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Design Optimization of Lightweight Lower Control Arm using Finite Element Method

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Abstract:

The lower control arm (LCA) is one of the important components in suspension system. The main function of the LCA is to manage the motion of the wheels and hold the wheels to go up and down when hitting bumps. In general, most of the control arm made from steel. Although it has higher strength properties but the weight of it can be found excessively heavy in automotive industry without any changes to its design. Light weight and high strength characteristic in the replacement of materials has become the mainstream method in the automotive industry since the weight of the vehicle will affected fuel consumption. In this article, the CAD Models were prepared using SolidWorks Software & finite element analysis using ANSYS software. The main significance of the analysis is to determine the optimal design among the three models of LCA that have been designed by comparing the maximum Von Mises Stress, total deformation and safety factor. The FEA results show that the proposed design (third design) of LCA can be considered as an optimum design due to lowest maximum Von Mises Stress, total deformation and safety factor, 96.407 Mpa, 1.116E-8 mm and 1.0373 respectively In additional, the comparison based on the weight and material cost of aluminum and Polyetherether ketone (PEEK) LCA using optimal design also was made. The comparison result shows that the production of LCA using the PEEK material is cheaper and lighter than aluminium material which reduced the weight of LCA up to 67% and 21% reduced in term of material cost.
Keywords: *lower control arm, finite element analysis, PEEK, fuel consumption, design optimization*

I. INTRODUCTION

The suspension system of a vehicle refers to the group of mechanical components that connect the wheels to the frame or body. A great deal of engineering effort has gone into the design of suspension systems. Suspension system plays an important role for a comfortable ride for passengers besides protecting the chassis and other working parts from getting damaged due to road shocks [1]. In term of safety, the strength of the design and the material used are play the main importance roles. For every car design the safety test will be run before it goes to the market to test either the vehicle are safety to use by the consumers.

Based on the lower control arm, it is the main part of suspension system that contributes the handling performance of the vehicle. The design of the lower control arm must have enough strength and stiffness to withstand the loads during braking and cornering of the vehicle. For the case of the failure of the lower control arm are occur at the fixed support which connected to the chassis of the vehicle as the load are distribute to the component of the lower control arm that connected to the wheel [2]. Most failure happened due to the motion of the LCA is up and down with the contribution of vibrations during running condition. During movement of the vehicle, the wheel can hit the bump and create vibration and repeated forces at the LCA. Thus, normally the variable forces can lead to the failure and fracture of the LCA at the welded joint [3]. In the modern technology, automotive must achieve the personal demands from users including elements of safety performance respectively such as safety, comfort and support the trend toward in improving the strength, stiffness at the same time can reduce the weight of the vehicle. A vehicle's weight is an important factor since it will affect the fuel consumption [4].

In the automotive industry, the principle of lightweight is the major requirement for the design development of automotive parts and components due to reducing the rate of fuel consumption. Nowadays, there are a lot of researchers that making research to reducing the weight of the automotive parts [5, 6, 7]. One of the ways for weight reduction is by optimizing the design of the automotive parts such as control arm, drive shaft and etc. In the way to reduce the weight of the control arm, they have to reduce the thickness of the sheet metal used and also suggesting the most suitable material. In addition, the cost of the lower control arm production also can be reduced. This can leads saving the cost and the quality of the product can be improved [8]. Furthermore, by substituting the materials also take the main role play for weight reduction. Besides of changing the materials, the strength and the stiffness of the materials also must be acceptable of safety requirement. This is very important to withstand the various loads and forces that are exerted from the road surface condition to the wheels and transmits to the chassis of the vehicle. The requirement for the improved design is the aim of this study to achieve the optimum design structure and the selections of materials of the lower control arm.

II. METHODOLOGY

The lower control arm consider as one of the most important parts of the suspension system, thus in this case an optimal design is required for better performance in order to make the vehicle more comfortable and safe. However, in this study two designs were developed based on the existing design to identify the most optimal design. All the designs were created using the SolidWorks software.

A. Initial Design

This design is considered as the reference for this study as it is model by previous researcher [5]. The FEA results of second and third design were compared to the FEA result of initial design. Therefore, the best design which maximum stress value is less than PEEK yield strength was selected as the optimal design. In the following Fig. 1 is the 3D model of the initial design.

Fig. 1. 3D Model of the Initial Design

B. Second Design

After completing the initial design, it has been modified to become the second design which the middle pocketing area of the initial design is removed. The second design is as shown in Fig. 2.

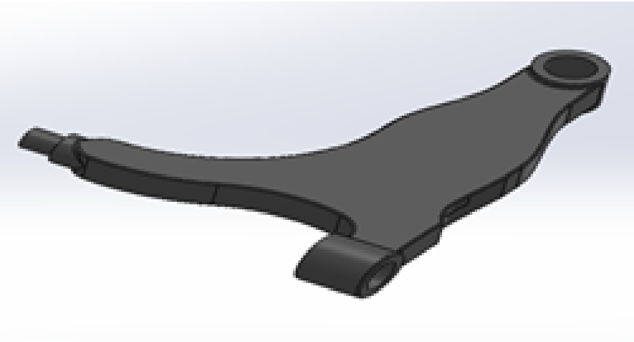

Fig. 2. 3D Model of the Second Design

C. Third Design

The second design also has been improved to third design by add a rib on the side of lower control arm in obtaining the optimum design. Fig. 3 shows the 3D model of the third design.

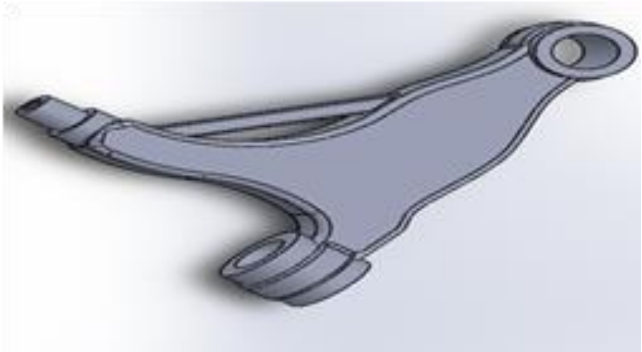

Fig. 3. 3D Model of the Third Design

D. Load Applied and Boundary Condition

The lower arm of the suspension system has two regions that attached to the vehicle; one is connected to the vehicle chassis and the other to the wheel. In this case, it is assumed that there is no rotational motion but, there is displacement in the z axis. However, the load condition of the lower arm of suspension system has been determined by testing various values of loads. The loads have been applied on the ball joint and the rear mount point where the front mount rear is fixed. Hence, it is possible to impose them to lower arm in order to make a real condition for the analysis. Furthermore, the loads used for this simulation are from 500 to 3000 N. The Fig. 4 shows the loads and it is direction and the fixed point.

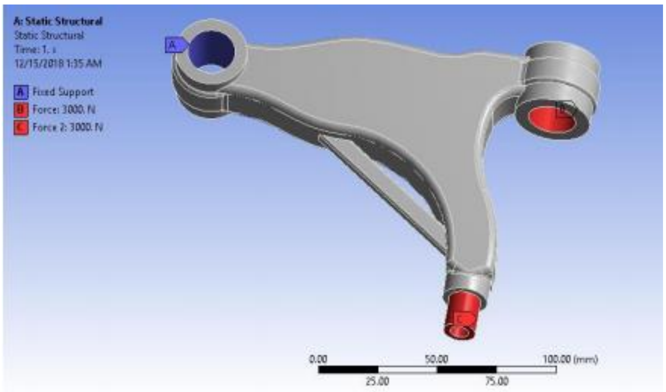

Fig. 4. Load applied and Boundary Condition

There are two materials were used for lower control arm in this study which are aluminium and Polyether Ether Ketone. The material details are described as in Table I.

Table II: Material Properties

Property	Aluminium	Polyether Ether ketone (PEEK)
Density	2.6898g/cm3	1320kg/m^3
Yield strength	240 MPa	100 Mpa
Young's modulus	70 GPa	3.6 GPa
Poisson's ratio	0.34	0.39

E. Finite Element Model Validation

The model validation was carried out to check either the FE model and FEA setup is valid and correct. The boundary condition and load applied were based on previous study that already published [9]. The FEA result obtained should at least similar in term of the trend such as the critical location. Based on the result obtained as shown in Fig. 5, the critical location which is the maximum stress value of 297.106 MPa is recorded at the bushing curve. This critical location is quite similar as found by Taylor et. al. via experiment [10].

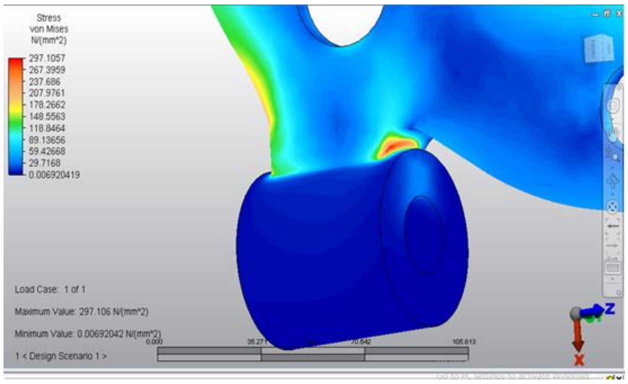

Fig. 5. Finite Element Model Validation

III. RESULTS AND DISCUSSION

The static strength analyses were conducted for all the three designs of the lower control arm using the polyether ether ketone (PEEK) material. Moreover, to select the most optimal design among the three designs of LCA, the stress value will be compared to the yield strength of the PEEK material which is 100 Mpa. The design that has max Von Mises Stress less than 100 Mpa will be chosen as an optimal design since max stress less than yield strength of the PEEK is considered will not fail or fracture.

A. Initial Design

The static strength analysis for the first design has been done and the result shows that the maximum

Von Mises Stress and the Total Deformation are 162.44Mpa and 2.8524e-8mm respectively. Since the maximum Von Mises stress value of the initial design is higher than PEEK yield strength, thus the design must be improved. The Fig. 6 and 7 are the FEA result for the initial design.

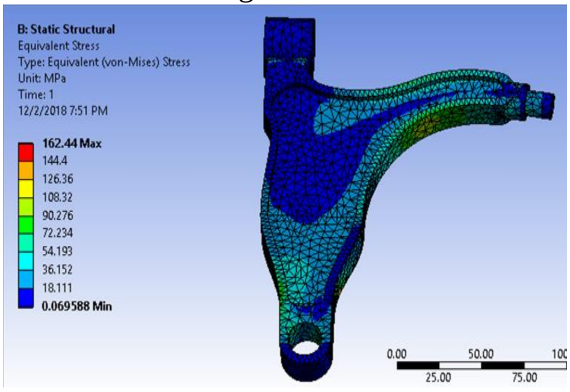

Fig. 6. Stress Von Mises for Initial Design

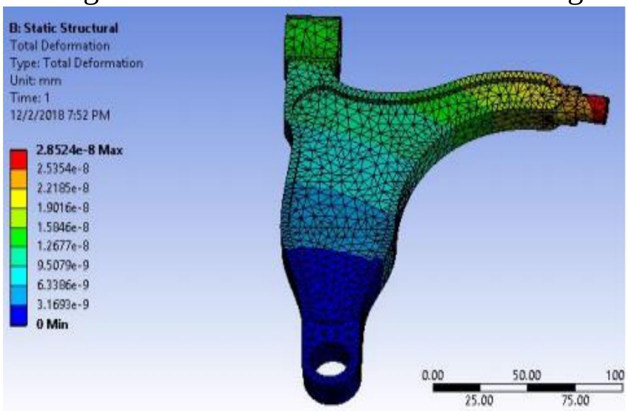

Fig. 7. Total Deformation for Initial Design

B. Second Design

After completing the analysis for the initial design which was inapplicable, the design of the lower control arm has been modified by removing the middle pocket area of the initial design where the high stress was found in it. However, the FEA results of the second design show that the Max Von Mises Stress and Total Deformation are 128.99 Mpa and 2.6694E-8mm respectively. The max stress has slightly decreased but it still more than PEEK yield strength (100 Mpa), thus the second design is also unsuitable for the lower arm to carry the highest load. The Fig. 8 and 9 below show the FEA results for the second design.

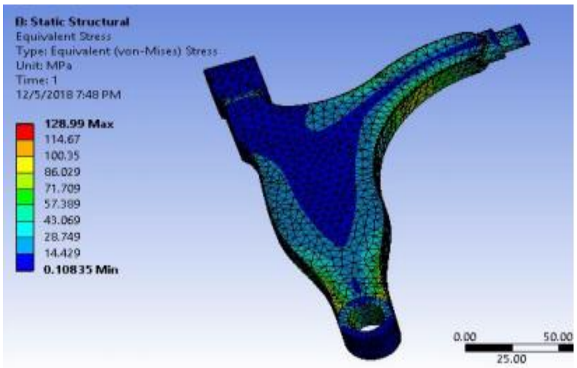

Fig. 8. Stress Von Mises for Second Design

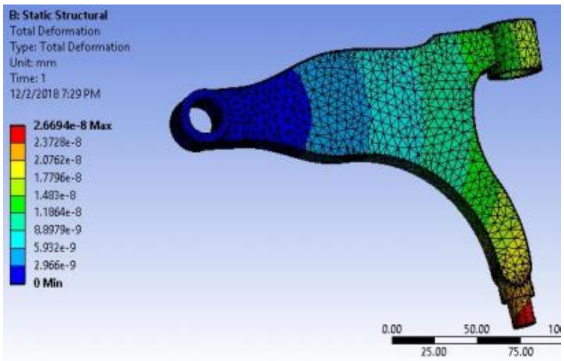

Fig. 9. Total Deformation for Second Design

B. Third Design

Since the first and second designs were inapplicable due to the higher value of maximum stress than yield strength of PEEK, the third design of the lower control arm has been modified by adding a supporting beam between the front and rear mount point. Though, the FEA results of the third design show that the Maximum Von Mises Stress is 96.407 Mpa and the Total Deformation is 1.116E-8 mm therefore, the Max Stress is less than the yield strength of the PEEK material which means that the third design is the most suitable design for the lower control arm that can carry the highest load. The Fig. 10 and 11 shows the FEA results for the third design.

May – June 2020
ISSN: 0193-4120 Page No. 1285 - 1291

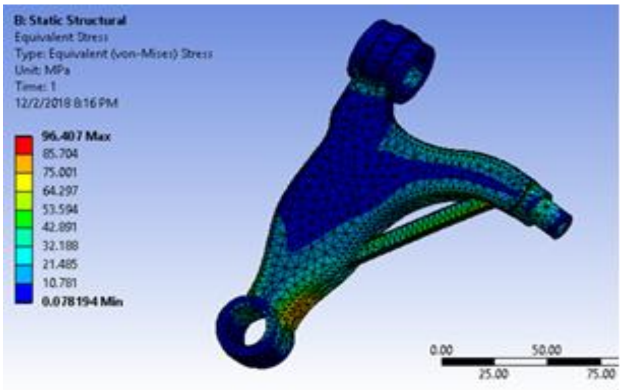

Fig. 10. Stress Von Mises for Third Design

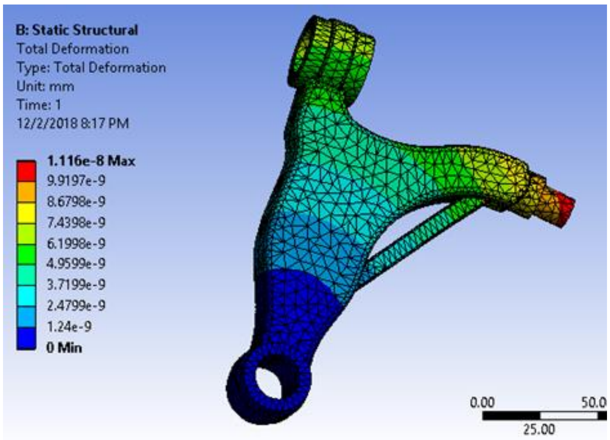

Fig. 11. Total Deformation for Third Design

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C. Optimal Design

The static analysis for the three design have been done and the third design was selected as the most optimal design for the lower control arm since its maximum stress is lower than yield strength of PEEK material and safe to use. Moreover, the safety factor of the optimal design is calculated as follow.

$$safety\ factor = \frac{yield\ strenght\ of\ the\ material}{maximum\ stress}$$

$$softey\ factor = \frac{100\ Mpa}{96.407\ Mpa} = 1.0372$$

Safety factor = 1.0372 › 1

The Max Von Mises Stress, Total Deformation and the safety factor for the selected optimal design at 3000 N load are shown in the Table II below.

Table II: Material Properties

Parameter	Value
Max stress	96.406 Mpa
Deformation	1.116E-8 mm
Safety factor	1.0373

D. Aluminium and PEEK Materials Comparison

Aluminium and PEEK materials will be comparing to each other based on the weight and material cost. The mass weight of both material for the optimal design of the lower control arm were obtained from the SolidWorks software as shown in the Fig. 12., The aluminium weight is 0.606271Kg and PEEK weight is 0.201452Kg.

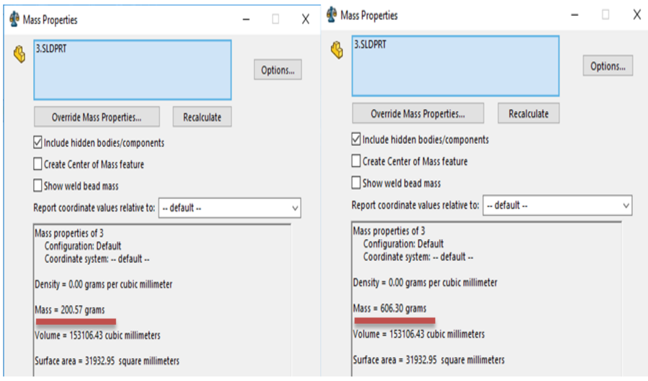

Fig. 12. Mass Properties of PEEK and Aluminium Lower Control Arm

While the material cost for both materials were as calculated below.

For Aluminium Alloy (6061-T6);
Aluminium weight = 0.606271 kg
Aluminium Alloy Price per 1 Kilogram = $2
Total price per 1 unit for aluminium = (2) × (0.606271) = $1.21

For PEEK;
PEEK weight = 0.201452 Kg
PEEK granule Price per 1 Kilogram = $5
Total price per 1 unit for PEEK = (5) × (0.201452) = $1.00

Table 3: Comparison Between Aluminum and PEEK in term of Weight and Price

Parameter	Aluminium	PEEK
Weight	0.606271 Kg	0.201452 Kg
Price per 1kg	$2	$5
Price per 1 unit	$1.21	$1.00

In general, the use of PEEK as a lower control arm material is better than aluminum in term of light weight and material cost. The using of PEEK for lower control arm can reduce up to 67% of weight and up to 21% reduced in term of material cost as shown in Table 3. Although the manufacturing cost of using PEEK for lower control arm still can be debated due to the need of lower control arm mould to produce PEEK lower control arm which it is well known that mould is quite expensive, so do the cost of die for aluminum lower control arm forging. Beside, further research need to do to analyze fatigue failure of our optimum design due to the repeating and continuous load occur when wheels hit the bump during car movement

IV. CONCLUSION

The FEA results show that the optimum design is the third design which it's maximum Von Mises Stress, total deformation and safety factor are 96.407 Mpa, 1.116E-8 mm and 1.0373 respectively. Moreover, the material comparison result shows that the production of 1 unit using the PEEK material is cheaper and lighter than aluminium material. Thus, it can be concluded that the third design of the lower control arm can be produced using PEEK material which is the most suitable material in achieving the lightest and cheapest automotive lower control arm.

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May – June 2020
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