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# Design Optimization and Analysis of Composite Automotive Anti-Roll Bar

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**Abstract -** *An anti-roll bar or sway bar is one of the suspension elements that improve the stability or aligning one wheel with the other one and control the rollover of the automobile while cornering or on the rough road surface. Basically, it is a U-shaped bar having two short lever arms that connects suspension members of the opposite wheel and at two more points, it attached to vehicle chassis with rubber bushings. Reviewed different materials used for manufacturing of anti-roll bar. In this present work, effects are investigated by changing conventional steel material with composite glass fiber epoxy. Response surface optimization technique used for the optimization of various parameters such as internal and external diameter, cornering radius, bushing distance for the composite bar. Results obtained by performing finite element analysis using ANSYS Composite PrepPost (ACP) software.*

***Key Words*: *Anti-roll bar, Geometry, composite material, response surface optimization, ANSYS.***

## 1.INTRODUCTION

While designing vehicles, the safety and comfort of the passenger are important points to consider because of that, when designing a suspension system for a car, the aim is to maximize comfort for passengers on uneven roads, increase vehicle stability, improve wheel alignment with the road surface and also reduce the potential impacts of moving suspension elements in the body of the car. A lot of attention is given to reducing the weight of the suspension elements without losing their characteristics. When the car accelerates, rotates and stops suspension system is responsible for the stability of the car, so a lot of attention paid to that.

Anti-roll bar or sway bar is one of the suspension elements that improve the stability or aligning one wheel with the other one and control the rollover of the automobile. The anti-roll bar is used to connect one wheel against another wheel i.e. when riding on an uneven road surface, and one wheel rides on unevenness and the other wheel stays on a level road surface, then it transfers torsional force from one wheel to the opposite wheel and provides stability to body and control rollover of the automobile. Designing the anti-roll bar is very important because its geometric parameters, which determine its rigidity, and the comfort or stability of the automobile is determined from its stiffness. So, its main function is by improving the stiffness of the suspension system reduces the rollover of the vehicles due to the irregularities of the road surfaces or in the case of cornering.

### 1.1 Working of Anti-roll bar

Anti-roll bar also called a stabilizer bar, is a rod or tube, which connects suspension members of the opposite wheel together to resist the roll of the vehicle which occurs during cornering or due to road irregularities, usually made of steel. The bar's torsional stiffness which is nothing but resistance to twist determines its ability to reduce body roll, and is termed as “Roll Stiffness”. An anti-roll bar also improves the handling of a vehicle by increasing stability during cornering. Most vehicles have front anti-roll bars and anti-roll bars at both the front and the rear wheels can reduce roll further. A spring rate increase in the front anti-roll bar will produce an understeer effect while a spring rate increase in the rear bar can be a cause for the oversteer effect. So, anti-roll bars are used to improve directional control and stability of the vehicle. Also, one more benefit of the anti-roll bar is that it limits the camber angle change caused due to body roll and improves traction. The geometry of anti-roll bars can differ from vehicle to vehicle, it may have irregular shapes to fit around chassis components, or maybe much simpler depending on the vehicle. So, two important parameters to consider while designing the anti-roll bar are first, stiffness of the anti-roll bar which shows the direct influence on handling characteristics and second, bar geometry which totally depends on the arrangement, space available and location of chassis components.

### 1.2 Geometry and Connections

The geometry of the anti-roll bar depends on the shape and location of chassis components but some factors should take care of such as eliminate the critical points which gain the highest stress concentration such as sharp bending at the arms or sudden change in cross-section. There are three types of cross-sections normally used in anti-roll bars: solid circular, hollow circular and solid tapered. Hollow and tapered are improved versions of the solid bar as they reduce the weight of the bar.

At four locations anti-roll bar is attached to the other chassis components. Generally use rubber bushings through which an anti-roll bar is mounted to the mainframe. The material of the bushing is also an important parameter to reduce stress concentration. Commonly used materials for bushings are rubber, nylon, polyurethane. Here care must be taken to locate correct attachment points to avoid interference with the suspension motion. Different types of attachments are: Bar and bayonet type link, bar with rubber insulated eye, bar with eye type link, bar with trapped rubber and washer, bar with rubber insulator block, bar with silent block bush eye. [1]

### 1.3 Material

Anti-roll bars are usually made up of steel material. Usually used alloy steel materials to manufacture anti-roll bar are AISI 9260, AISI 1020, SAE 9262, SAE 4340, SAE 5160 and some spring steel materials such as 51CrV4 spring steel (EN10089), 39MnCrB6 boron alloyed quenched tempered steel. Development of the anti-roll bar production from carbon fiber and aluminium has begun to reduce its mass. In order to increase the stiffness to weight ratio of an anti-roll bar the conventional steel material is being replaced by composite materials such as Carbon-Epoxy, Glass Epoxy, etc. Also, an attempt is given to the conceptual design of an anti-roll bar using natural fiber reinforced composites. The use of composite material reduces the mass of the bar as compared to the conventional steel anti-roll bar and helps to improve the natural frequency of the bar.

### 1.4 Literature Review

P.H. Cronje and P.S. Els, 2010 [3] have proposed and analysed the use of an active anti- roll bar to improve the handling of the off-road vehicle without sacrificing ride comfort. For vehicles that require both good on- as well as off-road capabilities, it is a significant challenge to design suspension. Vehicles having good off-road capabilities usually have poor on-road handling as they are designed with a higher center of gravity than a normal vehicle, but it results in bad handling and increased rollover tendency on-road. M. Cerit et al., 2010 [4] have analysed an anti-roll bar made of SAE 9262 using the finite element (FE) technique to determine stress distributions. The result of finite element analyses given that equivalent stress in the inner surface of the corner bend was the maximum, shear stress dominates and the effects of hardness and wall thickness of rubber used in bushing on stress distribution were investigated. The result was found that both soft rubber and thick wall thickness tend to reduce stress concentration and a significant amount of improvement in fatigue life is observed. Amol Bhanage and K. Padmanabhan, 2015 [5] have carried out static and fatigue simulations of automotive anti-roll bar before DBTT. For the results, linear static analysis is performed for AISI 1020, SAE 4340, SAE 5160, and SAE 9262 materials using ANSYS Workbench 15.0 and for the reliability of anti-roll bar used ANSYS n code Design life software. M.T. Mastura et al., 2016 [6] have presented a hybrid conceptual design approach for the development of a natural fiber-reinforced composite automotive anti-roll bar. In the comparison of the natural fiber-reinforced composite anti-roll bar with carbon fiber composite and a steel anti-roll bar showed that the natural fiber-reinforced composite anti-roll bar has more advantages where it satisfied more design requirements with respect to customers and the environment.

Kurhe Nikhil M. and Dheeraj Hari Daspute, 2018 [7] have done a dynamic Analysis of Anti Roll Bar. In this work composite material is utilized for the anti-roll bar and investigated the roll characteristics like Strength, Stress, deflection, roll stiffness and natural frequency. To increase the stiffness to weight ratio of the anti-roll bar as compared to conventional steel material composite materials like Carbon epoxy and E-Glass epoxy is used. The effects of fiber angle orientation on the composite antiroll bar are evaluated using ANSYS software. Ece Yenilmez et al., 2018 [8] have performed a topology optimization study using the Solid Isotropic Material with Penalization (SIMP) method to determine its dimensions and material to meet this target. Using MSC.Nastran commercial software, a finite element (FE) model of the anti-roll bar is developed in order to determine its torsional stiffness. Also, under the actual road load data coming from various road simulations fatigue performance of the anti-roll bar is assessed. T. Vinod Kumar et al., 2020 [9] designed an anti-roll bar that will be used in the front axle suspension of a 25 metric tonnes capacity rigid as well as construction Trucks focused. Then it is redesigned to minimize the stress concentration at the corner bends and after results obtained from the stress analyses using different values of these parameters and stress as well as mass alteration are assessed by trial and error method analysis. The transition from among the design candidates that gives Minimum stress concentration is determined. The results of dynamic analysis evaluated and suggested the outperformed design. V. Mohanavel et al., 2020 [10] performed a design and analysis study for the effectiveness of torsion of anti-roll bar to a passenger car and influence the handling of the vehicle from body roll. They used high strength tubular anti-roll bar in place of the forged Solid anti-roll bar so, reducing the weight of the product and increasing the fuel efficiency of the vehicle.

## 2. MODELLING AND OPTIMIZATION

The general information about anti-roll (torsion) bars and formulae for calculation given in “Spring Design Manual” [1] by Society of Automotive Engineers (SAE). The anti-roll bar geometry totally depends on the location of chassis components and space available, but the basic shape of the bar remains the same as U- shaped. Its dimensions and geometry change in each case. Steel material is used for designing the bar in the spring design manual. The geometry of the anti-roll bar is design as per the anti-roll bar geometry used in SAE Spring Design Manual.

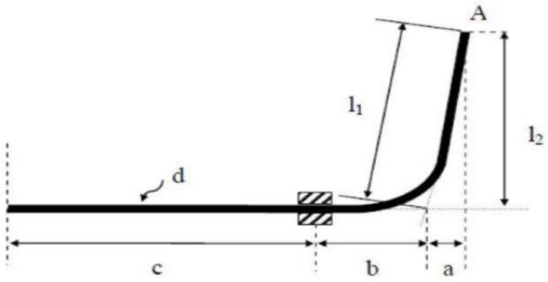

**Figure 1** Geometry of Anti-roll bar from spring design manual [1]

| Component | Length (mm) |
|---|---|
| a | 90 |
| b | 70 |
| c | 390 |
| $l_1$ | 250 |
| $l_2$ | 230 |

**Table 1** Dimensions of anti-roll bar [1]

Here first steel material used for the analysis and for bushing polyurethane rubber material is suggested in the literature. Table 2 shows material properties of materials like steel and glass fiber epoxy. From calculation got values for inner and outer diameter for steel as 18 mm and 22 mm respectively. For calculations used reference formulae and procedures from Spring Design Manual [1] and Race car vehicle dynamics [2].

Halftrack Length given by,

- $L' = a + b + c$

Relation between bar roll rate and applied load can be given by,

- $P = \frac{2\times k_R\times f_A}{L^2}$

Deflection of A is given by,

- $f_A = \frac{P}{3EI}\times\left[(l^3 - a^3) + \frac{L}{2}(a+b)^2 + 4l^2\,(b+c)\right]$

Bar diameter given by,

- $D = \left\{\left[\frac{128\,k_R}{3\pi L^2 E}\right]\times\left[(l^3 - a^3) + \frac{L}{2}(a+b)^2 + 4l^2\,(b+c)\right]\right\}^{\frac{1}{4}}$

Where, $f_A$ = Deflection at bar end (A) (mm)
P = Load applied at bar end (N)
D = Bar diameter (mm)

**Table 2** Material properties

| Properties | Glass fiber epoxy | Steel |
|---|---|---|
| Elastic Modulus(GPa) | $E_x$ = 44.8<br>$E_y$ = 8.04<br>$E_z$ = 8.04 | $E_s$ = 207 |
| Rigidity Modulus (GPa) | $G$ = 29.67 | $G$ = 77 |
| Poisson Ratio | $\vartheta$ = 0.22 | $\vartheta_s$ = 0.3 |
| Mass Density (kg/$m^3$) | $\rho$ = 2600 | $\rho_s$ = 7800 |

### 2.1 Boundary Condition

In the boundary condition, we fix two bushings at the outer surface and apply 2000 N force in +ve x-direction at one end and 2000 N force in –ve x-direction which is shown in figure 2.

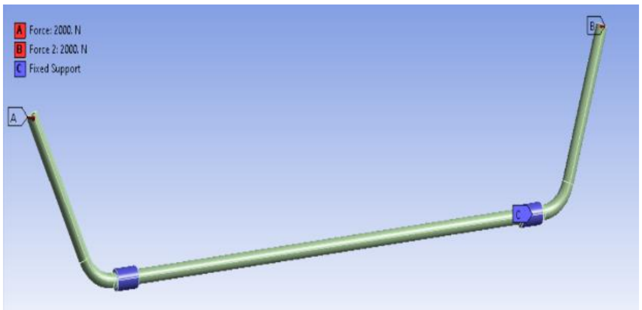

**Figure 2** Boundary condition for the anti-roll bar

### 2.2 Analysis results for steel material

So using ANSYS analysis software numerical analysis is performed on steel anti-roll bar and different results are checked for maximum deflection, maximum equivalent stress and maximum shear stress. So in the results, maximum deflection is 57.51 mm and maximum equivalent stress value is 990.22 MPa and maximum shear stress value is 569.57 MPa.

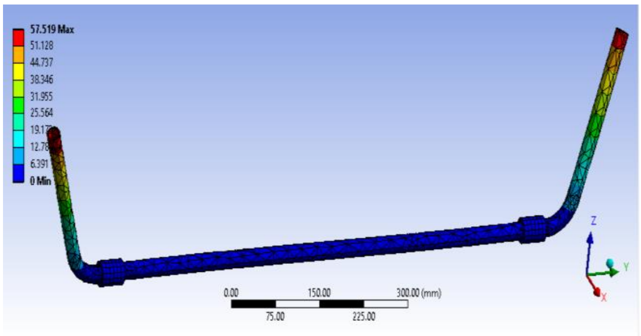

**Figure 3** Total deformation

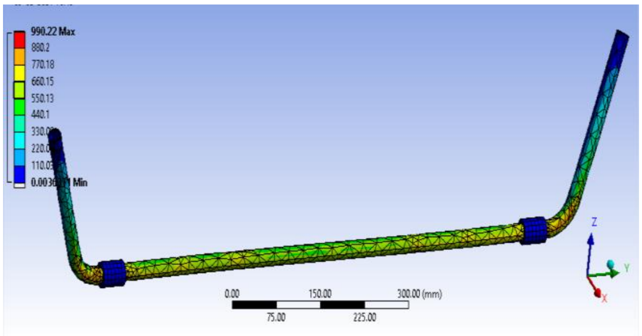

**Figure 4** Equivalent (von- Mises) stress

### 2.3 Optimization and Analysis for composite material

Now for optimization and analysis using ANSYS software response surface optimization method is adopted. In that various steps involved. First input parameters such as inner diameter, outer diameter, bushing location from center, cornering radius and output parameters such as total deformation, equivalent stress are considered for analysis.

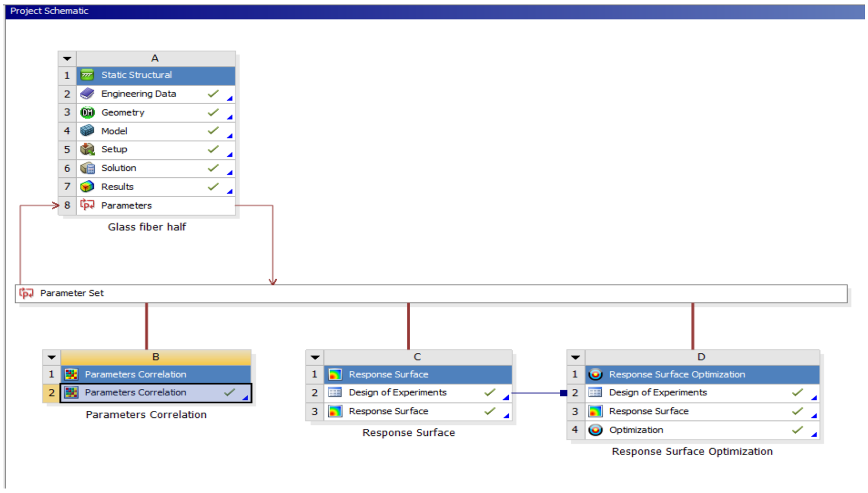

**Figure 5** Project schematic

### 2.4 Correlation matrix

The correlation matrix gives the relation between the considered two parameters. The rule for calculating the correlation coefficient is extremely straightforward. The computation of this correlation coefficient is contrasted with the rank of two successions. The correlation matrix can represent in color-coded form or directly value representation. The correlation value is displayed when you place the mouse cursor over a cell in ANSYS.

The relationship between parameters stronger as the absolute correlation value is closure to 1. A value of 1 indicates a positive correlation, which means that parameters have a direct relationship means when the first parameter increases, the second parameter increases as well. A value of -1 indicates a negative correlation, which means that parameters have an inverse relationship means when the first parameter increases, the second parameter decreases.

**Table 3** Correlation matrix

| Name | Inner Diameter | Outer Diameter | Bushing Distance | Cornering Radius | Equivalent Stress maximum | Total Deformation maximum |
|---|---|---|---|---|---|---|
| Inner Diameter | 1 | 0.230 | 0.076 | -0.134 | 0.160 | 0.221 |
| Outer Diameter | 0.23 | 1 | 0.041 | -0.015 | -0.894 | -0.881 |
| Bushing Distance | 0.076 | 0.041 | 1 | -0.279 | 0.019 | -0.019 |
| Cornering Radius | -0.134 | -0.015 | -0.279 | 1 | -0.002 | -0.024 |
| Equivalent Stress max. | 0.160 | -0.894 | 0.019 | -0.002 | 1 | 0.978 |
| Total Deformation max. | 0.221 | -0.881 | -0.019 | -0.024 | 0.978 | 1 |

### 2.5 Design of Experiments

Design of Experiments (DOE) is a technique used to scientifically determine the location of sampling points and is included as part of the Response Surface, Optimization, and Analysis systems. Once we set up your input parameters, we can update the DOE, which submits the generated design points to the analysis system for a solution. Design points are then solved either simultaneously or sequentially as per our given analysis system. After the solution is complete, we can update the Response Surface cell, which generates response surfaces for each output parameter based on the data in the generated design points.

### 2.6 Response surface

Response surfaces are functions of varying natures in which the output parameters are described in terms of the input parameters. Built from the Design of Experiments (DOE), they quickly provide the approximated values of the output parameters throughout the design space without having to perform a complete solution. DesignXplorer provides tools to estimate and improve the quality of your response surfaces. Once a response surface has been generated, we can create and manage response points and charts.

These post-processing tools help to understand how each output parameter is driven by input parameters and how you can modify your design to improve its performance. Here in response surface on one axis inner diameter and outer diameter plotted on the second axis. On the third axis, total deformation is plotted in figure 6 and equivalent (von-mises) stress plotted in figure 7.

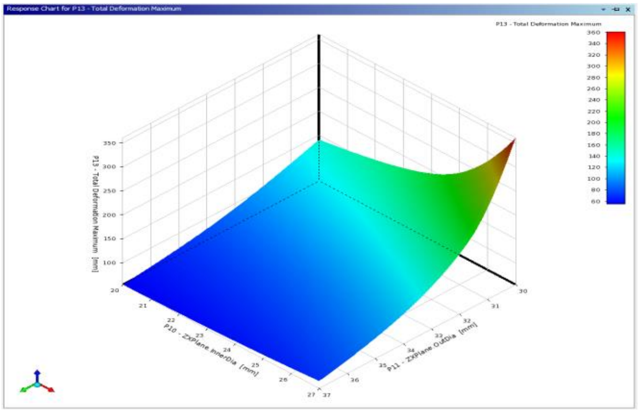

**Figure 6** Response surface for total deformation maximum

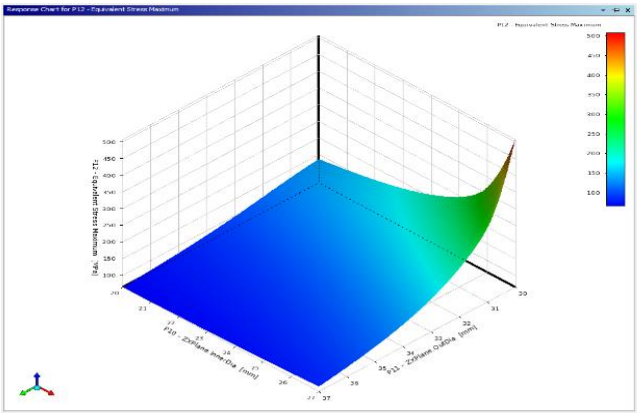

**Figure 7** Response surface for equivalent stress

### 2.7 Optimization objectives

When we edit the Optimization cell of a Goal-Driven Optimization system and select the Objectives and Constraints node in the tab Outline view, the Optimization Objectives section in the table view allows defining design goals in the form of objectives and constraints that are used to generate optimized designs. In this case, we have inserted objectives such as equivalent stress minimized and total deformation maximum is 70 mm. The optimization approach used in the design exploration environment departs in many ways from traditional optimization techniques, giving added flexibility in obtaining the desired design configuration. As a final result, we got values for inner and outer diameter for composite as 23 mm and 35 mm respectively.

## 3. ACP AND ANALYSIS

Composite materials are used due to their properties like they are light and strong. They manufactured by combining two or more layered materials (fibers and binding material). So composite materials have become a standard for products that are both light and strong. Properties of composites can be controlled by various parameters like the number of layers, materials, thicknesses and fiber orientations. In an analysis of these materials, important terms are stresses and deformations as well as a range of failure criteria. Here from ANSYS 18.1 package, ANSYS Composite PrepPost (ACP) used for the analysis of composite structures as it provides all the necessary functionalities.

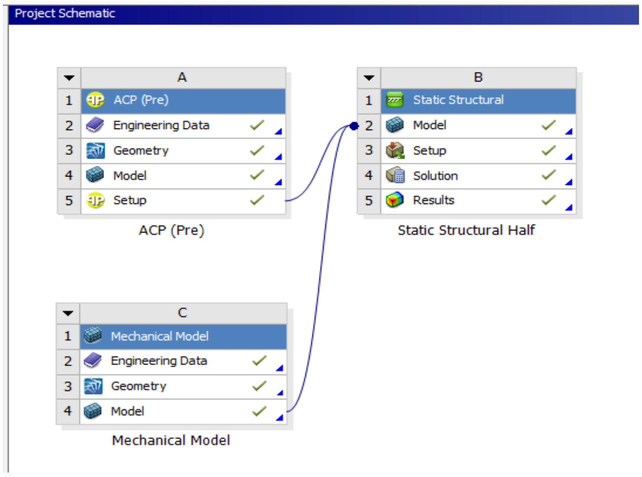

**Figure 8** Project schematic for ACP

### 3.1 Fabric properties

- **Material:** Material of the fabric inserted as glass fiber epoxy
- **Thickness:** here thickness is given of one layer
- **Weight/Area:** The mass per unit area is calculated based on the thickness and material density in material properties.

The **Polar Properties** of the fabric can be plotted as graphical information. It gives polar properties after analysis based on the number of layers and orientation.

### 3.2 Stack properties

A stackup is a fabric with a defined stacking sequence. Stacking sequence is orientation given for different layers. From a manufacturing point of view, the whole stacking sequence considered as one. For the analysis, a stackup is considered which is made up of six-ply layers. For every ply layer of the stackup, the fabric material and its orientation angle must be given. As here orientation is inserted as 0-45-0-45-0-45.

### 3.3 Rosette properties

Rosettes are coordinate systems. These are used to set the reference direction of oriented selection sets. In rosettes given axis considered as 0° direction for the composite lay-up. Coordinate systems that defined in static structural mechanical are imported by default by the software. Additional Rosettes can be defined to give an additional reference axis in ACP. There are 5 types of Rosettes. In the global coordinate system origin and directions of Rosettes are given. Here rosette gave in that 1st reference axis defined as along length and 2nd reference axis perpendicular to that.

### 3.4 Modelling ply properties

- Oriented Selection Sets: Defines the material and direction set.
- Material: Ply Material (Fabric, Stackup), as here stackup is taken

- Ply Angle: Here angle between the reference direction and the ply fiber direction. As in stackup ply angle is given so no need to give again fiber angle.

### 3.5 Analysis results for composite material

In the boundary condition, we fix bushing at the outer surface and one end of the bar and apply 2000 N force in +ve y-direction at the other end. So using ANSYS analysis software numerical analysis is performed on composite anti-roll bar and different results are checked for maximum deflection, maximum equivalent stress. So in the results, maximum deflection is 54.57 mm and the maximum equivalent stress value is 450.14 MPa.

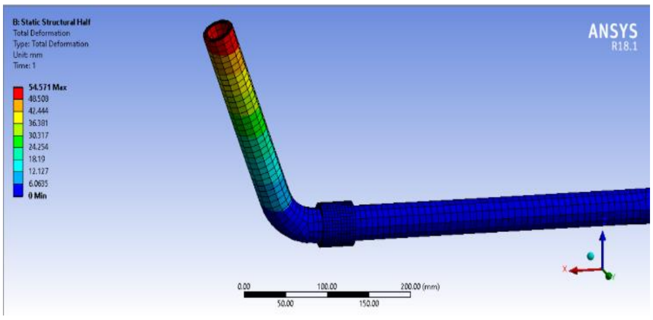

**Figure 9** Total deformation

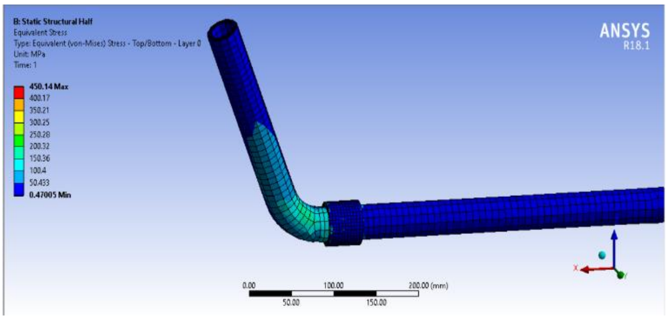

**Figure 10** Equivalent stress

## 4. CONCLUSIONS

Following are work-related results and conclusions we have reached from this study till now:

1. Two important parameters while designing the anti-roll bar, the first is anti-roll bar stiffness and the second is bar geometry.
2. Cross-section of the anti-roll bar is preferred hollow over the solid bar for weight optimization further use of composite will increase stiffness to weight ratio which helps to improve natural frequency as it has lower mass compared to a conventional bar.
3. Use of composite material also reduces the stress concentration at cornering bends which will improve the life of the anti-roll bar.
4. For smaller dimensions fiber does not sustain under shear force (does not take the torsional load) also due to less modulus of elasticity dimensions have to increase in the case of composite fiber material for better strength.

Further use of carbon fiber material can reduce weight as it has less density than glass fiber and as it provides weight reduction, it will more beneficial for higher and bigger dimension applications.

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