INVESTIGATION ON SMART MATERIALS FOR LIGHT DUTY GOODS VEHICLE CHASSIS FRAME USING FEA

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Abstract. Weight directly affects performance and emission parameters of vehicle. The main contributor of weight in heavy vehicle is chassis frame [1]. The reduction of weight of chassis improves fuel economy and reduces carbon dioxide emission. There are several conventional and non-conventional chassis materials available in the market [2]. Composite materials future looks promising because of their lesser weight and higher performance [3]. Proper usage of such product will help in fuel economy thus, saving the fuel and environment [4]. Also it helps to achieve higher performance readily than other conventional materials [5]. Hence, in this Project, we are going to reduce the weight of TATA ACE chassis using composites after the design and analysis of chassis frame [6]. Different materials are tested in ANSYS software are the material having the best desirable properties is recommended for further application in the automotive industry [7].

Keywords - Aluminum Propylene, principal stress, solid work, CATIA V5, ANSYS workbench v15.

1. Introduction

Chassis is a French term which is used to denote complete body and structure of the vehicle.

- It contains all the major units necessary to propel the vehicle direct its motion, stop it and allow it to run smoothly over uneven surfaces.
- The chassis is the major weight constituting part of automobile.
- The chassis constitutes about 20% of the automobile weight.

2. FUNCTIONS OF THE CHASSIS FRAME

1. To carry load of the passengers or goods carried in the body.
2. To support the load of the body, engine, gear box etc.
3. To withstand the forces caused due to the sudden braking or acceleration.
4. To withstand the stresses caused due to the bad road condition.
5. To withstand centrifugal force while cornering.

3. TYPES OF CHASSIS FRAME

3.1 Conventional Frame

It is non-load carrying frame. The loads of the vehicle are transferred to the suspensions by the frame. This suspension in the main skeleton of the vehicle is supported on the axles through springs. The body is made of flexible material like wood and isolated frame by inserting rubber mountings in between. The frame is made of channel section or tubular section or box section.
3.2 Integral Frame
This frame is used now a day in most of the cars. There is no frame and all the assembly units are attached to the body. All the functions of the frame carried out by the body itself. Due to elimination of long frame it is cheaper and due to less weight most economical also. Only disadvantage is that the repairing is difficult.

3.3 Semi-Integral Frame
In some vehicles half frame is fixed in the front end on which engine gear box and front suspension is mounted. It has the advantage when the vehicle is met with accident the front frame can be taken easily to replace the damaged chassis frame. This type of frame is used in some of the European and American cars.

4. Types of Frame Sections
The frames are made of following sections.
1. Box section
2. Channel section
3. Tubular section

Box section is rectangular in cross section. Box section is used in short members of the frame. Channel section is used in long members of the frame. Tubular section is used these days in three-wheelers, scooters and matadors, pick-ups frames.

Channel section is good for bending, tubular in torsion and box in bending and torsion.

![Box section, Tubular section, Channel section](image)

**Figure 4.** Various Frame Sections

5. **IMPORTANT FACTORS TO CONSIDER**

The material chosen should have lesser weight than previously used material for mini truck frame without compromising strength.
The chassis should be able to withstand various acting forces in the frame.
The newly designed chassis should be safe, efficient and economical.

6. **SELECTION OF MATERIALS**

The materials are selected by considering density, strength, cost and availability parameters. By studying the various properties of materials these materials are selected for Analysis. They are as follows.

- Steel
- Aluminum epoxy
- Aluminum propylene

6.1 **Steel**

Steel is existing chassis material of TATA Ace chassis so analysis is done on the reference of steel regarding their weight, cost and strength properties. Carbon composites and its growing use is one of the driving factor for analyzing. Carbon composites are having higher strength as well as good fatigue resistant properties. Aluminum epoxy is having very long pot life (working time) as well as less brittle in nature. The combined weight of aluminum along with the epoxy is lesser in comparison with the other composites. Aluminium propylene is already used in a new material called injector. It has already promised that this material can reduce the weight of chassis by 50% and enhance the performance of automotive vehicle.

6.2 **Aluminum Epoxy**

Aluminum/polymer composites are attractive materials for a wide range of industrial applications due to the combination of properties such as low density, corrosion resistance, thermal stability, and ease of fabrication. Aluminum/epoxy composites are fabricated by cast molding method using 10 wt. % unmodified and salinized aluminum powders. They are having excellent adhesive properties. Cost of epoxy is three times less than same weight of carbon fiber. Epoxy tends to be stronger than other resins and is less brittle in nature. Density of epoxy is same as polyester resin but viscosity is higher than other resins. They are much stronger in adhesion. They tend to have greater working life.
Table 1. Properties of epoxy

| Property              | Value       |
|-----------------------|-------------|
| Density               | 1100 kg/m³  |
| Young’s modulus       | 6.5 GPa     |
| Ultimate Strength     | 3450 N/mm²  |

Figure 5. Chemical representation of epoxy

6.3 Aluminum Propylene

Aluminum propylene is recently used as automotive material. Infector has developed a patented lightweight technology which uses aluminum skin bonded with an expanded propylene (EPP) core. Infector can reduce weight from 300kg typical for chassis to 160kg. To add to its advantage, the sandwiched material is 100% recyclable. It is lesser in weight but comparative stronger than other material counterparts.

Table 2. Properties of propylene

| Property              | Value       |
|-----------------------|-------------|
| Density               | 80 kg/m³    |
| Young’s modulus       | 9.162 GPa   |
| Ultimate Strength     | 321 MPa     |

Figure 6. Chemical representation of propylene
7. FRAME CALCULATION

7.1 C – Section Chassis

![C-section Chassis Diagram]

Figure 7. C – Section Chassis

Length of vehicle = 4340 mm
Width of vehicle = 1565 mm
Height of vehicle = 1858 mm
Wheelbase = 2380 mm
Track width = 1320 mm
Length of chassis = 4201 mm
Width of chassis = 808 mm
Dimensions of side bar = 100mm x 36mm x 5 mm
Dimensions of cross bar = 90 mm x 90 mm
Gross vehicle weight = 2180 kg
Kerb weight = 1180 kg

**Pressure:**

Hence the total area of application of load as calculated from chassis dimensions =

1182600 mm².

Total load to be applied = 2150 x 9.81 =

21091.5 N

Pressure to be applied = 1091.5 / 1182600

= 0.017834 MPa.

Volume Occupied = 2*(90*5*4201+36*5*4201*2) + 5*(808*90*5*2+798*80*5*2)

= 27133758 mm³

Structural steel

Density = 7850 kg/m³

Weight of the Steel Frame chassis =

Density * Volume Occupied

= 7850 * 27133758 * 10⁻⁹

= 213 kg
For applying composite over the chassis section we are going to modify the design structure of chassis having rectangular box frame instead of C channel frame.

### 7.2 Rectangular box chassis

Figure 8. Dimension of rectangular box chassis cross section

(Note: Dimensions of Aluminum epoxy and Aluminum Propylene chassis are same)

- Length of vehicle = 4340 mm
- Width of vehicle = 1565 mm
- Height of vehicle = 1858 mm
- Wheelbase = 2380 mm
- Track width = 1320 mm
- Length of chassis = 4201 mm
- Width of chassis = 808 mm
- Dimension of side bar = 70 X 50 X 5mm
- Dimension of Cross bar = 70 X 50 X 5 mm
- Total area of application of load = 1899850 mm²
- Gross vehicle weight = 2066 kg
- Kerb weight = 1066 kg
- Total load to be applied = 2050*9.81
  = 20110.5N
- Pressure to be applied = load/Area
  = 20110.5/1899850
  = 0.0105853 Mpa

Total volume Occupied = volume occupied by aluminum + volume occupied by resin

- Volume occupied by aluminum = 1300*4201*2+1300*5*708
  = 15524600 mm³
- Volume occupied by composite = 60*40*4201*2+60*40*5*708
  = 28660800 mm³

Total volume occupied = 15524600+28660800
  = 44185400 mm³

Volume Concentration of Aluminum = 15524600/(15424600+28660800)
  = 0.351

Volume Concentration of resin = 28660800/ (15424600+28660800)
  = 0.6486
For Aluminum Epoxy,

Weight of Aluminum epoxy chassis = weight of aluminum + weight of epoxy

\[ \text{Weight of aluminum} = \text{Density} \times \text{Volume occupied by aluminum} \]
\[ = 2700 \times 15524600 \times 10^{-9} \]
\[ = 41.91 \text{ kg} \]

Weight of epoxy = Weight of hardener + Weight of resin

Density of hardener = 940 kg/m³

Density of resin = 2250 kg/m³

Mix ratio for epoxy by volume = 7.23/1 (epoxy/hardener)

Weight of hardener = Volume*density
\[ = 28660800 \times 10^{-9} \times (1/8.23) \times 940 \]
\[ = 3.27 \text{ kg} \]

Weight of resin = Volume*density
\[ = 28660800 \times 10^{-9} \times 7.23/8.23 \times 2250 \]
\[ = 56.65 \text{ kg} \]

Total weight of chassis = weight of aluminum + weight of epoxy
\[ = 41.91 + 59.92 \]
\[ = 101.83 \text{ kg} \]

Young’s modulus of epoxy (E_{\text{epoxy}}) = 6.5 GPa

Young’s modulus of aluminum (E_{\text{aluminum}}) = 68.9 GPa

Equivalent Young’s modulus for Aluminum

Epoxy = 75.4 GPa

For Aluminum Propylene,

Weight of Aluminum propylene chassis = weight of aluminum + weight of Poly propylene

Weight of aluminum = Density * Volume occupied by aluminum
\[ = 2700 \times 15524600 \times 10^{-9} \]
\[ = 41.91 \text{ kg} \]

Weight of Polypropylene = Density of Polypropylene*Volume of Polypropylene
\[ = 80 \times 28660800 \times 10^{-9} \]
\[ = 2.3088 \text{ kg} \]

Total Weight of Aluminum Propylene Chassis
\[ = 41.91 + 2.3088 \]
\[ = 44.796 \text{ kg} \]

Young’s Modulus of Aluminum = 68.9 GPa

Young’s Modulus of Polypropylene = 9.162 Gpa

Equivalent Young’s Modulus of Aluminum

Propylene = 78.062 GPa

8. Design of Chassis Frame

After calculation of chassis frame, the sample chassis of TATA ACE mini truck frame is designed using SolidWorks software. The design procedure was based on creating a model, viewing it, assembling parts as required, and then generating any drawings which are required. The original chassis of Tata Ace is designed for structural analysis of steel frame. For analyzing composite section, the chassis design is modified. Instead of original C-channel section ladder frame, rectangular box section type ladder chassis is designed. The dimensions of both side bars and cross bars of modified sections are kept same.
9. RESULTS AND DISCUSSIONS

9.1 Analysis of Chassis Frame:

After designing the chassis frame, the frame is subjected to the analysis. The analysis is done in ANSYS software. CAD model of TATA is created and imported into ANSYS for FEA. The design created by SolidWorks is used in ANSYS for structural analysis. The C channel section which is the conventional chassis is used to analyze structural steel. The second modified design is used to analyze Aluminum epoxy and Aluminum propylene respectively. The size of elements is kept as minimum as possible to get the accurate results and at some points the finer meshing is also done to get better results. Static analysis is used to find maximum stress region. After analysis, the obtained results are used to conclude the best material.

The designed model from of chassis using SolidWorks is saved in IGES format which can be directly imported into ANSYS workbench.
9.2 Meshing:

The meshed view as shown in above figure has 28212 nodes and 13331 elements.

Figure 11. Mesh view of chassis using steel

The meshed view as shown in above figure has 28212 nodes and 13331 elements.

Figure 12. Mesh view of chassis using Aluminum Epoxy

The meshed view as shown in above figure has 28212 nodes and 13331 elements.
9.3 Load Applications and Boundary Conditions

Load in Tata Ace chassis is applied in two different chassis design in the form of pressure. Pressure of magnitude 0.017834 MPa is applied in Original C-Cross section chassis whereas 0.0105853 MPa is applied in modified rectangular Cross section chassis. There are two boundary conditions which includes fixing the front and the rear axle.

Figure 13. Mesh view of chassis using Aluminum Propylene

Figure 14. Loading and boundary Condition of C-section Tata-Ace chassis
10. ANALYSIS

Analysis is conducted by testing different materials on two different chassis and Equivalent stress (Von-misses stress), maximum principal stress, maximum shear stress and total deformation are found out. The results including above mentioned parameters are shown as follows.

10.1 Equivalent Stress (Von-misses) stress

- Structural steel

![Figure 15. Loading and boundary Conditions of rectangular Cross-Section Chassis](image)

![Figure 16. Equivalent stress in Structural steel C-section chassis](image)
Aluminum epoxy

![Equivalent stress in Aluminum Epoxy chassis](Image)

**Figure 17.** Equivalent stress in Aluminum Epoxy chassis

Aluminum propylene

![Equivalent stress in Aluminum propylene chassis](Image)

**Figure 18.** Equivalent stress in Aluminum propylene chassis
10.2 *Maximum Principal Stress*

- **Structural steel**

![Figure 19. Maximum Principal Stress in Structural steel C-section chassis](image)

- **Aluminum epoxy**

![Figure 20. Maximum Principal Stress in Aluminum Epoxy chassis](image)
Aluminum propylene

Figure 21. Maximum Principal Stress in Aluminum propylene chassis

10.3 Maximum Shear Stress

Structural steel

Figure 22. Maximum Shear stress in Structural steel C-section chassis
Aluminum epoxy

![Image of Aluminum epoxy chassis]

Figure 23. Maximum Shear stress in Aluminum Epoxy chassis

Aluminum propylene

![Image of Aluminum propylene chassis]

Figure 24. Maximum Shear Stress in Aluminum propylene chassis
10.4 Total Deformation

- Structural steel

![Figure 25. Total Deformation in C-section steel chassis](image1)

- Aluminum epoxy

![Figure 26. Total deformation in Aluminum Epoxy chassis](image2)
Aluminum propylene

Figure 27. Total deformation in Aluminum propylene chassis

| Table 3. Result comparison |
|---------------------------|

| Material                | Equivalent stress (MPa) | Max principle stress (MPa) | Max shear stress (MPa) | Total deformation (mm) |
|-------------------------|-------------------------|---------------------------|------------------------|------------------------|
| Structural steel        | 30.248                  | 22.32                     | 17.419                 | 0.35532                |
| Aluminum Epoxy          | 14.596                  | 12.13                     | 8.2613                 | 0.26938                |
| Aluminum propylene      | 13.139                  | 10.47                     | 7.4806                 | 0.24502                |

11. CONCLUSION
The design and Tata Ace chassis using C-section and rectangular cross section is done in SolidWorks and imported to ANSYS for finite element analysis. The analysis is conducted in conventional steel, Aluminum Epoxy and Aluminum Polypropylene respectively. After analysis a comparison is made between existing conventional steel chassis and composite materials in terms of deformation and stresses, to select the best one. From the calculations, it is found out that Aluminum Propylene has the lowest weight compared to steel and aluminum epoxy. Also, Aluminum Polypropylene has the lowest equivalent stress, principal stress, shear stress and lowest deformation induced. Based on the results it was inferred that Aluminum Polypropylene composites with rectangular box section has superior strength to withstand high load and induced low deformation and stress distribution when compared to steel.

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