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Topology Optimization of Laptop Stand from Material Waste using Finite Element Analysis

I Made Gatot Karohika [1,*], Gregorius Renaldi Siswoyo[1], I Made Widiyarta[1], Dewa Ngakan Ketut Putra Negara[1]

[1] Mechanical Engineering Department, Udayana University, Bukit Jimbaran, Bali 80361, Indonesia

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ABSTRACT

In this research, the laptop stand made from waste drum brake shoe material will undergo variations in mass reduction through the stages of static structural simulation and topology optimization using Ansys Workbench to achieve mass reduction, total deformation, equivalent stress, and safety factor for each mass reduction variation. The laptop stand geometry will be subjected to a load of 44 N and supported as needed. Based on the simulation, the initial design of the laptop stand produces an equivalent stress of 2.07 MPa, total deformation of 0.08 mm, and a safety factor of 12.46. For the 50% mass reduction variation, the data obtained was: equivalent stress 2.78 MPa, total deformation 0.11 mm, safety factor 13.858. For the 75% mass reduction variation, the data obtained was: equivalent stress 3.06 MPa, total deformation 0.26 mm, and safety factor 8.42. For the 80% mass reduction variation, the data obtained was: equivalent stress 3.88 MPa, total deformation 0.40 mm, and safety factor 6.63. For the 85% mass reduction variation, the data obtained was: equivalent stress 14.14 MPa, total deformation 0.89 mm, safety factor 1.82.

1. Introduction

Human life cannot be separated from waste or rubbish resulting from human activities. The amount of waste produced also increases in line with the rate of population growth. Especially in Indonesia, it is recorded that in 2022, Indonesian people will produce a total amount of waste (garbage piles) of 35,833,450.64 tons of waste. As much as 36.07% of the total amount of waste is unmanaged. Waste composition is based on the type of waste. The following is a graph of Indonesian society's waste composition 2022 [1].

* *Corresponding author.*
E-mail address: gatot.karohika@unud.ac.id

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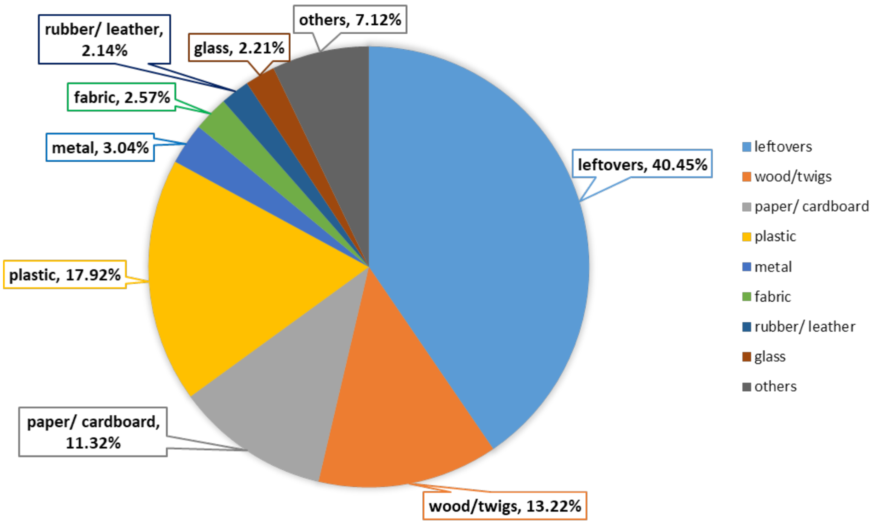


Fig. 1. Graph of Waste Composition Based on Waste Type [1]

Unmanaged waste will cause environmental pollution, both in terms of water, air, and land. Soil pollution occurs as a result of waste that is difficult to decompose and takes a long time to decompose. One of the wastes that is difficult to decompose is metal waste. Even though metal waste is recorded to contribute as much as 3.04% of the total amount of waste available, metal waste is classified as difficult for the soil to decompose. One example of metal waste is brake lining (drum brake shoe). For this reason, the concept of waste management, namely 3R (Reduce, Reuse, Recycle) has begun to be implemented to reduce the volume of waste that will end up in the TPA (Final Processing Place). The concept of waste management to reduce metal waste in this research is recycling, that is, managing waste by reprocessing waste into another form that has a function, in this case, brake lining waste.

Several researchers have researched how to reuse metal waste, especially brake linings. Such as using the aluminum content in used brake shoes to make brake handles [2]. Furthermore, the utilization of aluminum alloy waste as a footrest support for motorcycles [3].

Along with the rapid development of science and technology, the human need for equipment that supports electronic goods is also increasing. One of them is the activity of using a laptop. When people use a laptop, most people will be hunched over the laptop. Without them realizing that when they work on a laptop, their sitting posture is not perfect. Changes in body posture over a long duration can have an impact on pain complications in certain parts of a person[4]. Based on this, to help maintain a good sitting position while working, a supporting tool is needed, namely a laptop stand.

Laptop stands on the market such as in e-commerce are generally made of pure wood, plastic, and pure metal. Therefore, to reduce pure materials, replacement materials are needed that have the same good quality. In this research, replacement material was used in the form of drum brake shoe waste.

The use of finite element-based software is commonly used in the design process to analyze [5-15] and optimize designs [16,17]. Topology optimization (TO) is one of the most commonly used optimization categories within structure optimization (SO) [18,19]. Extraneous material is either moved or removed from the discretized design domain of the structure to create a layout that meets the given target functions and structural limitations. The main consumers of TO are engineers who are interested in material reduction or other optimization objectives including stress, deflection, and cost.

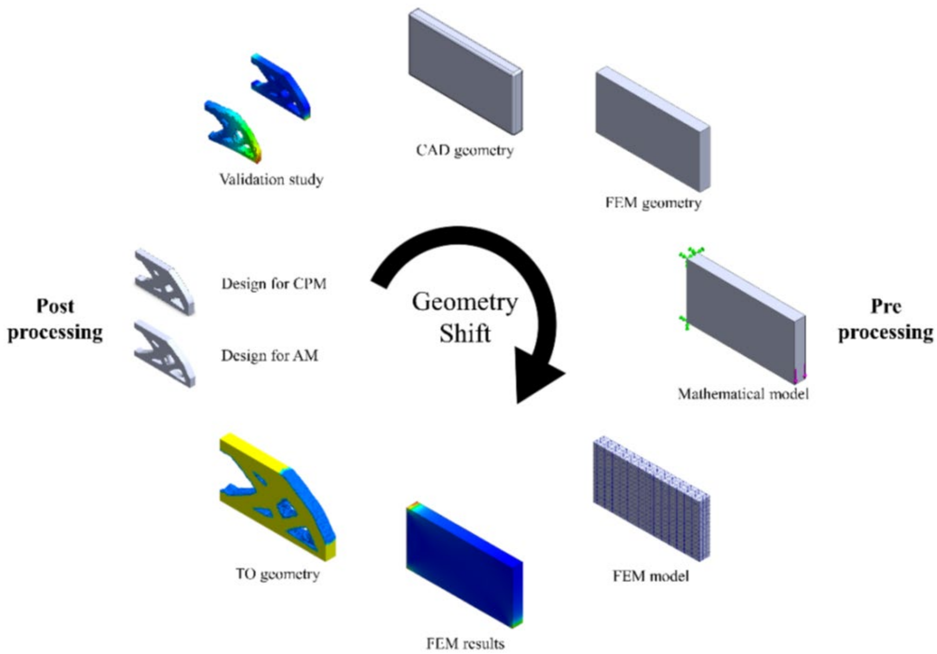


Fig. 2. A Topology Optimization (TO) workflow [19]

Figure 2 divides the pre-processing and post-processing duties, which are the TO's two main responsibilities. Pre-processing of the design includes, on the one hand, the design phase, discretization of the design space into finite elements, and application of the finite element method (FEM) with the creation of the mathematical model. This activity concludes with the results being presented and evaluated. At this point, the CAD designer needs to decide which TO program will best suit their needs, whether optimization is feasible, and which optimization method to employ. But post-processing, the second step, is when the optimized designs are prepared for manufacture through the use of additive manufacturing (AM) or conventional production processes (CPM). This implies that a great deal of choices, or inputs from the CAD designer, need to be made during the TO process. These inputs fall into four categories: loads, supports and connections, design limitations, and geometrical restrictions brought on by manufacturing limitations [19]. Design constraints are the parameters that define the size and shape of the CAD model. The connections and supports impose constraints on the degrees of freedom of the model. Put another way, they outline the relationship between the model and its environment, including how it interacts with other components. Loads are all the load instances that a CAD designer needs to take into account when working on optimization tasks.

In this research, the author aims to make a laptop stand with materials derived from drum brake shoe waste, as well as carry out topology optimization simulations on the laptop stand using Ansys software, to obtain an optimal laptop stand design.

2. Material and Method

In this research, the author conducted research on optimizing the topology of laptop stands with the constituent materials coming from drum brake shoe waste. Therefore, the author will carry out tensile tests to obtain data on the mechanical properties of drum brake shoe waste material. For this reason, tensile test specimens are required which are obtained by sand casting.

Laptop stand design that has been created with ANSYS Workbench software for simulation. Data on the mechanical properties (properties) of the material used are data from tensile test results. Then a simulation is carried out using static structural simulation. Next, the author will optimize the topology of the laptop stand to optimize the design in terms of mass and volume, but the new design is still within the safety factor limits in this research set 1.5.

Fig. 3. Waste brake shoes on the motorcycle

Brake shoe waste is cast at a heating temperature of 700 degrees Celsius and molded using the sand casting method into tensile test specimens. Based on the tensile test results, the yield stress data was 25.78 MPa, the ultimate stress value was 101.94 MPa, and the Young's modulus value was 1.4 GPa. This data is entered into the mechanical properties table in the Engineering Data section of the ANSYS Workbench software.

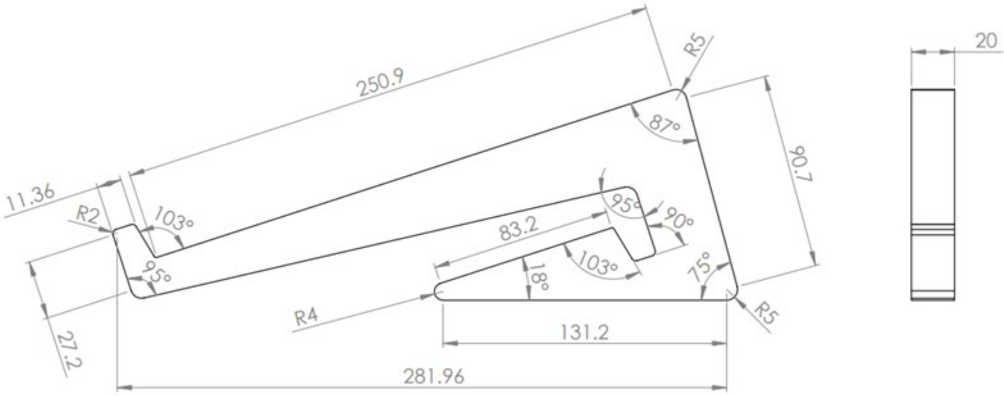


Fig. 4. Stand Laptop dimension

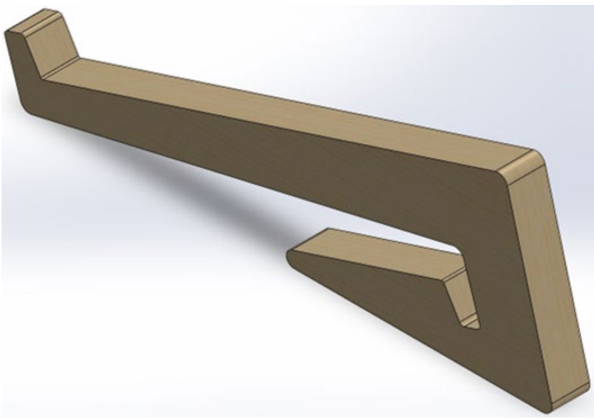


Fig. 5. Stand laptop modeling

The geometry entered into the ANSYS Workbench software in the Static Structural system analysis section is the geometry of the laptop stand which has been redesigned. After that, the process of checking and improving the geometry design of the laptop stand was carried out using the facilities provided by ANSYS SpaceClaim.

Then the geometry of the laptop stand will be meshed. The mesh size used is 2 mm with skewness as the mesh quality metric. The shape and arrangement of the mesh settings can be seen in Figure 6 and Figure 7.

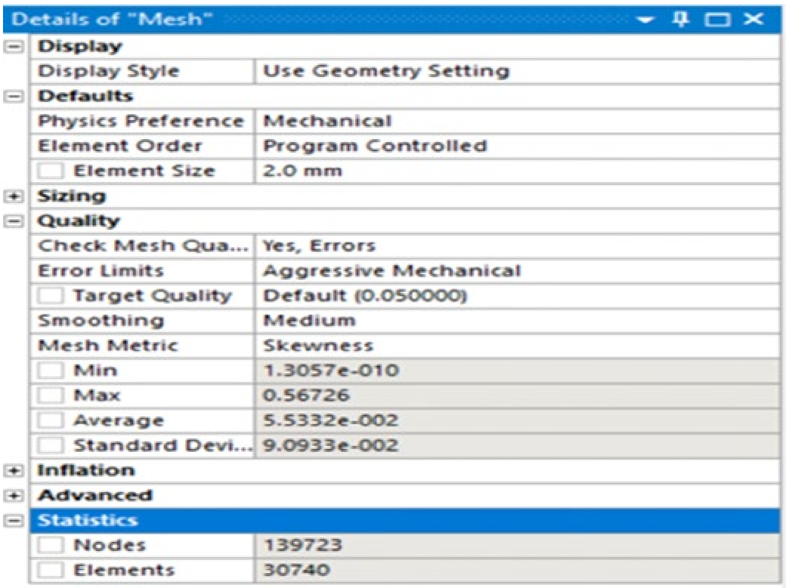


Fig. 6. Mesh quality Metric of Laptop Stand

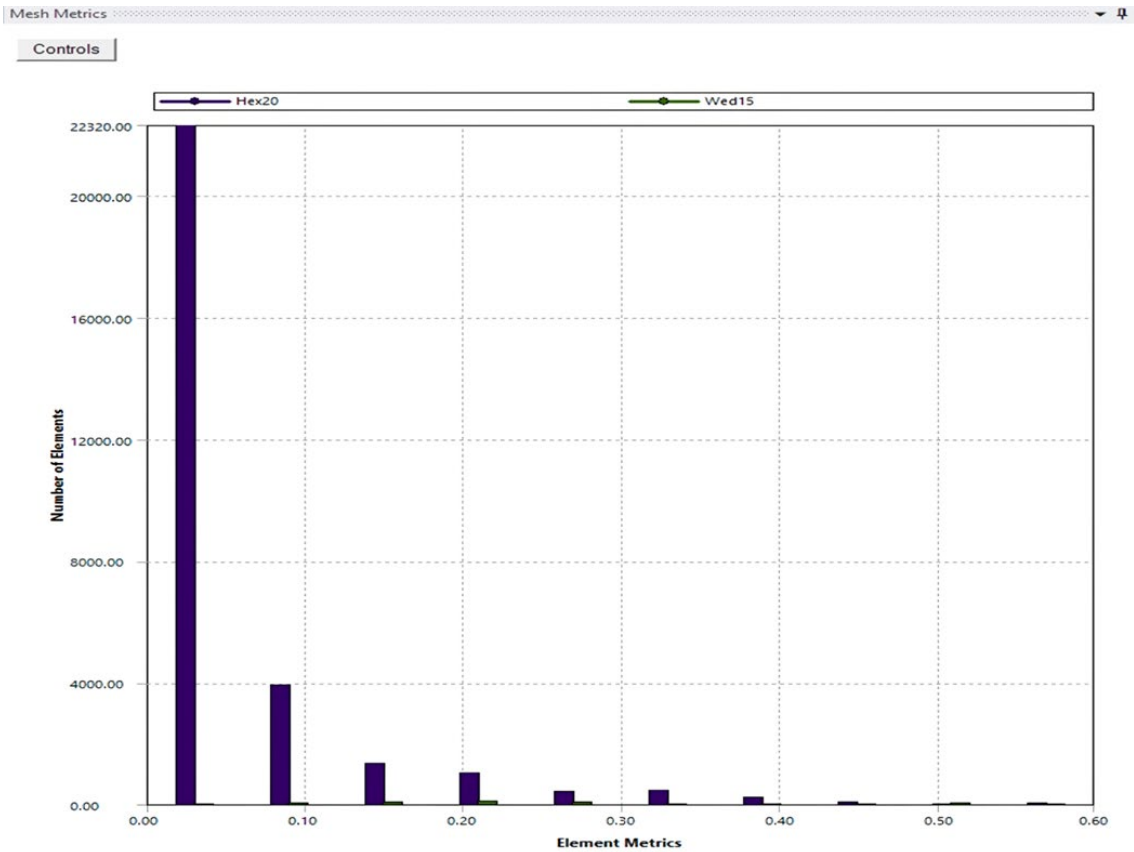


Fig. 7. Mesh Metrics Laptop Stand distribution

After the model stage is carried out, it continues with the setup stage, namely the stage of providing boundary conditions or boundary conditions such as loading points (force) and support points (fixed support). The load given to the laptop stand design is 44 Newton's statically. Images of providing force and fixed support can be seen in Figure 8 and Figure 9.

The static loading given during the laptop stand simulation is as follows:

- Laptop mass (m) = 8.8 kg
- Gravitational acceleration (g) = 9.81 m/s2

So the total load of laptops is:

$$F = m\,x\,g = 8.8\,kg\,x\,9.81\,\frac{m}{s^2} = 86.328\,N \quad (1)$$

This load is the maximum load accepted. Because there are 2 laptop stands, the load received by each laptop stand is:

$$F_t = \frac{F}{2} = \frac{86.328}{2} = 43.16\,N \quad (2)$$

where
m: mass of laptop
g: gravitational acceleration
F: Load of laptop
F_{t}:: load received by each laptop stand

Then we use 44 N as the load on the stand laptop.

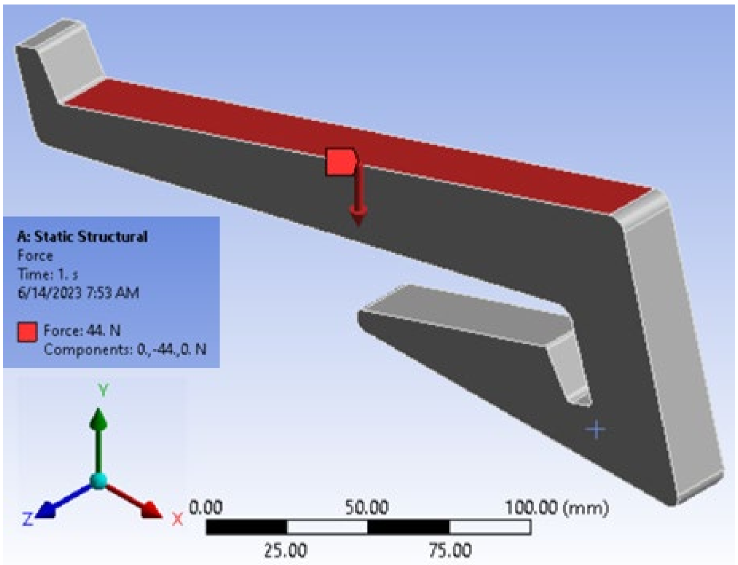


Fig. 8. Application of Force

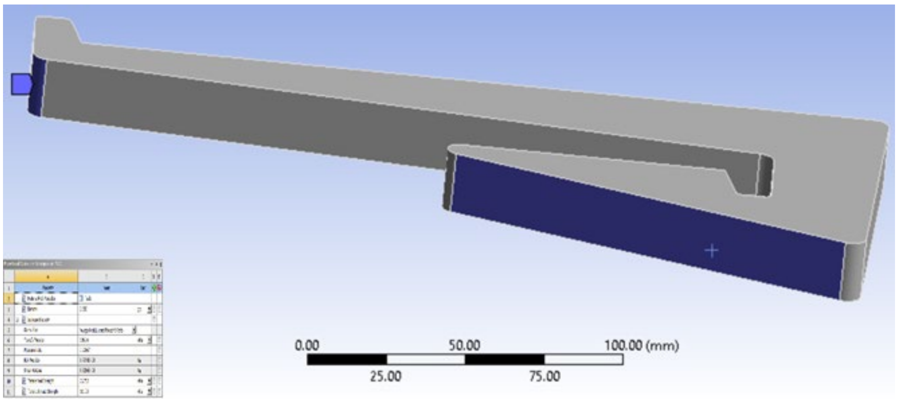


Fig. 9. Fixed Support setting

The next stage is to organize the solution you want to know. The final results you want to know are Von Mises stress, deformation, maximum principal stress, and safety factor.

The final stage is to optimize the laptop stand topology by setting the optimization region (Fig. and response constraints according to the specified variations as shown in Figure 10 and Figure 11. The following are the process and settings for carrying out optimization in this research.

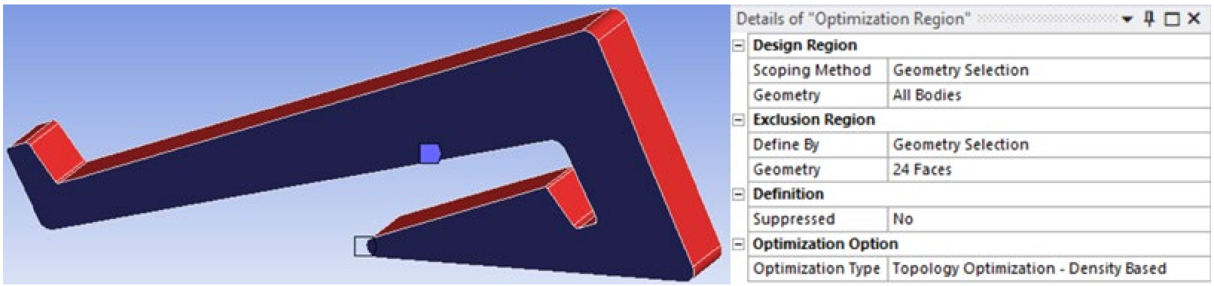


Fig. 10. Optimization Region Settings

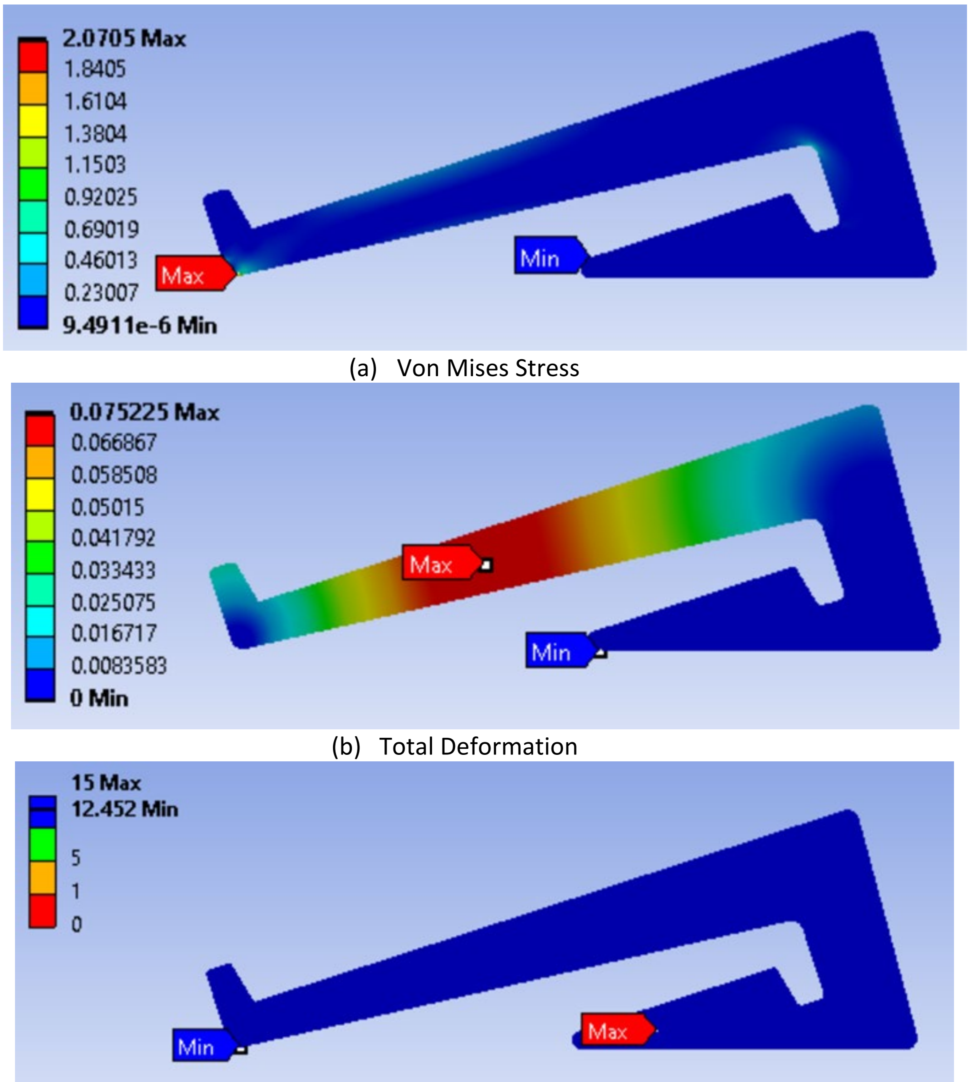
Details of "Response Constraint"	
Scope	
Scoping Method	Optimization Region
Optimization Region Selection	Optimization Region
Definition	
Type	Response Constraint
Response	Mass
Define By	Constant
Percent to Retain	50 %
Suppressed	No

Fig. 11. Response Constraint Settings

3. Result

A Von Mises stress distribution that happens on the components under examination represents the simulation findings. In addition to the distribution of stress, the position with the greatest (maximum) and lowest stress, deformation, and safety factor is also indicated. The distribution is represented visually with the greatest values in red and the lowest values in blue.

The output of the existing stand laptop model static stress simulation is displayed in Figure 12(a). In general, the stress that develops is still less than the material's yield strength, even though the stress distribution in the left support is somewhat higher than at the other side at 2.20705 MPa at the bottom left corner end (max mark), the area under maximum stress is located there. In contrast, the inner end of the support, at 0.000009491 MPa (min mark), is under the least amount of stress. This component remains safe even when it is under laptop load. As shown in Figure 12 (b) and Figure 12 (c), the existing stand laptop model generates a total deformation of 0.075225 mm and a safety factor of 12.452.



(a) Von Mises Stress

(b) Total Deformation

(c) Safety factor

Fig. 12. The existing model

ANSYS SpaceClaim must be used to smooth the geometry of the topology optimization findings. To smooth and clean up the surface after topology optimization, ANSYS SpaceClaim offers a shrink-wrap function. Table 1 displays the improved design.

By reducing mass and increasing design stress and deformation value, the program employing topology optimization seeks to make laptop stands lighter. This is because a drop in mass causes the stress distribution to broaden [20]. The design following optimization is demonstrated by Table 2's stress and total deformation and Table 3's safety factor. Table 4 displays a comparison between the design optimization findings and the original design.

Table 1
Laptop stand refined shape

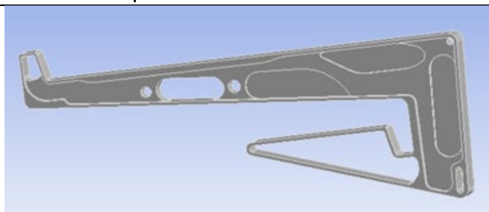
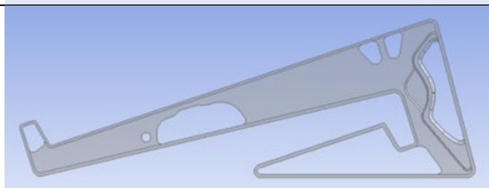
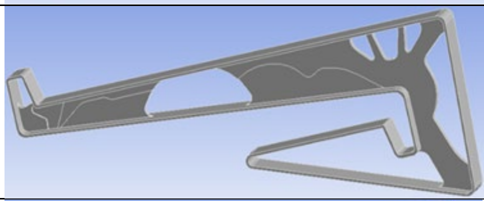
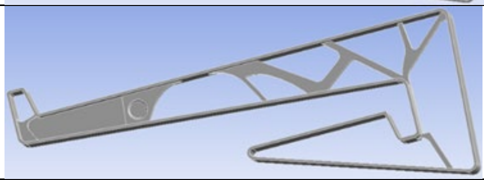
Mass Reduction	Refined shape
50%	
75%	
80%	
85%	

Table 2
The stress, and total deformation for each shape obtained after topology optimization

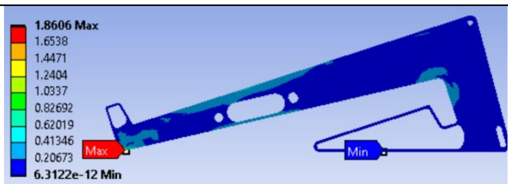
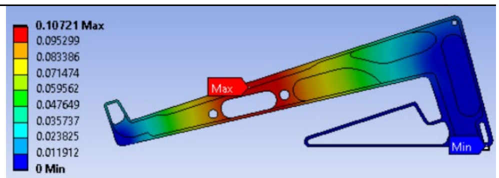
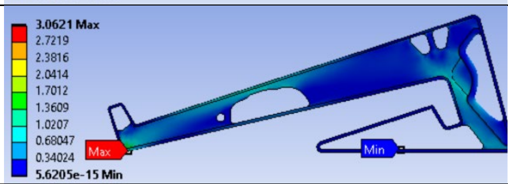
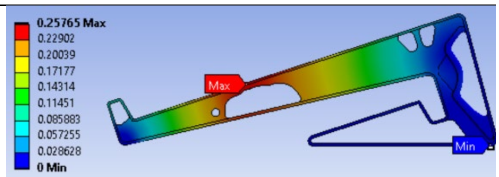
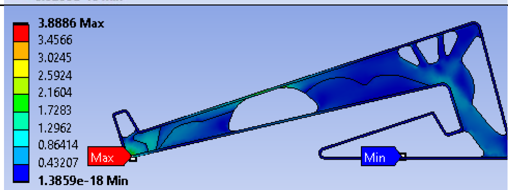
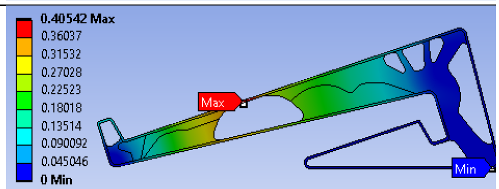
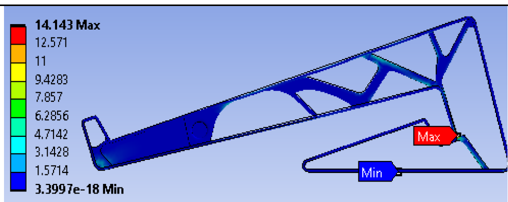
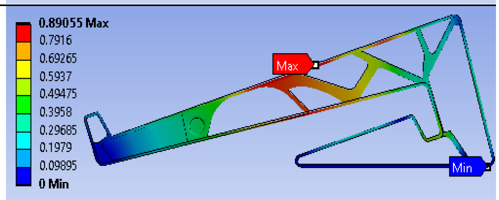
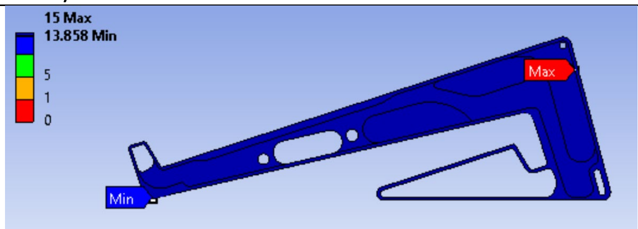
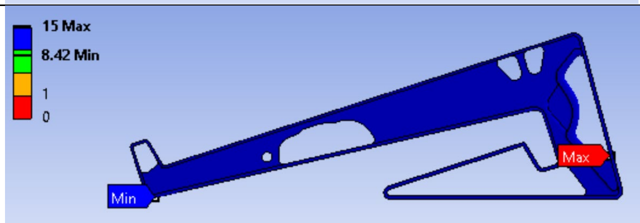
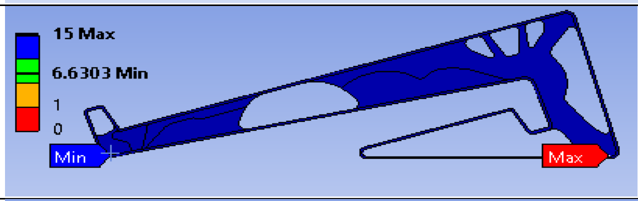
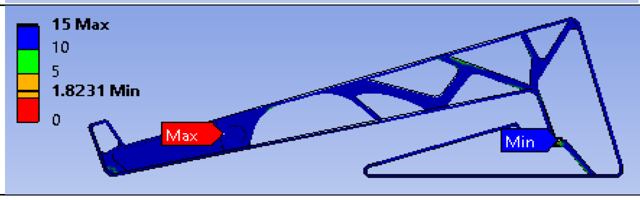
Mass Reduction	Von Mises Stress	Total deformation
50%		
75%		
80%		
85%		

Table 3
The safety factor for each shape obtained after topology optimization

Mass Reduction	Safety factor
50%	
75%	
80%	
85%	

The outcomes of the design optimization procedure at the maximum cutting location are displayed in Table 2. This procedure applies mass reduction, a topology optimization technique, to already-existing components. Only components with comparatively low Von Mises stresses or those represented in blue in the Von Mises distribution and subject to mass reductions of 50% to 85% are subject to mass reduction controls. The highest stress occurs at the inner section at the 85% mass reduction, but the stress that occurs is still below the yield stress. This mass reduction causes a change in the position of the maximum and minimum stresses.

As can be seen from the above table, yield strength is used as the safety factor. We can use the formula yield strength of material divided by Von Mises stress to validate the value of the yield strength safety factor. The safety factor is 1.82 for 85% mass reduction or 25.78 MPa/14.143 MPa. The safety factor derived from the simulation results is used in the same computation. The goal of the yield safety factor is to avoid plastic deformation. Since the safety factor remains over 1.25 and the mass reduction is substantial, an 85% variation is, therefore, the most ideal design. Table 4 displays comprehensive results.

Table 4
The result of topology optimization

Mass Reduction	Mass (gram)	Von Mises Stress (MPa)	Total Deformation (mm)	Safety Factor
Existing	627.33	2.05	0.08	12,46
50%	317.63	1.8	0.11	13.858
75%	156.95	3.06	0.26	8.42
80%	123.69	3.88	0.40	6.63
85%	100.18	14.143	0.89	1.82

5. Conclusion

In this work, a specific burden has been given to the topology optimization techniques of the current stand-laptop model. Numerous mass-minimization scenarios have been examined, leading to the development of multiple stand-laptop configurations that are optimized. The ensuing deductions are reached:

i. A structural mass reduction of up to 85% from the starting mass is effectively achieved through topology optimization. This is a very efficient method of building a lightweight construction that will be crucial for the advancement of design in the future. The topology optimization approach can also offer a wide range of geometrical choices for the design of a lightweight stand laptop, according to numerous constraint investigations.
ii. Based on the topology optimization results at 85%, the mass decreased from 627.33 g (existing) to 100.18 g (85%). The topology optimization results also revealed a decrease in the safety factor yield, from 12.46 to 1.82.
iii. There is room for improvement in the future, including the ability to conduct more thorough experimental tests to confirm structural optimization and improve the use of the stand laptop in specific applications.

Acknowledgment
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