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Development of Carbon Fibre Suspension Linkages for Formula Sae Vehicles

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Abstract: *Reducing weight while maintaining structural integrity is one of the key challenges of Formula SAE teams, during the design of suspension of the formula car. The purpose of this paper is to present experimental data on designing and optimizing a carbon fibre suspension system for formula cars. The reason carbon fibre suspensions are favoured over the current steel suspensions are because they can reduce the weight of the suspension system by 75 %. Pull tests on a universal testing machine were performed on two different specimens made of carbon fibre tubes with different inserts bonded on each tube i.e. mild steel and aluminium insert. Pull tests were carried out to test the strength of the adhesive bond between the aluminium and mild steel inserts with the carbon fibre rod. Aluminium insert adhesive bond failed at 18.14 kN and the Mild Steel insert adhesive bond failed at 16.24 kN. Both of them are much higher than the maximum force the rods will experience.*
Keywords: *Suspension, A-arm, Carbon Fibre Reinforced Plastics, Adhesive, Formula Student/Formula SAE competition*

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I. Introduction

The suspension system of a race car transfers the forces acting on the tyres to the chassis of the car. A basic level suspension system is a system of linkages which limits the degree of freedom of a wheel with respect to the car. Most of the race cars use a wishbone type suspension system. Each car will have a different geometry of suspension linkages depending upon the requirements. But at a basic level, each suspension geometry can be defined as a series of binary linkages which are interconnected. These linkages transfer enormous amounts of forces during certain worse case scenarios. Thus, it has to be strong enough to withstand it. Traditionally MS rods were used to manufacture it due to its strength and reliability.

II. Carbon Fibre Suspension Linkages

3D model of the CFRP suspension linkages are shown in Fig.1.

2.1 Sprung mass vs unsprung mass

In a racing car it is always a priority to reduce the weight of the car for better acceleration but it is even more advantageous to reduce the unsrpung weight of the car or in other words the parts which are always moving with respect to the body of the car. Suspension linkages form an unsprung mass and make it lighter for better performance. Thus it was decided to use any non conventional technique to create lightweight and reliable suspension arms.

2.2 Design constraints

The main function of CF rods is to take the compressive and tensile forces from the upright of the car and transfer it to the chassis. All the rods can be approximated as 2-force members and these linkages must be strong to withstand compressive and tensile loads of 7,000 N. The outer diameter of the rod should be kept low (<18 mm) so that the rods won't interfere with other components when they move. It should be detachable from the other components of the car. Due to manufacturing errors in other parts of the car there should be a method to vary the length of the rod by small amounts for perfect assembling. Keeping in mind the various design constraints, the following design was innovated and implemented. The various components of the design are as follows

- A-arm end
- Mild steel inserts
- Aluminium inserts
- Adhesive

- Carbon fibre rod
- Threaded insert

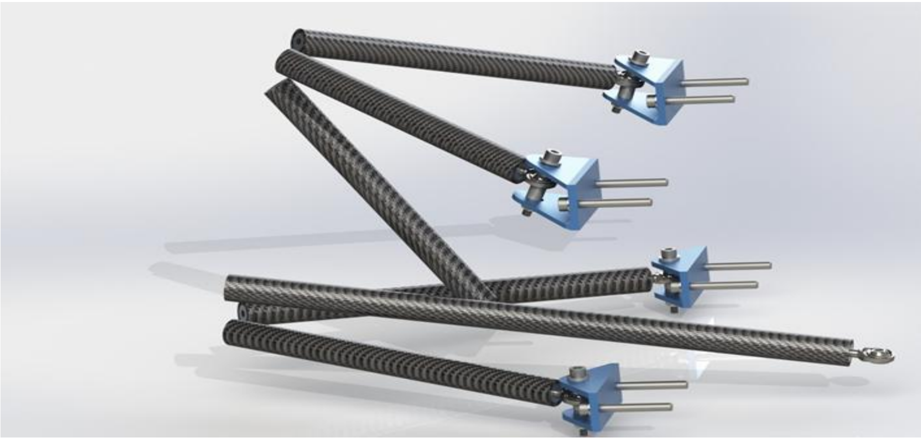

Fig.1. 3D model of the CFRP suspension linkages

1.1.1. A – arm end

A-arm end (Fig.2a) is an integral part of the suspension geometry which connects the suspension linkages to the upright and hub. To implement carbon fibre linkages the design of A-arm ends has to be modified from the conventional design. It was decided to make A-arm ends out of aluminium 6061. It was not possible to directly join the carbon fibre rods and the A-arm end because it might be manufactured again in case the rods didn't align exactly with the chassis of the car due to manufacturing errors. Also it was advantageous to have a small control over the length of the linkages to tune the vehicle dynamics parameters. Hence it was decided to join the A - arm end and the carbon fibre rods using threading. By loosening or tightening the threads it is possible to adjust the length of the rods.

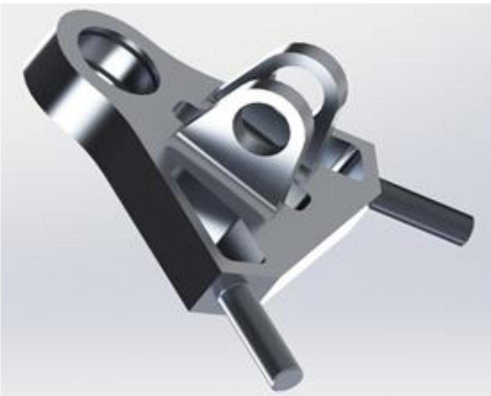

Fig.2a. A – arm end

Fig.2b. External thread insert

An external thread will be constructed on the two protrusions seen in the Fig.2b and the links are attached through these threads. Due to the huge forces acting on the A - arm end the minimum outer diameter of the protrusions were found to be 6 mm.

1.1.2. Mild steel inserts

The threaded insert is put on the protrusions of the A-arm end. This is necessary because it is not advised to directly attach the external threads on the A-arm end made of aluminium with another thread due to the inherent weakness of aluminium threads. Inner diameter of the thread insert is 6 mm and the minimum outer diameter available is 10 mm. The strength of the adhesive bond which holds the Mild Steel insert and the CF rod together is very sensitive due to the following factors

- The total adhesive surface area
- Nature of the insert material and the CF rod
- Surface treatments

Thus the length of the insert was decided so that adhesive sufficient surface area is available. A small step was provided at the bottom of the insert to block the adhesives from flowing away during the manufacturing. Careful attention was given to ensure that the bond length of the adhesive remained uniform and ideal. A bond length of .004” - 0.012” was found to be the ideal bond length. Thus .008 inches was approximately equal to 0.2 mm was chosen to be the bond length. Due to the weak nature of threads in Aluminium A - arm end an extra thread insert was put between the MS insert and the A - arm end. The minimum outer diameter of the thread in A - arm end is 6 mm. A thread insert of thickness 2 mm was put over it. Another MS insert of thickness 1.8 mm was put over the thread insert. The thickness of the adhesive or the bond length is ideally 0.2 mm. Hence the total outer diameter became 14 mm.

$$6 + 2*2 + 1.8*2 + 0.2*2 = 14 \text{ mm}$$

14 mm was the minimum possible outer diameter since each of the three components has been kept at their minimum dimensions. Thus the minimum inner diameter of CF rod was determined to be 14 mm. Another alternative was to make the A - arm end out of steel but the weight addition was larger than the weight loss due to changing the steel inserts to aluminium inserts.

1.1.3. Aluminium inserts

Cylindrical aluminium 6061 billet was used for making aluminium inserts as shown in Fig.3. It was also made similar to steel inserts. The strength of the adhesive bond which holds the aluminium insert and the CF rod together is very sensitive. The various factors which affect as follows;

- The total adhesive surface area
- Nature of the insert material and the CF rod
- Surface treatments

A small step was provided at the bottom of the insert to block the adhesives from flowing away during the manufacturing. Careful attention was given to ensure that the bond length of the adhesive remained uniform and ideal. This was done with the help of fixtures. The Aluminium inserts were anodized for better surface finish and this increased the adhesive strength. Insert 3D model was designed by CATIA as shown in Fig.4.

Fig.3. Aluminium inserts after anodized

Fig.4. Insert 3D model

A bond length of .004” - 0.012” was found to be the ideal bond length. The OD of the aluminium inserts is 14 mm. It could have been made smaller to reduce the weight but since the minimum ID of CF rod is 14 due to the constraint from steel inserts, the OD of Aluminium also had to be 13.6 mm such that bond length strength of 0.2 mm could be achieved.

The analysis of the Aluminium insert on a tensile load of 5000N is shown in Fig.5.

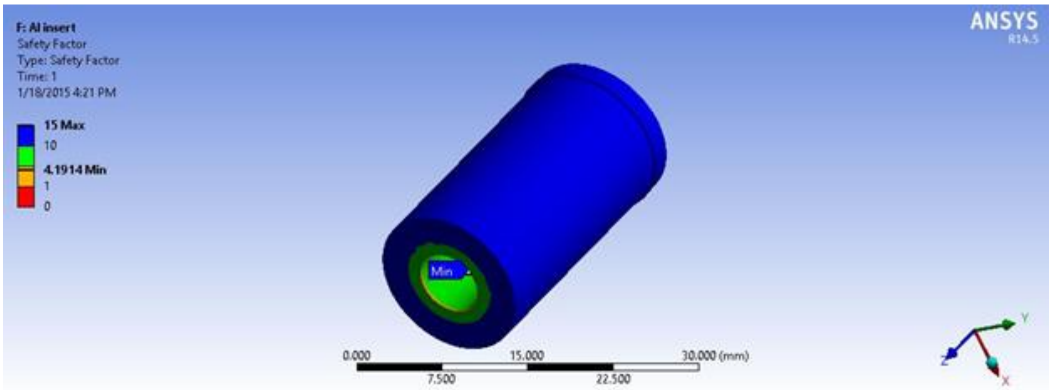

Fig.5. Analysis of Aluminium inserts

Even though the Factor of Safety was high the design wasn't modified since it was not possible to reduce the thickness. There was a possibility of weight reduction by removing some material between the outer and the inner surface.

1.1.4. Adhesive

Loctite E-120HP Hysol epoxy adhesive was used for joining the inserts and the carbon fibre rod. It requires a fixturing time of 3 h and curing time of 24 h. Adhesive was applied on the aluminium and steel inserts and it was immediately placed concentrically to the tubes using fixtures so that uniform bond length exists on all sides.

1.1.5. Carbon fibre rod

The main function CF rods are to take the compressive and tensile forces from the upright and transfer it to the chassis. All the rods can be approximated as 2-force members and they need to be strong only under compressive and tensile forces. A main constraint on the OD of CF rod was that a higher OD will increase the overall size of the rod and chances of interference would become higher in case of any manufacturing error. Theoretical calculations and analysis showed that for the tubes a thickness of 1.5 mm would be sufficient. This was later verified through compression and tensile tests.
Thus the OD of CF rod is 14 + 2*1.5 = 17 mm.

III. Manufacturing

Carbon fibre tubes are most commonly manufactured using two methods:
Pultruding and roll-wrapping: Pultruded – 100% of the fibres are aligned with the axis of the tube. These tubes are prone to delamination and must be protected from exterior damage. Delamination is a condition where the bonds between the fibres break. An example of a pultruded tube is shown in figure. It is barely noticeable but you can see that the fibres are aligned along the axis of the tube. Roll-wrapped carbon fibre tubes are multi-directional fibre aligned. These tubes have excellent torsional strength, axial strength, and lateral strength. An example of a roll-wrapped tube is shown in Fig.6. You can notice thin lines perpendicular to the axis of the tube that show that the fibres are wrapped around the circumference of the tube. Roll-wrapped tubes can have fibres aligned in multiple directions and angles with respect to the axis of the tube.

Carbon fibre tube is manufactured predominantly using unidirectional carbon fibre oriented to provide maximum strength in the lateral (length-wise) axis but the use of unidirectional CF reinforcement oriented at 90° also ensures that the tube has good crush-strength; ideal for real-world applications. While comparing both the types, roll-wrapped process carbon fibre tubes are inexpensive and easy to manufacture.

Fig.6. Bonding of CF rods with MS and Al inserts


Fig.7. After bonding and curing

After all the linkages were ready they were assembled onto the upright of the car with the help of the internal threads on the inserts as shown in Fig.7.
Carbon fibre A arms as shown in Fig.8. Assembled CF suspension linkages system as shown in Fig.9. CF suspension linkages assembled with IIT Bombay FSAE race car as shown in Fig.10. Carbon Fiber A – arm with FSAE race car as shown in Fig.11.

Fig.8. Carbon fibre A – arm

Fig.9. Assembled CF suspension linkages system

Fig.10. CF suspension linkages assembled with FSAE race car

Fig.11. Carbon Fiber A – arm with FSAE race car

IV. Result And DISCUSSION

Pull tests were carried out to test the strength of the adhesive bond between the Aluminium and Mild steel inserts with the CF rod. CF linkages test samples are shown in Fig.12.

Fig.12. CF linkages test samples

Aluminium insert adhesive bond failed at 18.14 kN and the Mild Steel insert adhesive bond failed at 16.24 kN. Both of them are much higher than the maximum force the rods will experience. Aluminium inserts test result is shown in Fig.13 and MS inserts test result is shown in Fig.14.

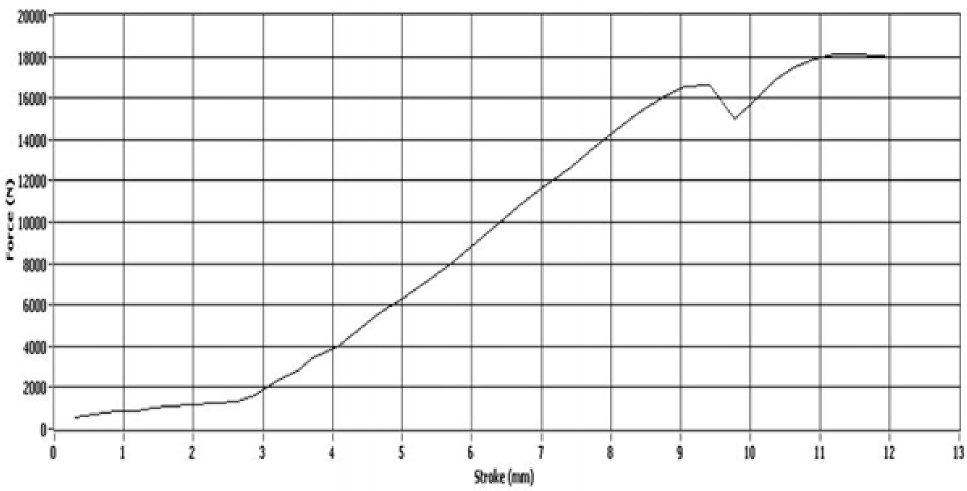

Fig.13. Aluminium Insert result

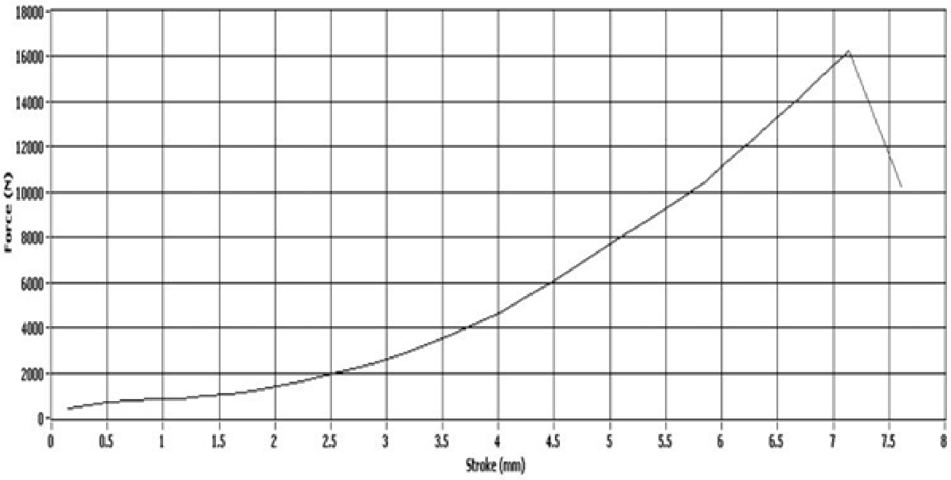

Fig.14. Mild steel Insert result

A major disadvantage about the carbon fibre A - arms is that the strength of the adhesive bond is variable in nature and it is quite sensitive to the processes while manufacturing. Also the only way of testing the ultimate strength of the final adhesive bond is through intrusive techniques which will render the rod unusable. Hence it was decided to use the same settings and parameters as the one which gave an adhesive bond strong enough to withstand 16 kN though the maximum force experienced by the rod would be much lower.

V. Conclusion

The design developed and implemented can be extended to any engineering application where weight reduction needs to be achieved. More tests and results from the engineering application will give a better idea of the fatigue strength and reliability of the design. Effect of grooves on the surface, adhesive bond length etc needs to be studied further. To achieve stronger bonding it is necessary to understand the thermal effects on the bonding too.

Acknowledgements

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