International Conference on Advancements in Design and Tribology (ICADT 2021)

Design, Analysis and Testing of Composite Suspension A-arms

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Abstract: Reducing weight as well as maintaining structural integrity is one of the key challenges that Formula SAE teams face as we try to design the suspension of the formula car. Weight is one of the most important factors that affect a car's performance. Thus, carbon fibre tubes with aluminium housing were chosen to replace the conventional mill steel a-arms as composite materials are known for their stiffness to weight ratio. Using these materials helped in a weight reduction of unsprung mass by 58% without compromise in stiffness. In this paper, an exhaustive study on Carbon Fibre Suspension A-Arms is presented. Designing as well as testing of the composite a-arms is presented in this paper along the different parameter analysis which includes bond gap analysis, weight analysis, cost analysis and lap time analysis.

Keywords: Composite Suspension A-arm, FSAE, UTM machine, Vehicle Dynamics

1. Introduction

1.1 FSAE

FSAE is a worldwide collegiate competition hosted by the Society of Automotive Engineers (SAE). Teams composed of undergraduate and graduate students who design, build, and compete for a formula-style race car under combustion, electric and driverless category. More than a racing competition it is an engineering and project management competition. The event is broadly divided into three segments: Technical Inspection, Static Events and Dynamic Events. In the dynamic disciplines, teams compete in timed events on various track kayouts.

1.2 Suspension System

Suspension system is the most important systems that affects the performance of a car. Suspension systems supports both road handling and ride quality. There are various types of suspension systems that can be used for a car. But double wishbone suspension is one type that is used predominantly in FSAE as well as in formula one cars. Lowering the weight of components without compromise in stiffness is always one of the primary goals for suspension engineers as it increases the overall performance of car.

2. Fundamental Concepts

2.1 A-arm design procedure

Designing of the carbon fiber suspension is reported earlier [1, 2]. The procedure for design of control arms is depicted in Fig. 1. Design of control arms start with the selection of the type of tubes. Then, we start with the insert design. Insert supports the tube from inside or the outside depending on the design.

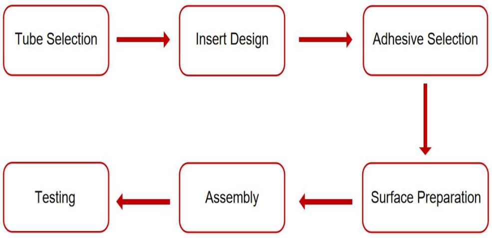


Figure 1: Design Flow

Then we begin with the glue selection. It is considered to be the weakest point or the point of failure and hence must be selected carefully. Surface preparation can highly affect the bond strength and the adhesive properties. It is done on the insert surface where our tube will be bonded. Some of the surface preparation that can be used are sandblasting, anodizing, and roughening. The method which gives maximum bond strength will be selected.

2.2 Tube Selection

Composite materials are known for their weight to strength ratio. But they also have anisotropic properties. Thus, the selection of tubes must be done carefully considering the directions of load conditions. Figure 2 shows the images of putrated and roll-wrapped tubes. Figure 3 shows a comparison between steel and carbon fiber tubes based on their selection criteria. Next came the selection between pultruded and roll wrapped tubes [3]. In pultruded tubes, 100% of the fibers are aligned along the axis of the tube. Roll-wrapped tubes due multi-directional fiber alignment have excellent torsional strength, axial strength, and lateral strength. Roll wrapped tubes were chosen as pultruded tubes are more prone to delamination. Also considering the loading conditions roll wrapped tubes were preferable.

Figure 2: Pultruded vs Roll-Wrapped Tubes

Figure 3: Radar chart- Mild Steel vs Carbon fibre

2.3 Housing Design

The previous design was made from mild steel which was welded with mild steel tubes. But with the goal of making it lighter, aluminum 7075-T6 was used. A single-piece aluminum housing that was designed which apart from reducing the weight also reduces the manufacturing effort than the previous design. Also, this design will more likely increase the accuracy of the a-arms as the problem of welding is eliminated with the new design.

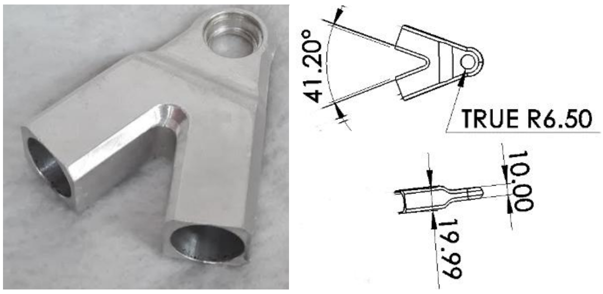


Figure 4: Housing Geometry

A design was made with a female insert rather than a male insert as it would require 5-axis CNC machine. Female insert design required 3-axis CNC machine which is easier to get our hands on. Also, the total manufacturing time would be reduced but with the downside of more weight than male insert design. Figure 4 shows the female insert design which was finalized. It weighed 76 grams and reduced the weight of housing by 32%.

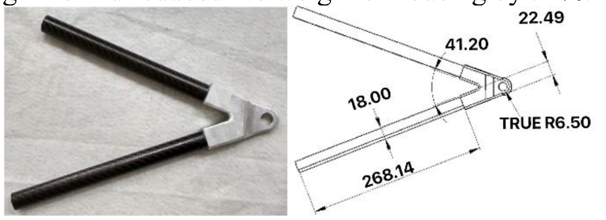
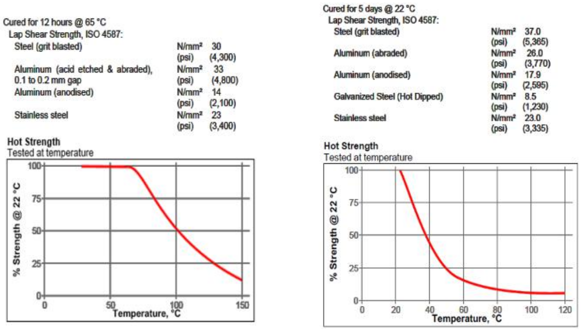


Figure 5: A-arm design geometry

2.4 Glue Selection

Various epoxy adhesives from different companies like Loctite, 3M, and Araldite were searched and listed. These glues were then narrowed down based on availability, cost, strength, and reviews from FSAE forums. Finally, adhesives for tests and application selected were E-120hp and 9466 hysol. These adhesives were selected based on their application for bonding different substrates, especially between metal and fiber.

A part of the technical data sheet is presented below which helped us in selecting the optimum glue [4, 5].



Cured for 12 hours @ 65 °C
Lap Shear Strength, ISO 4587:

Steel (grit blasted)	N/mm² (psi)	30 (4,300)
Aluminum (acid etched & abraded), 0.1 to 0.2 mm gap	N/mm² (psi)	33 (4,800)
Aluminum (anodised)	N/mm² (psi)	14 (2,100)
Stainless steel	N/mm² (psi)	23 (3,400)

Cured for 5 days @ 22 °C
Lap Shear Strength, ISO 4587:

Steel (grit blasted)	N/mm² (psi)	37.0 (5,365)
Aluminum (abraded)	N/mm² (psi)	26.0 (3,770)
Aluminum (anodised)	N/mm² (psi)	17.9 (2,595)
Galvanized Steel (Hot Dipped)	N/mm² (psi)	8.5 (1,230)
Stainless steel	N/mm² (psi)	23.0 (3,335)

Figure 6: Glue comparison datasheet
a) E120Hp, b) 9466 hysol

From the above Two adhesive E120Hp is selected as sstrength of Loctite 9466 A&B for temperatures rise from 22degrees to 30 degrees decrease by 50%. According to our prior experience from testing the temperatures would normally rise above 30degrees. Also due to the unavailability of Loctite 9466 A&B, it was decided to shift to an adhesive that could maintain strengths at higher temperatures and at the same time was easily available. Loctite E-120 HP was selected which could continue maintaining strengths of up to 75% till 80 degrees.

2.5 Loading Conditions

The forces on A-arms were found using a self-developed MATLAB calculator. Forces were calculated for 1.3g braking and 3g bump force conditions as braking results in maximum forces on arms. Figure above shows the forces on arms where negative sign means compression and positive is for compression. The loading conditions were chosen according to the car specifications and the competition track. The team uses a Hoosier tyre with R25B compound and from previous experience and validation it is known that the tire can produce a maximum of 1.3g braking condition.

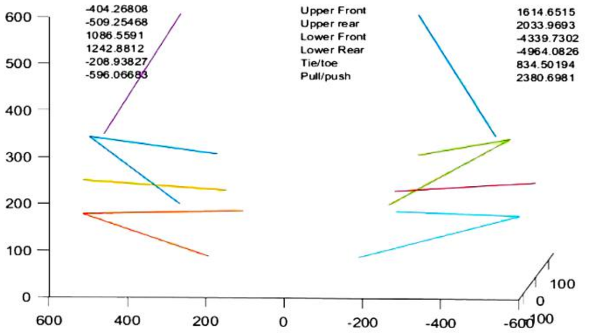


Figure 7: Loads on A-arms in MATLAB calculator

Moreover, braking conditions were used over acceleration as maximum loads act on a-arms during braking conditions. Comparing figure 3-10 and 3-11 shows the difference in forces during maximum braking and maximum cornering condition Also a bump force of 3g was chosen based on the track and the data recorded by the team during previous competition. Although the bump force recorded was less than 3g but as it's our first design a higher FOS was kept.

3. Verification

3.1 Computational Analysis

Ansys software was used for the analysis of the a-arm housing. Aluminum 7065-T6 was the material used as it is stronger than pure aluminum. After material selection, the first step was meshing. Mesh study was done where edge lengths of 0.21, 0.18, 0.15 mm were simulated. Since 0.18 gave an acceptable result without too much computational effort, it was finalized.

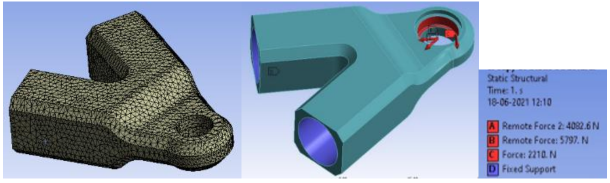


Figure 8: a) Meshing b) Boundary Conditions

Tetrahedral cells were used in the mesh to obtain the maximum number of nodes possible. Refinements were applied on the faces where loads were to be applied. The part where the tube would be glued was considered as fixed support and the loads were applied at the center of the bolted joint along the direction of tubes as shown in figure 8. Finally, the model was solved to obtain the solutions for total deformation, maximum stress, and FOS.

Result Plots: The analysis showed that the maximum deformation obtained was 0.14 mm and was close to the fixed bolted joint. Also, the minimum FOS was 2.94 which was sufficient according to the load conditions. The maximum stress was less than the ultimate tensile strength of Al 7065-T6. Figure 9 shows the analysis results

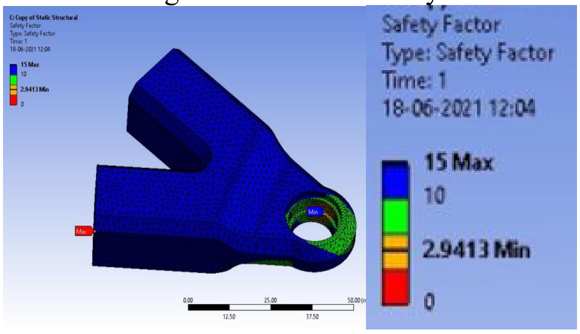


Figure 9: FoS results

Another simulation model of the assembly was made to analyze the loading on the assembly. To verify the results from the model, a simplified model was made based on UTM testing. These results can be verified by simple hand calculations to check if the results are within a margin of error. Further, testing on UTM can be done to validate the simulation model.

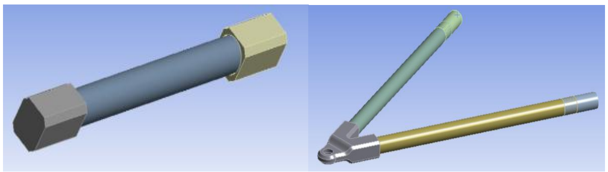


Figure 10: a) UTM model b) A-arm model

The UTM Model is a simplified version of the actual assembly to verify and validate the simulation model. The major difference is that this model consists of only one tube with housing on each side of the tube. The loading is done similarly to the loading scenario in an actual UTM. One of the housing ends is fixed. While the load is applied to the housing at the other end. This creates symmetric loading on either end. Such a loading leads to stresses in the composite tube and the glue bonding the tube with the housing.

Figure 11: Boundary Conditions for UTM model

The model assembly consists of the following parts:

- Tube
- Insert (one each on the left and right)
- Glue geometry (one each on the left and right)

The tube was modeled as a shell geometry and then specified as a composite layup in Ansys ACP and Hyperworks. The thickness of the tube is 1mm with an ID of 16mm and an OD of 18mm. The insert geometry is a simplified version of the actual insert geometry such that it could be used for testing in a UTM.

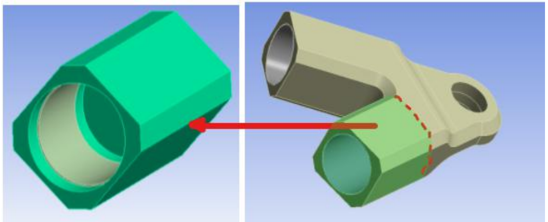


Figure 12: Simplified insert from housing

It has a simple shape which represents the half part of the actual housing in the A-arms. The material selected for this was Aluminum 7065-T6. The glue geometry was modelled using a tube-shaped geometry. The thickness of the glue was kept at 0.25mm for the initial iteration.

Meshing: The meshing for the insert is done the same as in the analysis shown earlier for the housing. However, since we have already optimized the critical part of the housing geometry, the resolution of the meshing is of lesser importance when simulating the entire assembly. To save on computational resources, a tetrahedral dominant mesh with a cell size of 1mm is chosen for meshing the insert. Similarly for the glue body a hexahedral mesh with a cell size of 1mm is chosen. However, it is soon apparent that such a cell size of 1mm for the glue geometry is too large to calculate the shearing stresses which act across the glue layers. Hence, an inflation layer is added across the cylindrical surface to get better resolution in that section. This helps in better resolving the shear stresses across the glue surfaces. For the tube meshing, A simple hexahedral mesh with element size 1mm was chosen which runs along with the face meshing. This is to mainly evaluate the tensile stresses along the tube length.

Result Plots: The main part to be analyzed is the glue layer which has about 25 MPa of stresses developed in it. However, maximum shear stresses reached are about 15 MPa.

Equivalent Stress (Von Mises) [In N/m^2]

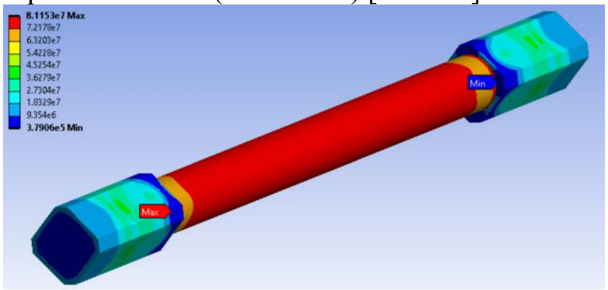


Figure 13a: Equivalent Stress (Von Mises)

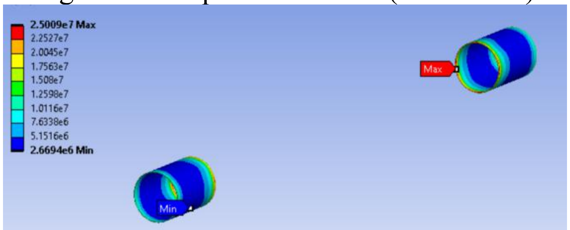


Figure 13b: Maximum Shear Stresses

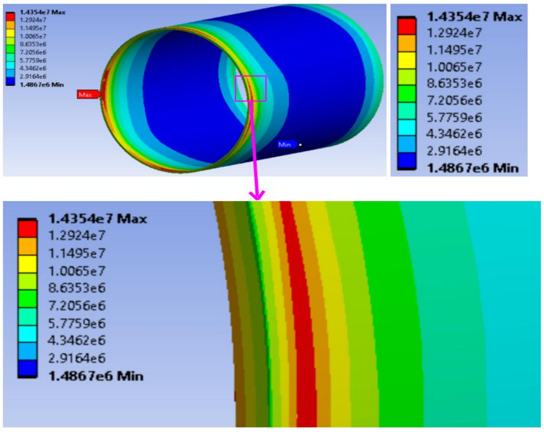


Figure 13c: FE Analysis results of UTM model

3.2 UTM Testing Results

Since all the properties can't be exactly predicted with simulations, the model was verified with actual testing. For this a different UTM housing insert was made with similar parameters. This model also helped test for surface preparation methods and bond gap when applying the adhesive which have drastic effects on glue strength. The UTM testing of sample is shown in figure 14.

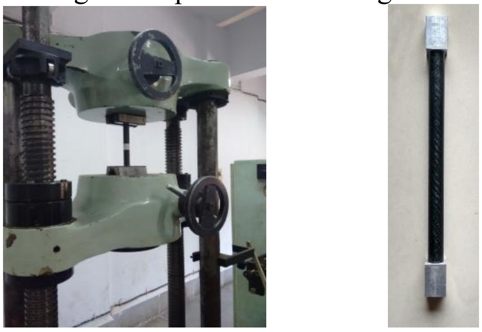


Figure 14: a) Testing of sample b) UTM sample

The results were obtained for varying bond gap after testing on a standard UTM. Surface preparation methods like sandblasted as well as roughened inserts for various bond gaps were tested. The results obtained were as shown in the figure below.

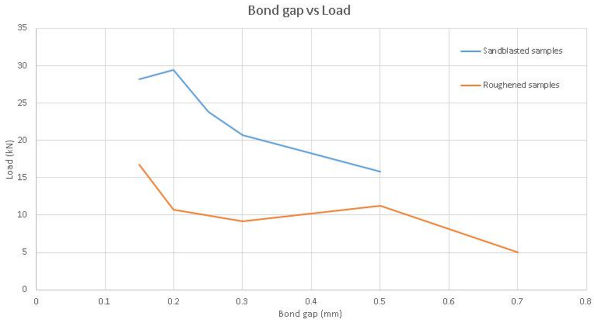


Figure 15: Bond gap vs Load to failure

3.3 Parameter Analysis (Weight, Cost, Lap time)

Weight Analysis: Weight reduction was the main goal of this project. Since we know carbon fiber and steel both being 5 times and 2.5 times lighter than steel helped us in weight reduction by more than 50%.

Table 1: Weight Analysis of old and new designs

All weight is in kgs	Front		Rear	
Component	Mild Steel	Carbon Fiber	Mild Steel	Carbon Fiber
A-arm rods	2.164	0.678	1.958	0.586
Inserts	0.104	0.037	0.104	0.037
Upper Housing	0.412	0.316	0.434	0.16
Lower Housing	0.218	0.192	2.702	0.358
Total	2.898	1.223	2.702	1.141

Table 1 shows the detailed weight distribution of each part. As we can see from the table, tubes were the major source of weight reduction, and they alone reduced the weight by approximately 40%. Also replacing the mild steel housing with aluminum housing helped us with further weight reduction. The original weight was 5.6kg which after the new design will be reduced to 2.364kg. Thus, the total weight reduction achieved by the new design was 3.264kg.

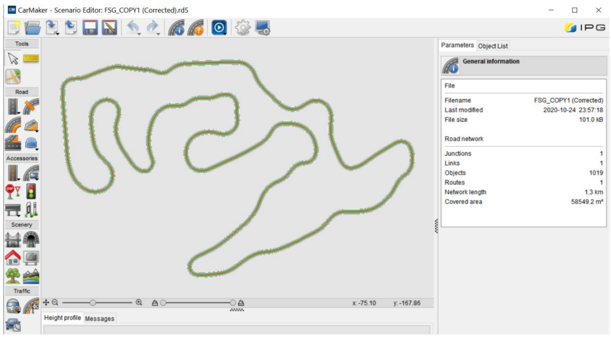
Cost Analysis: The original design and the new design required completely different material and manufacturing methods. The older one had processes like laser cutting, facing turning on a manual lathe, and welding where the new design required high precision CNC milling and expensive materials like epoxy glues. Cost analysis was carried out for the two designs. We compared the raw materials as well as the manufacturing and assembly cost for the two designs.

Table 2: Cost comparison of old and new designs

All cost is in INR	Mild Steel		Carbon Fiber	
Type of Cost	Component	Cost	Component	Cost
Raw Material	MS Tubes	2300	CF Tube	7000
	MS Sheets	200	Glue	13000
	MS Billet	350	Aluminum	1050
Manufacturing Cost	2.898	1.223	2.702	1.141

Table 2 shows the cost distribution for both designs. For the manufacturing cost, self-developed excel based calculators were used which gave us the process hourly rate. The total time of manufacturing was taken from the manufacturer and hence the final cost for each process was calculated. We can see that the cost for the new design has increased almost 6 times. The major rise in cost was due to the raw material cost which is clearly depicted in figure below. Carbon Fiber being expensive along with the high-strength epoxy glue was the major source of cost. Also, advanced high precision CNC machining and nonconventional machining like waterjet also added to the rise in the cost of the new design. Although this may seem that the cost has increased by 600% if we consider the total cost in making the vehicle this increase in cost is only 0.5% and its performance, weight, and other benefits outweigh this 0.5% extra expense that the team will have to bear.

Lap time Analysis: IPG carmaker software is used by the team for the time and performance-based simulation. IPG carmaker provides us with the option of varying the car parameters as well as the track of the car. This is quite useful for analyzing the behavior of any changes in terms of car performance and see how it affects the overall time. Figure above shows in short, the steps on how to use IPG Carmaker for time-based simulation.



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Filename FSG_COPY1 (Corrected)
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Road network

Junctions 1
Links 1
Objects 1019
Routes 1
Network length 1.3 km
Covered area 58549.2 m²

Figure 16: IPG Carmaker for lap time

We used IPG Carmaker to find the delta in time due to the reduction in weight caused by the new suspension control arm design for all the events at FSAE competition and the time for each event was recorded. Formula Student Germany endurance track was used to compare the endurance event lap time changes. First, the simulation with the original weight was conducted followed by the reduced weight. Table 3 shows the time for both designs the delta as well in time due to the design change. Although the time changes may look small, we will get a better understanding once we see the gain in points, we get for all events due to these time changes.

Table 3: Lap time Analysis

All times are in seconds	Time (old)	Time (new)	Time (delta)
Skidpad	4.76	4.75	0.01
Acceleration	3.74	3.72	0.02
Autocross	79.09	78.36	0.73
Endurance	1758.24	1752.3	5.94

4. Conclusion

In this report the design procedure along with how the components were selected for the new design was explained. We had finalized roll wrapped carbon fiber tube and E-120HP epoxy glue for our suspension. New a-arm housing was designed with aluminum 7065-T6 which further reduced the weight.

- Minimum FOS of 2.9 was achieved with total deformation less than 0.14mm.
- FEA analysis of bond strength was also performed on Ansys as well as Hyperworks with a model like tensile testing on UTM. The stresses obtained were less than the failure strength given in the data sheet hence the design was validated and approved.
- The effect of the new design was also analyzed based on 4 other parameters which included weight, cost , lap time and points.
- Weight analysis showed us that the new design reduced the weight by approximately 58% from the original design.
- But the cost analysis showed us that the cost of the new design was almost 6 times the cost of the original design and raw material was the main source of cost.
- Although the lap time analysis did not show any significant gain in time for each event, we get a clearer idea when the time is compared with the number of points gained in each event. The resultant lap time reduction gave the team approximately an additional 10 points.

5. Acknowledgement

We would like to express gratitude towards K J Somaiya College of Engineering for giving opportunity to work on this topic. We would like to thank our teammates at Orion Racing India; especially J. Shah, P. Jhaveri & S. Shaikh without the support of whom this project would not have been possible.

6. References

[1] Tube research by Reid Olsen, Andrew Bookholt, Eric Melchiori: 2010 at California Polytechnic State University, San Luis Obispo.
[2] Design of a Carbon Fiber Suspension System for FSAE Applications by Alban C. Cobi
[3] Guide to Composites - Gurit
[4] Adhesive Bonding and Integrally Cocured Structure: A Way to Reduce Assembly Costs through Parts Integration
[5] ISO 4587:2003 - Adhesives — Determination of tensile lap-shear strength of rigid-to-rigid bonded assemblies