

Comparative Finite Element Analysis of Al 7075-T6 and Al 2024-T4 for the Upright Component of a Racing Car

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Article Information	ABSTRACT
Article History Received : September 20, 2025 Revised : October 18, 2025 Published : October 26, 2025	Topology optimization is a method for reducing mass without compromising structural strength, resulting in an optimal design tailored to the loads acting on the Upright. This study aims to evaluate the stress and deformation of the front Upright design of racing car before optimization and analyze the stress, deformation, and safety factor after topology optimization. Various mass retain percentages are considered to identify the best design that can be manufactured using a 3-axis CNC milling machine. The research includes load analysis on the front Upright during deceleration, acceleration, and cornering, which subjects the Upright bearing. The front Upright design is simulated using static structural analysis finite element with ANSYS software . Topology optimization simulations are then conducted with mass retain percentages of 60% dan 40%. Static structural simulations are performed for each optimized design. The results indicate that the Upright design with a 40% mass retain using At a mass retain of 40% of the Al 2024 T4 material, the mass reaches 459 g with a total deformation of 0.0416 mm and a maximum stress of 84,997 Mpa. 0.04161. The research results obtained lighter materials so that 3-axis CNC production with three stages or sides using one jig and suggested that it is very necessary to validate the simulation results and ensure the design meets technical and safety specifications.
Keywords: <i>CAD;</i> <i>Optimation;</i> <i>Upright;</i> <i>Racing Car;</i> <i>Topology.</i>	

INTRODUCTION

The suspension and steering system are two important components of a racing car, whose performance determines the handling stability and smoothness of the car (Cheng et al, 2023). The primary function of a vehicle's suspension system is to absorb shocks and maintain wheel contact with the road surface. Suspension geometry affects not only ride comfort but also handling characteristics. Race car suspension settings are specifically designed to maximize performance under certain conditions. In general, in race cars, double wishbone suspension with pull rod and pushrod is used because of its simple design and lighter components (Saurabh, et al, 2016).

An upright is an automotive component that connects all suspension components, such as wishbones, shock absorbers, tie rods, and pull rods. Race car uprights come in various designs depending on the suspension configuration. The upright transfers braking, driving, and steering forces and moments from the wheels to the suspension arms. Designing the upright will affect how

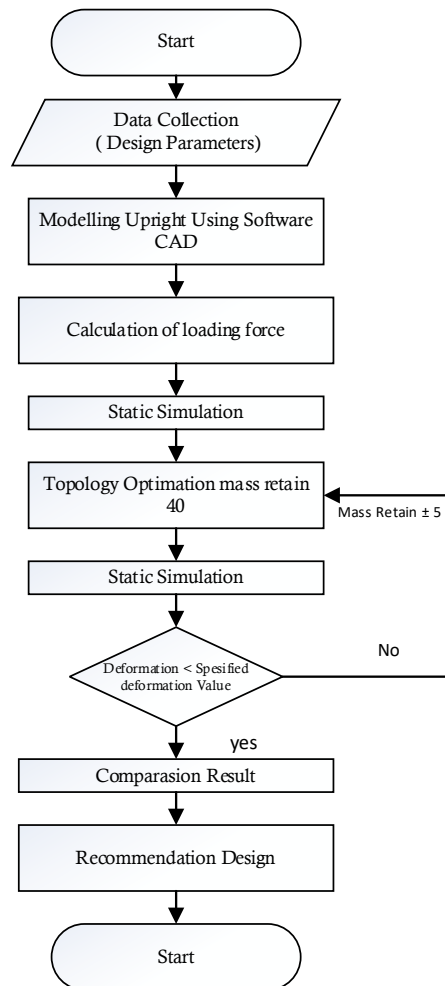
the driving dynamics are adjusted. For example, changes in suspension bar length will affect wheel alignment, camber, caster angles, and kingpin angles. This allows for the installation of a steering column for better steering options (Mihaly et al, 2024). In race cars, the upright's weight is a key parameter. The basic requirements for a race car upright are minimum weight, maximum stiffness, and sufficient strength (Hunar et al., 2020). This also applies to FSAE competition race cars which do not have minimum weight requirements so they can reduce weight without limits. Reduction in the weight of the vehicle also improved the vehicle handling performance. Therefore, it would be a great advantage for the team if the weight of the vehicle components is reduced. Maximizing stiffness equates to minimizing the average flexure of the structure under a given load. This problem can be solved not only for components but also for the vehicle's structural frame (body structure) (Bendsoe et al., 2019). Therefore, the upright must have a very light mass. Low component weight and maximum stiffness are crucial requirements, which are crucial for racing cars and are often difficult to achieve (Mesicek et al., 2018). Other important factors to consider when designing uprights are material availability, cost, and ease of machining (Kumar et al., 2019).

Static stress analysis is generally used to analyze the design of vehicle component. Reducing the safety factor is one method that can be adopted. Topology optimization involves changing the shape while maintaining some of the upright's properties, with the primary goal being the efficient use of material for the upright. Topology optimization can produce part with enhanced performance and mechanical properties (Prathyusha et al., 2022). Given that design optimization is often difficult in conventional production processes, more modern technology is needed for the production process. The results of topology and shape optimization can reduce the design mass compared to the initial design (Karadere et al., 2021). Additive manufacturing can increase structural stiffness, reduce weight, and maintain the safety factor of a fiber component, improving overall performance (Mittal et al., 2020). The purpose of this research is to maximize suspension performance by creating an upright design as light as possible while maintaining strength. In racing cars, one of the determining factors for vehicle stability is the weight and strength of each component. Topology optimization is an optimization method to minimize mass and volume by using a stress distribution approach on a material in a specific design.

The research was conducted using manual calculations and Computer Aided Engineering (CAE). The choice of material used is aluminium alloy which will compare between Al 7075 T6 and Al 2024 T4. This material has a lighter weight and affordability. Al 7075 which has higher strength, and its design can also be optimized, and the frame has a lighter weight without sacrificing strength (Sindhukavi et al., 2020). Al 7075 could be used on outer layer to resist aerodynamic loads, while Al 2024 could be used inner layer to suppress crack and propagation, this design would extend service life and reduce maintenance costs (Dong et al, 2025). Aluminium alloy has a higher deformation value than other material such as Ti alloy (Putra & Pradani, 2020) so that in its use aluminium alloy is often used for vehicle bodies because of its lighter.

RESEARCH METHODS

The initial step is to determine all design parameters that will guide the design of the race car. The design process includes supporting data from the upright structure, such as component geometry, materials, and analysis of the working forces received by the upright. The research flowchart can be seen in figure 1.

**Figure 1** Research Flowchart

Design Parameter

In the design process, the first step is to determine the design parameters that will serve as a guide in designing the vehicle. The design parameter is a design imitation so that what we design is right on target in accordance with regulations that refer to the FSAE rules. The following is data regarding the design parameters that have been set:

Table 1. Design Parameter of Race Car

Parameter	Front Wheel	Rear Wheel	Units
COG height	300	300	Mm
Length COG Roll Axis	270	260	Mm
Rim Velg Diameter	10	10	Mm
Wheel Diameter	406,4	406,4	Mm
Disc Brake Diameter	200	200	Mm
wheelbase	1560	1570	Mm
Trackwidth	1200	1140	Mm
Total Mass with a driver	300	300	Kg
Upsprung Mass	65	65	Kg
Sprung Mass	235	235	Kg
Total Mass Distribution	141	159	kg
Mass Distribution	40	60	%

CAD Design

The first stage, namely data collection, begins with determining the reference model of the upright that will be used as a basis. This process involves research through journals that review upright components in racing cars. The type of suspension used is a double wishbone. In addition, it also involves searching for data on the geometry of components connected to the upright, such as the size of the bearing, caliper, rod end, and suspension geometry. The second stage is creating a constraint model of the upright that will be created using Computer Aided Drawing (CAD) software with ANSYS software. Overall, this upright component CAD design emphasizes structural integrity, weight efficiency, and manufacturability, making it suitable for applications in high-performance illustrated on Figure 2.



Figure 2. CAD Design

Calculation of Loading Force

Calculate of loading force for deceleration, acceleration and cornering. When a car decelerates, the vehicle's centre of gravity shifts to the front, resulting in an increase in the force received by the front wheels compared to the rear wheels, which causes a load transfer to the front wheels, usually called longitudinal load transfer. In this calculation, we can assume an acceleration due to gravity of 9.81 m/s^2 . Acceleration loading force calculation is carried out when a car accelerates, the vehicle's centre of gravity shifts rearward, causing the front wheels to experience less force than the rear wheels, thus shifting the load to the rear wheels. When the wheels are rotating in a straight line, we can assume that the acceleration force on the tires is at the centre of the wheel. Then cornering when a car turns, all of its weight tends to shift to the outside wheel, resulting in a lateral load transfer to the outside wheel.

Break Force Momen

$$FB = F2 - F1 \quad (1)$$

$$MB = M1 + M2$$

$$FB \times r = F_1 \times b + F_2 \times a \quad (2)$$

Acceleration Force

$$FA = F1 + F2 \quad (3)$$

$$MA = M1 + M2 \quad (4)$$

Lateral Force and momen

$$FL = F2 - F1 \quad (5)$$

$$ML = M1 + M2 \quad (6)$$

Simulation and Material

The pre-processing stage involves inputting data, including boundary conditions and mesh modelling. Next, the processing stage involves calculating the input data using iterative equations. The final stage is post-processing simulation and optimization, where the results are interpreted in the form of images or graphs, the simulation illustrated on figure 3.

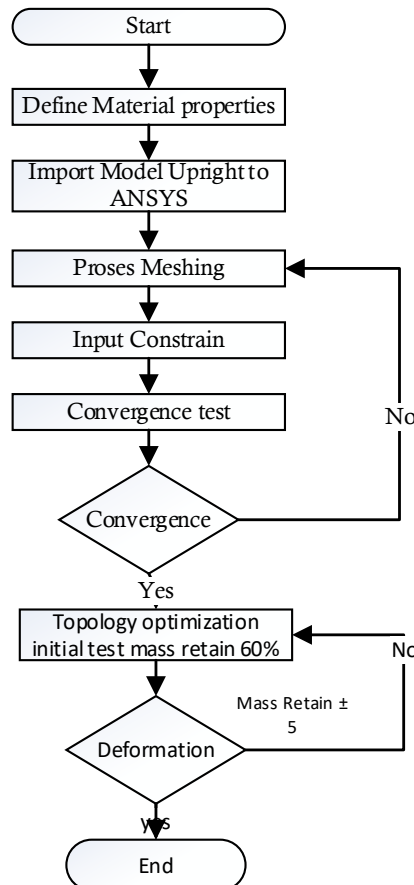


Figure 3 Simulation Flowchart

The type of material to be used must be determined, including mechanical property data such as density, Young's modulus, Poisson's ratio, etc. The type of material to be used is Al 2024 T4 and Al 7075 T6, the choice of this material is because the upright material currently used, Al 6061, has a lower yield strength than the two materials.

Table 2 Mechanical Properties

No	Mechanical properties	Al 2024 T4	Al 7075 T6	Units
1	Density	0.00278	0.0028	g/mm ³
2	Poisson's Ratio	0.33	0.32	
3	Ultimate Tensile Strength	480	572	MPa
4	Modulus young	71	72	Gpa
5	Yield Strength	310	503	MPa

The meshing method used Tetrahedrons with a maximum element size of 10 mm and a minimum size limit of 0.3 mm to achieve element quality that meets the target average of 0.8-1.0 mm.

The next step is the configuration process (set up) which includes defining the size and location of the load in the software, as well as determining the constraints, namely the reaction force of the support (F1) Upper wishbone, the wheel lift force (FN), the reaction force of the

support (F2) Lower Wishbone and the reaction force when there is a deceleration load on the caliper mounting.

Next, we must determine what percentage of the upright's mass will be retained, called mass retain. In this simulation, the author started with a mass retain of 60% in the initial optimization stage.

If deformation occurs in the mounting, it will change the behavior of the vehicle. The permissible deformation limits for mounting the upright steering rod are less than 1.5 mm on the X, Y, Z axis. Mounting Lower Arm less than 1.5 mm X axis, 3.34 mm Y axis, 0.7008 mm Z axis. On the Upper Arm less than 1.5 mm X axis, 2.78 mm Y axis and 0.762 Z axis. and Caliper mounting deformation less than 15 mm X axis, 2 mm Y axis, 2.7 mm Z axis.

RESULTS AND DISCUSSION

Initial design analysis using 7075 T6 and AL 2024 T4 materials, The analysis of the meshing convergence results was carried out by using fixed loading and comparing the yield of maximum principal stress. In the mesh convergence analysis process, data collection was carried out using an initial mesh size of 12 mm. To evaluate the stability of the results and the level of accuracy, the mesh size was gradually reduced by 1 mm for each sample, until it reached a size of 8 mm.

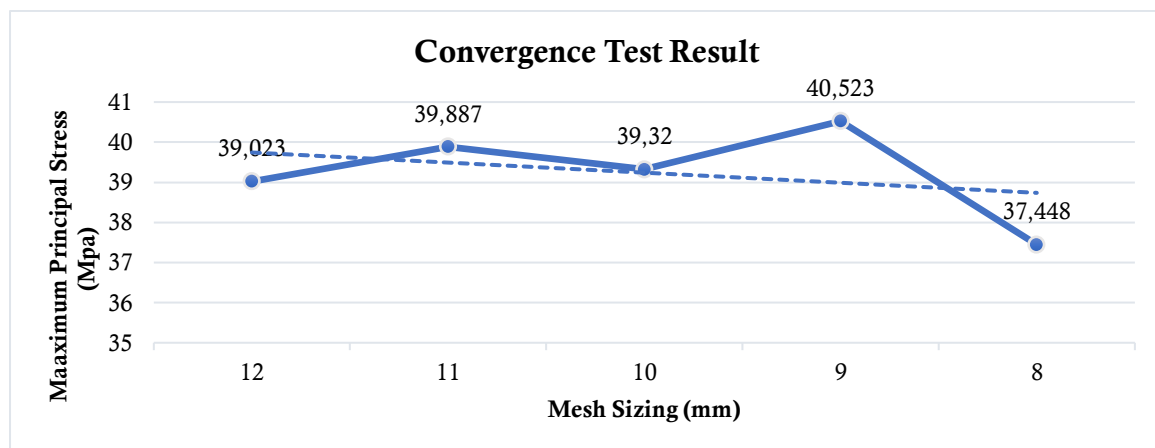


Figure 4 Convergence Test Graph

Based on the graph analysis, it can be seen that the resulting stress values exhibit stability, with the error margin decreasing as the mesh size decreases. After further evaluation, a mesh size of 10 mm was selected as the optimal size for perpendicular analysis. This decision was taken because at this size the smallest mesh error value was obtained, namely 1.142%, so it was considered capable of providing a balance between accuracy of results and efficiency of computing time. The smaller the optimized part thickness, the longer the simulation takes (Hunar et al 2020). Experiments with evenly distributing the material composition across the mesh elements and minimizing the number of elements at a certain material threshold can reduce mesh complexity. (You et al., 2015)

Load Simulation on Initial Upright Design

Initial design analysis using 7075 T6 and AL 2024 T4 materials is reviewed from three types of loading conditions, namely acceleration, deceleration and cornering. In this section, we will discuss the initial part of the upright design simulation results, and a comparison of the simulations can be seen in Figure 5.

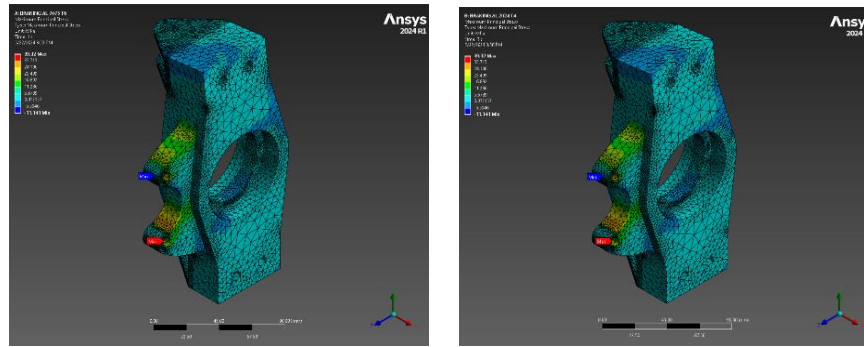


Figure 5 Maximum Stress in the initial design using the material (a) Al 7075 T6, (b) Al 2024 T4

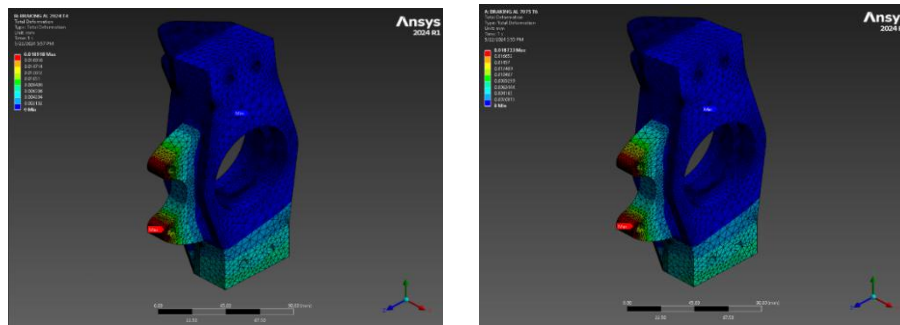


Figure 6 Total Deformation of Deceleration in Initial Design using material (a) Al 7075 T6 (b) Al 2024 T4

The initial finite element model was calculated and analyzed, and the stress contour and deformation of the frame under static load are shown in Figure 5 and Figure 6, respectively. The maximum stress value obtained is 39.32 MPa, and the maximum deformation is 0.019 mm for aluminum 7075 T6 and aluminum 2024 T4 materials. Therefore, the material properties of the initial structure of the designed racing suspension front frame have not been fully utilized, and weight reduction can be further optimized.

Based on the deformation simulation results under deceleration the upright experiences deformation. The red area indicates the maximum positive deformation, while the dark blue area indicates the maximum negative deformation. The Al 2024 T4 material has a larger deformation of 1.87×10^{-3} compared to the Al 7075 T6 material of 1.89×10^{-3} for deceleration loading, while the cornering upright experiences deformation in the Al 2024 T4 material of 4.21×10^{-3} compared to the Al 7075 T6 material of 4.17×10^{-3} . The material considered for the design of the rear upright was Aluminum Alloy 7075-T6 as it has superior mechanical properties in terms of stiffness (Wheatley et al., 2020) but in this case Al 2024 T4 is better. The Al 2024 T4 material experiences slightly greater deformation than the Al 7075 T6. Negative stress values were found for the right turn, this was found using a maximum principle stress probe at the critical location with positive values indicating tension thus negative indicating compression (Wheatley et al., 2020).

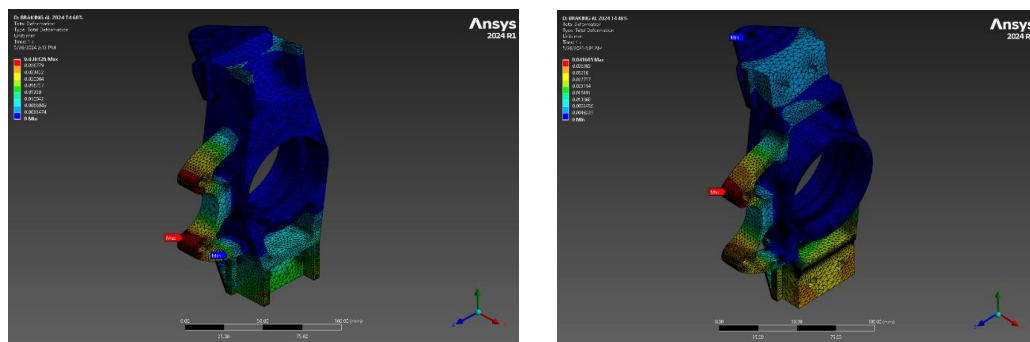
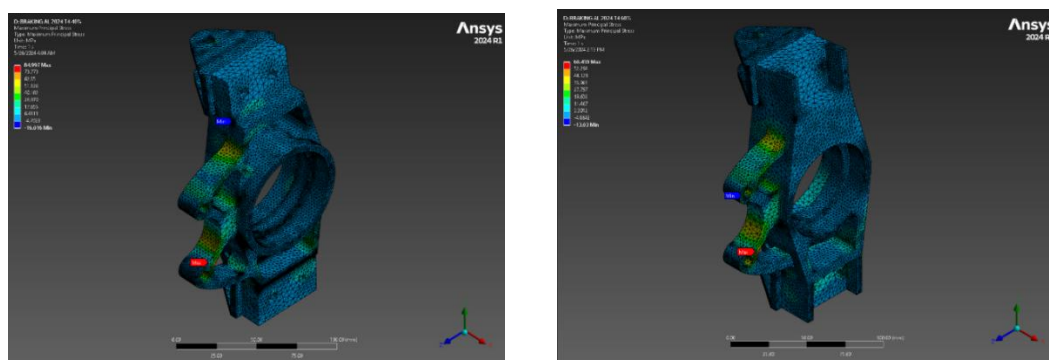
Analysis of Topology Optimization Simulation Results with 60% Mass Retain and 40%

Analysis of the initial design results with 60% and 40% mass retain using 7075 T6 and Al 2024 T4 and Al 2024 T4. This analysis is reviewed from three types of loading conditions, deceleration and acceleration.

Table 3 Loading Optimization Simulation Results

Material	Mass retain 60%			Mass retain 40%		
	Maximum Stress (MPa)	Total Deformation (mm)	Safety Factor	Maximum Stress (MPa)	Total Deformation (mm)	Safety Factor
Acceleration						
Al 7075 T6	4.4876	0.00461	15	9.846	0.00831	15
Al 2024 T4	4.5118	0.00465	15	10.079	0.00839	15
Deceleration						
Al 7075 T6	60.459	0.02983	8.6644	84.997	0.04119	6.3359
Al 2024 T4	60.459	0.03013	5.3399	84.997	0.04161	3.9048
Cornering						
Al 7075 T6	10.852	0.00488	15	14.106	0.00541	15
Al 2024 T4	10.607	0.00493	15	15.245	0.00546	13.572

From the table, it is found that the total deformation of the Al 7075 T6 material has a lower value of 0.02983 compared to the Al 2024 T4 material. 7075-T6 has a higher yield stress but lower toughness compared to 2024-T4 (Zhi xing, wang, & Xiu Jiang, 2013). While 7075 exhibits superior strength, its high machining costs and susceptibility to welding defects limit its feasibility (Ding et al., 2025). Then, The higher the safety factor compared to the minimum limit, the stronger and safer the component (Wakid et al., 2020). This improvement could potentially enhance suspension responsiveness and cornering stiffness—critical parameters for competitive performance.

**Figure 7** Total Deceleration deformation using Al 2024 T6 material with (a) mass retain 60% (b) mass retain 40%**Figure 8** Simulation results of maximum stress deceleration using Al 2024T6 material with (a) Mass Retain 60% (b) Mass retain 40%

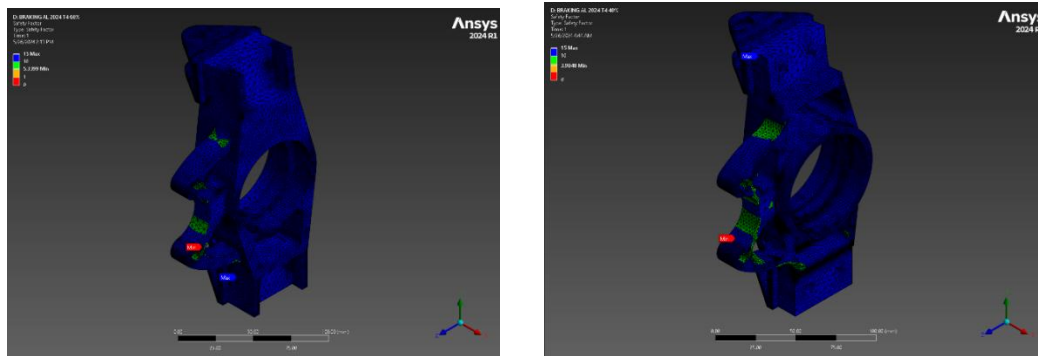


Figure 9 Safety Factor Deceleration Simulation Results using Al 2024T6 Material with (a) Mass Retain 60% (b) Mass retain 40%

According to the results of the static analysis, where the blue area denotes the optimized area while the red area denotes the non-optimized area, and the optimization constraint is set to 60% and 40% of the selected area mass. The maximum deformation and stress value was good enough to avoid failure in structure. Furthermore, the distribution of stress was below the yield strength of the material. So that with the maximum stress value being much smaller than the yield point value, the weight of the optimized structure is reduced (Li, Tan, & Dong, 2020). Topology-optimized upright 40% lighter, but it is also designed to withstand maximum loads with a safety factor greater because of uprights are among the unsprung parts of the chassis, where each lightening of the material has a great influence on the driving properties, for example In high-dynamic racing scenarios, even minor mass reductions can substantially enhance handling responsiveness and energy efficiency (Ding et al, 2025). In other condition although reducing the shape and weight is lighter, it doesn't reduce the stiffness. The shape optimization gives small change in deformation when several loads are applied, which means that change of volume and shapes does not influence significantly to stiffness of the structure (Azmeer et al., 2017).

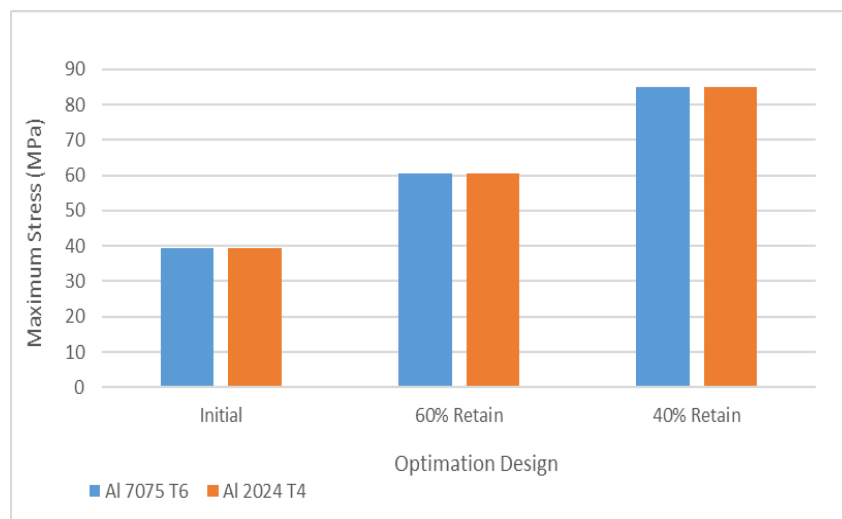


Figure 10 Maximum Stress Comparative Simulation Results

Based on the graph in Figure 8, a comparison of the maximum stress on the uprights shows that the maximum stress occurs in the range of 40–90 MPa. After optimizing the design with 60% mass retain, the maximum stress was approximately 60 MPa. Then, a further reduction was made with 40% retain, increasing the maximum stress to 80 MPa.

The graph shows that optimizing the design with a 40% mass retainer will increase the maximum stress that occurs in the material, this is in accordance with reducing the weight of the upright will increase the strength of the upright (Kumar et al., 2019). Based on the maximum stress results at a 40% mass retainer, this value is lower than the yield stress of the material, so the design

with a 40% mass retainer is acceptable. During the optimization, we were maintaining the structural strength of the construction of the upright, despite the mass reduction, thus preserving or even increasing the safety of use.

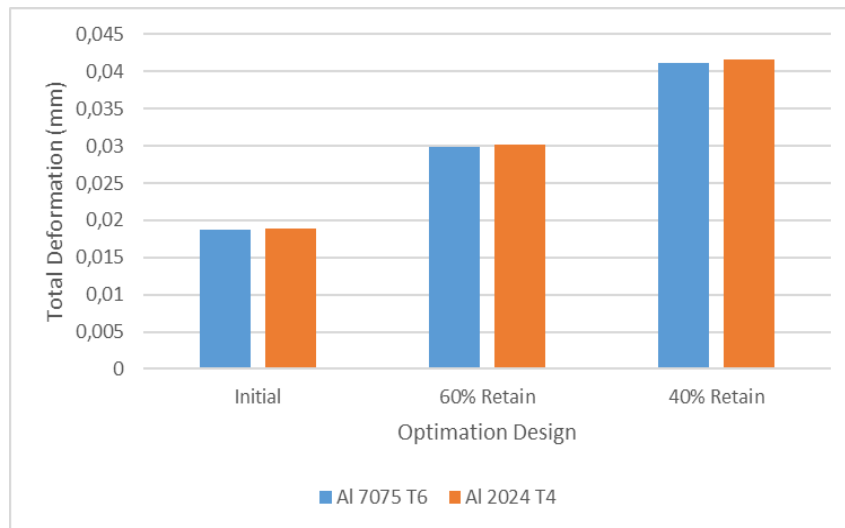


Figure 11 Total Deformation Comparative Simulation Results

Based on the graph shows the total deformation in the initial condition until the mass reduction occurs in the upright design. In the initial condition the deformation that occurs is around 0.02 mm, after a 60% mass reduction the total deformation increases to 0.03 mm. then a 40% reduction in the total deformation increases to 0.04 mm. Various parameters such as Von-misses Stress, and Total Deformation are analysed in both manufacturing methods designed for Upright There is a significant mass reduction in the 3D design (Mittal., 2020).

Comparison between the initial design and the optimized design based on the differences in mass, safety factor, maximum principal stress, and deformation. The optimized result can be considered good if it meets the following requirements The deformation is minimal and does not exceed the specified deformation limit and It has the lightest mass. The upright with optimized topology allows development for the next season, with the aim of reducing weight and increasing stiffness. One benefit of the topological optimization is that the geometry created with this method has better deformation values than the geometry made by the generative design (Mihaly at al., 2024).

CONCLUSION

Based on the research, the best design recommendation is with a mass retain of 40%. Based on the Initial Design, the Al 2024 T4 material has a mass of 1118 g with a maximum deformation of 0.0189 mm. At a mass retain of 40% of the Al 2024 T4 material, the mass reaches 454 g with a total deformation of 0.0416 mm and a maximum stress of 84,997 Mpa. 0.04161. Based on the comparison of simulation results in, the upright mass retain 40% design with Al 2024 T4 material can still be applied to the suspension of racing cars, especially formula student cars. The deformation value that occurs in the upright mass retain 40% does not cause the car to experience changes in vehicle behavior and does not cause failure. The safety factor value that occurs in the upright mass retain 40% is said to be safe and meets safety standards. According to the structural characteristics of the topologically optimized geometric model obtained by the finite element analysis of the suspension front upright to meet the performance requirements, the mechanical manufacturing process was designed. The upright mass retain 40% design can be manufactured using a 3-axis CNC. Manufacturing is done in three stages or sides and uses one jig and suggested that it is very necessary to validate the simulation results and ensure the design meets technical and safety specifications.

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