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Topology Optimization of Car Doorstep from Waste Metal

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Doorstep, simulation, topology, optimization, static, structural

Abstract

The car doorstep is a device designed to facilitate access to the roof of a car. It is a sturdy tool capable of supporting human weight while lifting items onto the car's roof. In this study, the car doorstep was made using waste drum brake shoe material, and its mass was reduced through static structural simulation and topology optimization in Ansys Workbench. The objective was to achieve reduced mass, total deformation, equivalent stress, maximum principal stress, and safety factors for each variation. The car doorstep's geometry was subjected to a load of 1765 N and appropriate supports were applied. Based on the conducted research, the car door step's geometry with a 40% variation resulted in the most optimal data, with the following values: mass of 1,4 kg, total deformation of 1.81 mm, equivalent stress of 21.47 MPa, and safety factor of 1.2.

1. Introduction

One of the big problems in countries in the world currently related to the environment is the accumulation of waste. The accumulation of waste certainly comes from daily human activities and the management of this waste is still not optimal. It cannot be denied that the volume of waste which is increasing day by day is an implication of human population growth and the pattern of consumerism in society, which is increasing every year, as is also the case in Indonesia. Based on 2022 data, the amount of waste that has not been properly managed in Indonesia is 37.98% of the total waste pile of 35,421,817.61 tons/year, and 3.04% is metal waste [1].

This is very worrying because metal waste is a type of waste that takes a long time to decompose. If not managed, this waste can cause environmental pollution which will harm society in terms of health and comfort, in this context drum brake shoe waste is one of them. Based on data from the Association of Indonesia Motorcycle Industry in 2022, the largest sales are scooter types which of course use a drum brake shoe braking system [2].

To overcome this, this research further attempts to promote the concept of recycling by reprocessing metal waste, specifically drum brake shoes, into new products that have new prices and functions. In this research, we chose a recycled product in the form of a supporting tool to replace stairs, namely a car doorstep. Along with the development of technology, the human need for equipment that helps human activities in using cars is also growing. One of these activities is when placing items or cleaning the roof of the car, most of whom will use a ladder to reach the roof of the car. The ladder used to reach the roof of the car will require a large storage space in the car, so it is not efficient. Therefore, the use of car doorstep is very effective and efficient.

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 [3]. Furthermore, the utilization of aluminum alloy waste as a footrest support for motorcycles [4].

The use of finite element and numerical method-based software is commonly used in the design process to analyze. Uses such as analyzing the performance of metal gaskets [5], [6], to determine the effect of layers on gaskets and their performance [7], [8], control system [6], [10], metal gasket formation process and manufacturing parameters [11], [12], influence of die type on mold results [13], identification of hardness testing to predict material properties [14], [15], influence in ergonomics [16], influence of blade shape on wind turbine performance [17], crash box design [18], distal collarbone fracture treatment [19], and optimize designs [20], [21].

Within structural optimization (SO), topology optimization (TO) is one of the optimization categories that are most frequently used [22], [23]. To construct a layout that satisfies the specified goal functions and structural constraints, extraneous material is either shifted or deleted from the discretized design domain of the structure. Engineers interested in material reduction or other optimization goals including stress, deflection, and cost are the primary users of TO.

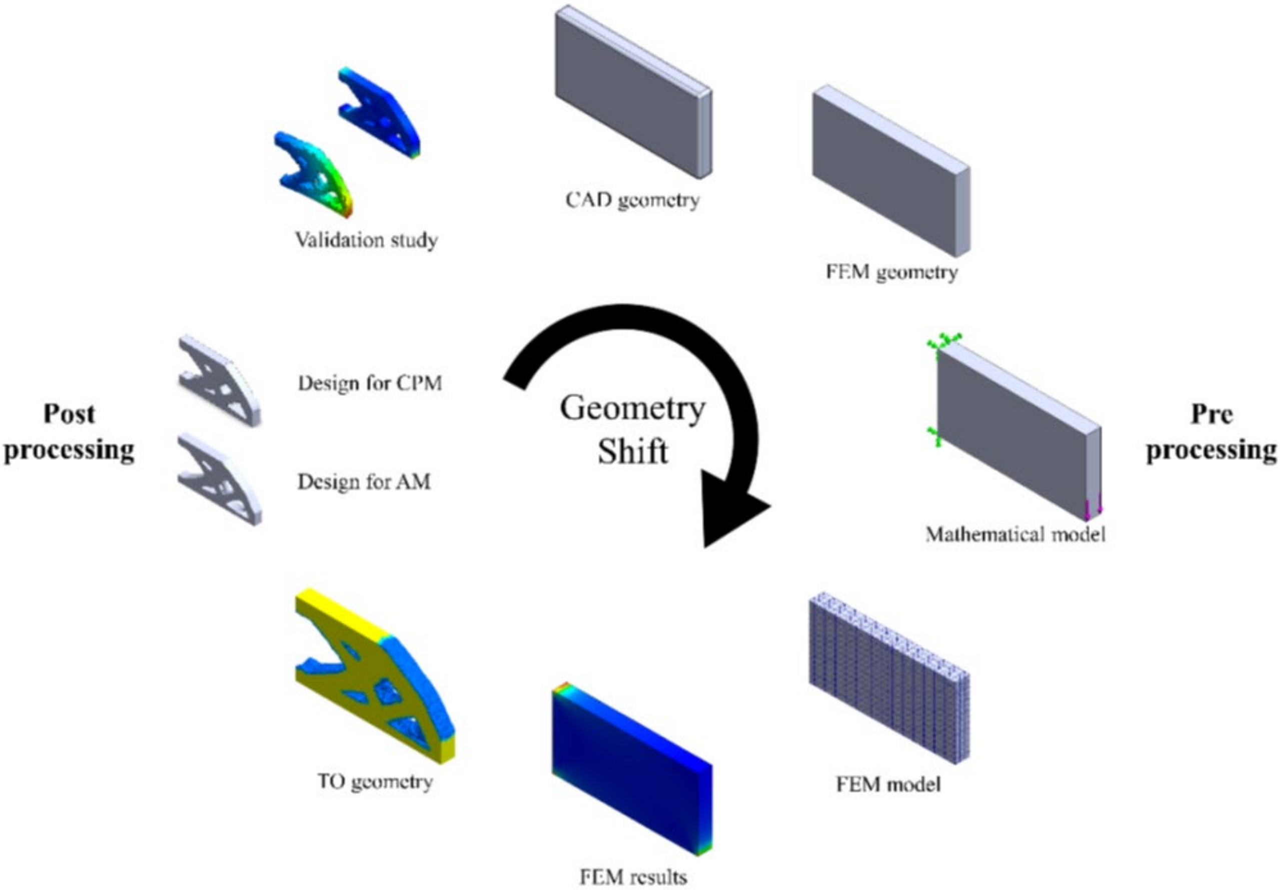


Fig. 1 *A topology optimization (TO) workflow [23]*

The two primary responsibilities of the TO—pre-processing, and post-processing—are separated in Fig 1. On the one hand, the design phase, the discretization of the design space into finite elements, and the application of the finite element method (FEM) with the formulation of the mathematical model comprise the pre-processing of the design. The presentation and assessment of the outcomes mark the end of this task. At this stage, the CAD designer must determine whether optimization is possible, the optimization technique to use, and which TO software will best meet their requirements. The second stage, however, is post-processing, when the optimized designs are ready for production using additive manufacturing (AM) or conventional production methods (CPM).

This means that a lot of decisions, or the CAD designer's inputs, must be made during the TO procedure. The four groups of these inputs are the loads, the supports and connections, the design constraints, and the geometry limitations resulting from manufacturing constraints [23]. The CAD model's dimensions, which determine its size and shape, are known as design constraints. The model's degrees of freedom are constrained by the connections and supports. Stated differently, they delineate the connection between the model and its surroundings, including how it interacts with other elements. All the load instances that a CAD designer must consider when performing optimization work are referred to as loads. This research aims to determine the quality of car doorsteps using drum brake shoe waste material to obtain the optimal shape and dimensions of the car doorstep. Optimization was carried out by applying TO using ANSYS Workbench software by minimizing the mass of the car doorstep but still meeting the safety factor criteria.

Nomenclature is included if necessary

W	Weight of
m	mass of
g	gravitational acceleration

2. Material and Method

This research will optimize the car doorstep topology with the constituent materials coming from drum brake shoe waste as shown in Fig. 2. Previously, this research had collected data on the mechanical properties of drum brake shoes. The data that has been obtained will be used in the simulation process. Design and simulation process for car doorsteps using ANSYS software with static structural analysis. After that, the car doorstep design will be topologically optimized to optimize the design in terms of mass and volume, but still within safety factor limits. The car doorstep drawing is shown in Fig. 3. The sand-casting method is used to form brake shoe waste into tensile test specimens at a heating temperature of 700 degrees Celsius. 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 based on the findings of the tensile test. This information is entered into the ANSYS Workbench Software’s Engineering Data section's mechanical properties table. The load that will be given to the car doorstep will be one person and the goods will be lifted by that person. The assumed human weight is 100 kg while the weight of goods is assumed to be 80 kg. Load calculations can be seen in equations 1 and 2.

Fig. 2 *Waste brake shoes on the motorcycle*

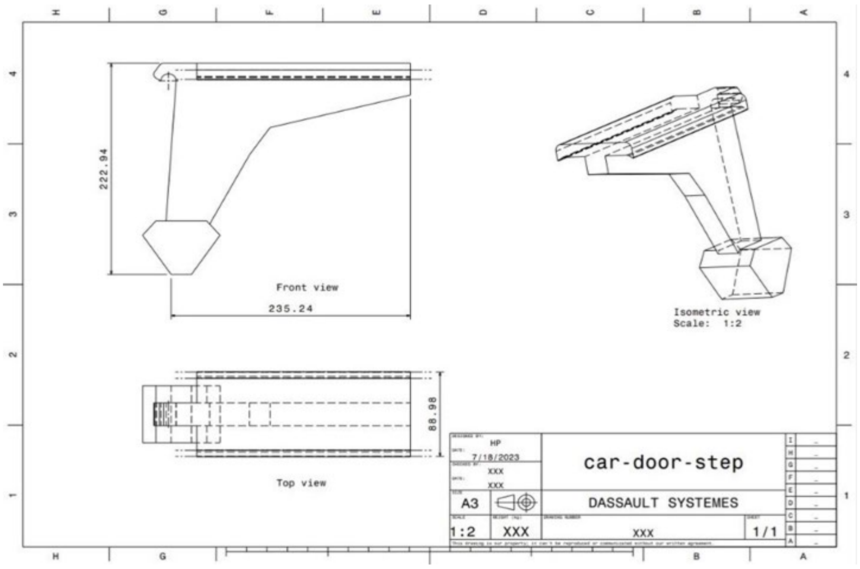


Fig. 3 *Drawing car doorstep*

a. Human weight

$$Whuman = m\ x\ g$$

$$Whuman = 100\ Kg\ x\ 9{,}81\frac{m}{s^2}$$

$$Whuman = 981\ N \quad (1)$$

b. Goods weight

$$Wgoods = m\ x\ g$$

$$Wgoods = 80\ Kg\ x\ 9{,}81\frac{m}{s^2}$$

$$Wgoods = 784\ N \quad (2)$$

Wtotal = Whuman + Wgoods = 981 N + 784 N = 1765 N (3)

The geometry that has been made solid by ANSYS SpaceClaim is then carried out in the meshing stage. The mesh size applied is 2 mm with skewness as the mesh metric. The results of the meshing obtained were meshing quality with an average of 0.41. Looking at Fig. 4, this mesh size was chosen because the average value of 0.42 is in the very good category. The size and quality of the mesh can be seen in Fig. 5. After filling in the model section, continue with the setup section, namely the stage of placing boundary conditions such as load positions and support locations. This research was carried out by giving a total load of people and goods of 1765 N. Images of the load placement at the midpoint of the red area and the supports in the blue area can be seen in Fig. 6 and Fig. 7. Next, list the solutions to be achieved in the simulation. The solutions that will be included are von Mises stress, total deformation, and safety factor. After achieving the desired results, the next step is to carry out topology optimization by setting the optimization region and response constraints according to the desired variations.

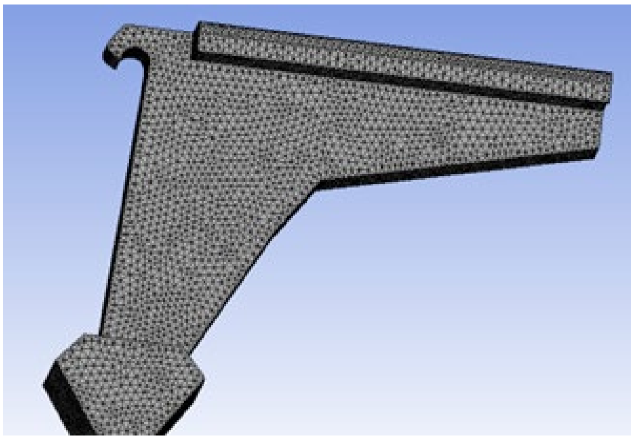


Fig. 4 *Mesh on car doorstep geometry*

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	2, mm
Sizing	
Quality	
Check Mesh Qua...	Yes, Errors
Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	Skewness
Min	8,0395e-004
Max	0,98965
Average	0,4277
Standard Deviati...	0,20165
Inflation	
Advanced	
Statistics	
Nodes	90434
Elements	51242

Fig. 5 *Mesh quality check*

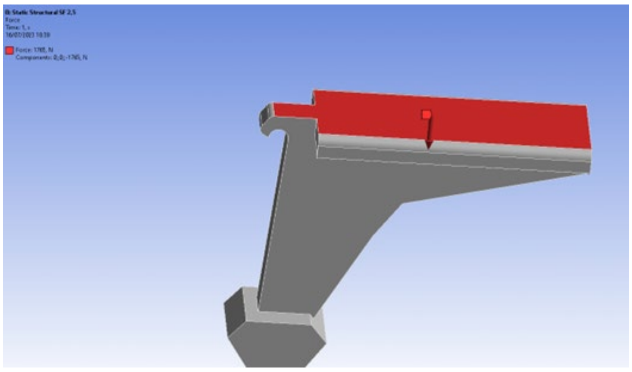


Fig. 6 *Load position*

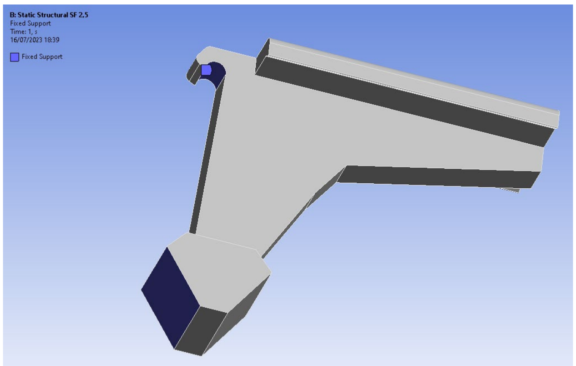
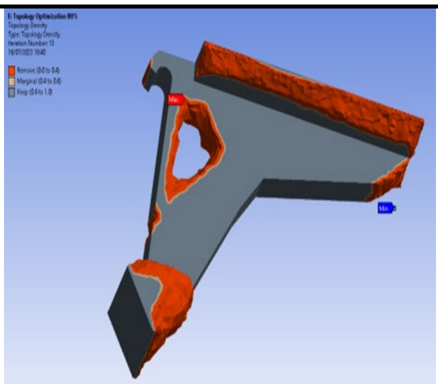
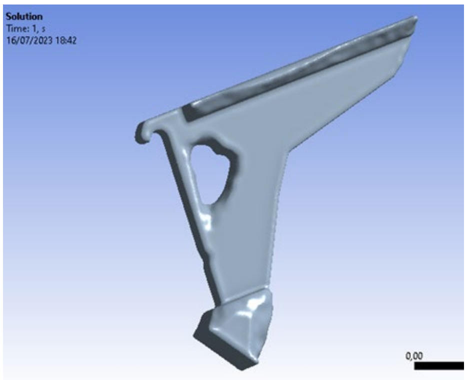
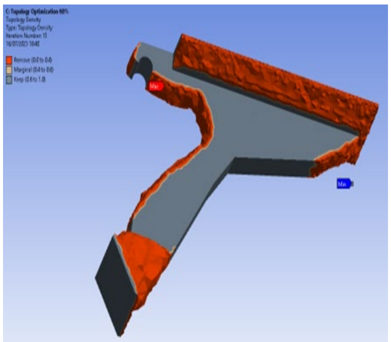
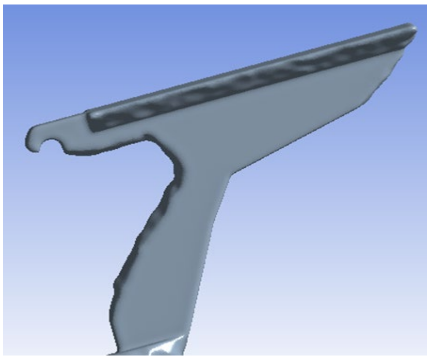


Fig. 7 *Support position*

3. Results and Discussion

The simulation results are in the form of a Von Mises stress distribution that occurs on the components under consideration. Apart from the stress distribution, the position that experiences the highest (maximum) and minimum stress, deformation, and safety factor is also presented. This distribution is shown by color degradation from the highest in red and the lowest in blue. Fig. 8 shows the results of the existing car doorstep static stress simulation. The stress distribution in the middle is relatively higher than at the ends, but generally, the stress that occurs is still below the yield strength of the material. The area experiencing maximum stress is at the bottom center corner end (max mark) at 10,254 MPa, while the area experiencing minimum stress is at the outer end of the footing at 0.00010794 MPa (min mark). When the load acts on this component, the component is still safe. The existing car doorstep produces a total deformation of 1.56 mm, and a safety factor of 2.51, as can be seen in Figs 9, and 10. The topology optimization results need to have their geometry smoothed using ANSYS SpaceClaim. ANSYS SpaceClaim provides a shrink-wrap feature to clean up the results of topology optimization and smooth to make the surface smoother. The before and after refined design can be seen in Table 1.

Table 1 *Design before and after refined*

Mass Reduction	Before	After
20%		
40%		

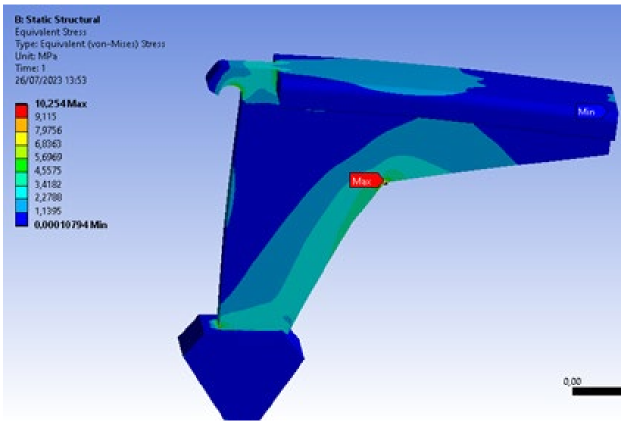


Fig. 8 *Von mises stress*

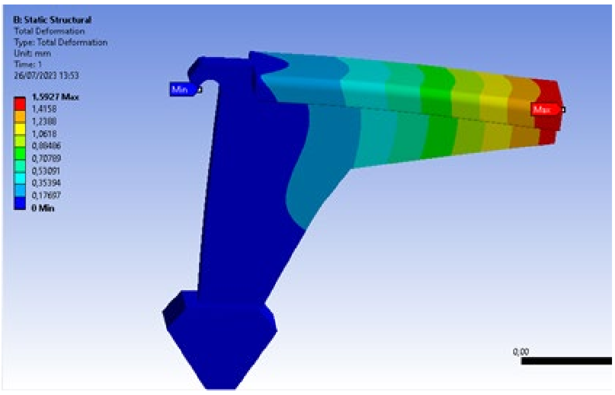


Fig. 9 *Total deformation*

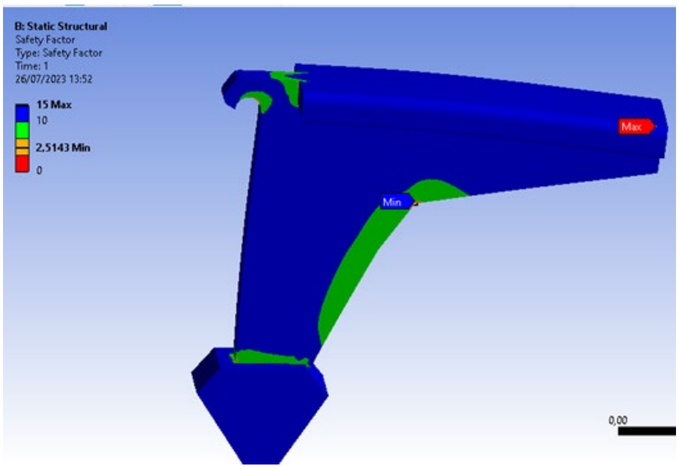


Fig. 10 *The safety factor*

The application using topology optimization aims to design car doorsteps become lighter, where the mass value decreases so that the design stress and displacement value increase, this is due to a reduction in mass so that the stress distribution widens [24]. This is shown by the design after optimization in Table 2 and a comparison of the design optimization results with the initial design in Table 3. Table 2 shows the results of the design optimization process at the highest maximum cutting position. This process uses a topology optimization method, namely mass reduction on existing components. Mass reduction is controlled only on parts that experience relatively small Von Mises stresses or parts visible in the Von Mises distribution in blue with mass reductions of 20% and 40%. As a result of this mass reduction, there is a change in the position of the maximum and minimum stress, where the maximum stress occurs at the hook section, however, the stress that occurs is still below the yield stress. From Table 3, the safety factor used is a safety factor that uses yield strength. To validate the value of the yield strength safety factor, you can use formula the yield strength of the material divides by the Von Mises stress. For 20% mass reduction the safety factor is 25.78 MPa/16.54 MPa is 1.56. This calculation is the same as the safety factor from simulation result. The yield safety factor is sought to prevent plastic deformation. Therefore, a 40% variation is the most optimal design because the mass reduction is large, and the safety factor is still above one. Detailed results can be shown in Table 3.

4. Conclusion

In this paper, topology optimization methods of the existing car doorstep design have been applied with a certain load. Several scenarios of mass minimization have been investigated resulting in several optimized car doorstep designs. The following conclusions are obtained:

1. The topology optimization successfully provides structural mass reduction of up to 40% from the initial mass. This is a very effective way to create a lightweight structure that is important in the development of future design. From several constraint investigations, the topology optimization method is also capable of providing many geometrical options for the design of a lightweight car doorstep.
2. From the results of 20% and 40% topology optimization, there was a reduction in mass from the initial 2.28 Kg to 1.80 Kg (20%) and 1.40 Kg (40%). The results of topology optimization also found that the safety factor yield was reduced from 2.51 to 1.56 (20%) and 1.20 (40%).

3. Improvement opportunities can be made in the future involving more detail of experimental studies to validate the structural optimization to enhance the application of the car doorstep in some applications.

Table 2 *The stress, total deformation, and safety factor for each model after topology optimization*

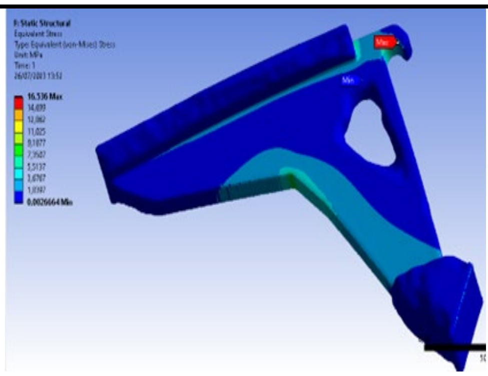
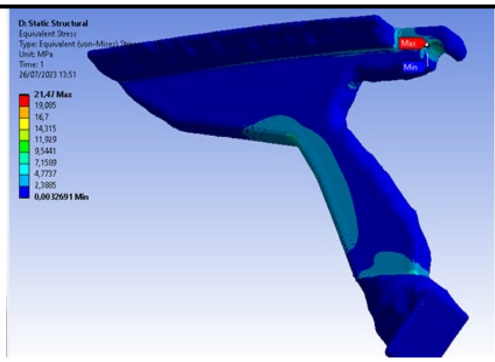
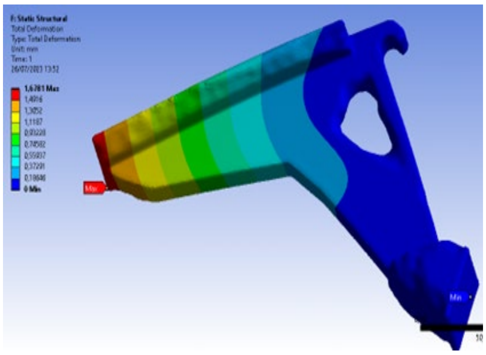
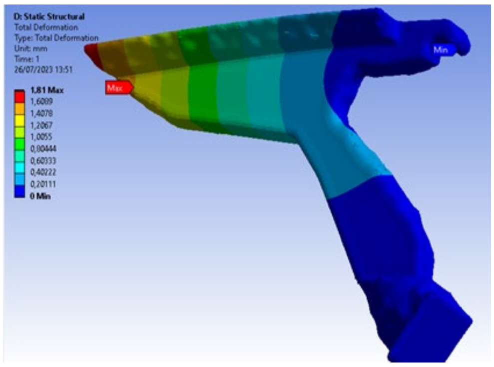
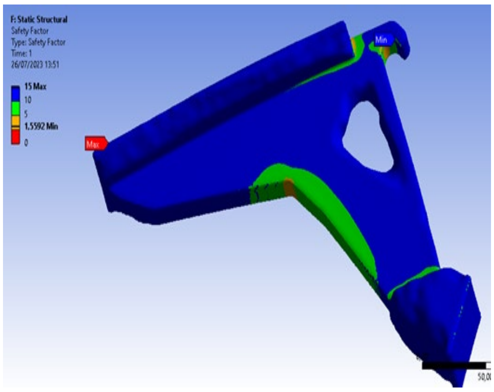
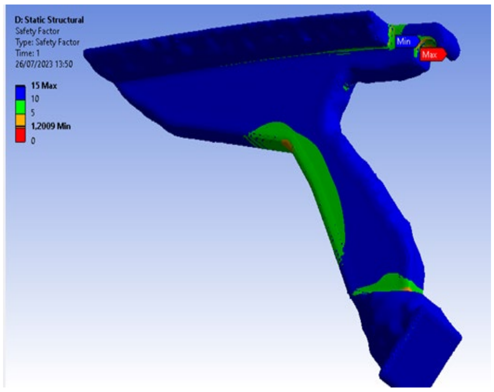
Mass Reduction	20%	40%
Von Mises Stress		
Total Deformation		
Safety factor		

Table 3 *The result of topology optimization of the car doorstep*

Mass Reduction	Mass (kg)	Von Mises Stress (MPa)	Total Deformation (mm)	Safety Factor
Initial/existing	2.28	9.79	1.5927	2.51
20%	1.80	16.54	1.6781	1.56
40%	1.40	21.47	1.81	1.20

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***study conception and design:*** *I Made Gatot Karohika, I Made Widiyarta, I Nyoman Gde Antara, I Komang Ari Mogi;* ***data collection:*** *I Made Gatot Karohika, Muhammad Farizqi Rimasfirli;* ***analysis and interpretation of results:*** *I Made Gatot Karohika, I Made Widiyarta;* ***draft manuscript preparation:*** *I Made Gatot Karohika, Muhammad Farizqi Rimasfirli. All authors reviewed the results and approved the final version of the manuscript.*

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