{7}Pa and yield strength of 1.658x10^{8}Pa which make the safety factor is 1.7 with highest mass reduction.

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