High specific strength steel as an alternative material for heavy vehicle chassis – an explicit analysis

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Abstract. The chassis frame forms the backbone of a heavy vehicle which carries the load for all designed operating conditions. An important consideration in chassis design is adequate bending stiffness along with strength for better handling characteristics. Maximum shear stress and deflection are the important criteria in chassis design. The present paper is on the design of heavy vehicle chassis and its strength and rigidity analysis. In the analysis under identical load conditions, currently used chassis materials like low and medium carbon steels and cast iron are compared with high specific strength steel which can be an effective substitute material for the chassis. High specific strength steel has low density and possesses high strength properties. The dimensions of an existing vehicle chassis of AMW 2523 TP truck is taken for analysis. Rectangular Box type cross section is considered as it is observed to undergo least deflection. For validation the design is done by applying the vertical loads acting on different horizontal cross sections. The modelling and analysis are performed using SOLIDWORKS 2016 and ANSYS16.0. The results show that HSSS has the least deformation and stress induced and the proposed material provides enough strength and rigidity to the chassis.

1. Introduction

Chassis is one of the major parts in vehicle construction. It undertakes all the stresses on the vehicle in static as well as dynamic loading conditions. Chassis supports the mechanical body parts and maintains static and dynamic loads handling without any distortion. Generally heavy vehicle chassis is made of steel which is heavier thereby resulting in a number of disadvantages; the prominent one being the loss of performance of the vehicle. An improved power to weight ratio will enable the vehicle to speed up, improve handling characteristics, reduce the braking period and ultimately reduce the fuel consumption and emission. While selecting a chassis material, the main objective must be to reduce the weight of the chassis without compromising on the strength and other requirements of the chassis. So High Specific Strength Steel (HSSS) is proposed as an alternative material for ladder chassis. The applications of the HSSS in the automobiles is still not prevalent due to the lack of knowledge related to application properties so far [1]. Above all, processing problems as a result of high Al and Mn contents are the main issues. The future developments will therefore have to concentrate on the alloying and processing strategies. An improved processing strategy and a high value for the Young’s modulus will go a long way towards up scaling these steels to real automotive applications. Perceived barriers to the introduction of high strength steel are categorized as technical barriers, knowledge barriers, scrap management barriers, suitability barriers and cost barriers. The present work aims to design and analyze the heavy-duty chassis with commonly
manufactured materials such as low and medium carbon steels, cast iron and to compare with the material proposed namely high specific strength steel (HSSS).

Figure 1 shows the design of ladder frame chassis. It is the simplest and oldest of all designs, which is mainly used in trucks. It consists of two symmetrical rails or beams and cross member. This design offers good beam resistance, but poor resistance to torsion.

Figure 1. Ladder Frame Chassis

2. Literature Review
The selection of material for a designed chassis is of utmost importance and is carried out on the basis of mechanical properties of the materials. Since chassis forms the backbone of the vehicle, utmost priority should be given to the safety aspect. The chassis is subjected to a number of loads such as fluctuating loads, loads due to vibration, loads due to torsion etc. which it must be able to withstand. Chassis also must have adequate bending stiffness for better handling. Hence maximum stress, maximum equilateral stress, maximum equivalent strain and deflection are the important criteria for designing the chassis. Weight factor also plays an important role in the material selection. Extensive number of works has been carried out in the area. Karita et al. examined the aptness of using 6061-T6 aluminium alloy as chassis material and reported that aluminium chassis meets the target of weight reduction, strength and rigidity. Fui and Rahman studied the vibration induced by road roughness and excitation by the vibrating components mounted on chassis and examined the chassis responses by stress distribution and displacements. They suggested that mode shape results can be used to determine the suitable mounting locations of components like engine and suspension systems. Sane et al. analyzed the light commercial vehicle chassis using FEM and simulated the failure during testing. They concluded that local stiffeners can be used for reducing the magnitude of stress on the chassis by which the stress values can be reduced by 44%. The road roughness also affects the stress distribution in heavy vehicle chassis. Static and dynamic analyses using Finite Element Analysis are widely used for reducing the cost and getting the optimum design. From the studies it is understood that the dominant loading on the truck chassis comes from cargo and its contents as static loading. The road roughness has not given a significant effect to the stress of component. Optimization of the thickness of truck chassis can also be performed by using Finite element technique which will help to reduce the material usage and material cost. This is attempted by Coban et al. Finite element methods are also effectively utilized to study the effect of various stress distribution using Ansys software which can be validated by linear static analysis. Hence finite element methods can be successfully implemented in the design and analysis of chassis frames of automobiles.

3. Methodology
For chassis modelling and analysis, the component is modelled by utilizing the functionality of SOLIDWORKS 2016 modelling software. The individual parts are modelled in the part module and the assembly of each part is done by a bottom-up method in the assembly module. For analysis under
dynamic loading conditions, the model is imported into ANSYS 16.0, which is tested as design constraints for stress and deformation. From the analysis, the chassis of commonly used materials and HSSS are compared in terms of deformities and stress.

4. Analysis
In this paper, the fore mentioned chassis is used for explicit analysis which is also known as dynamic analysis and is done for different materials [2-4]. A 3D model of ladder chassis is generated using SOLIDWORKS 2016 software and the file is exported to STEP format and imported in ANSYS 16.0. Here materials are applied and, in the model, the left end is constrained and force is applied in the z-direction. Then the model is meshed with fine mesh size and, finally the model is solved and observed results are plotted [5].

Assumptions made in ANSYS for analysis include:
- Point load is taken into consideration
- Material assumed is linear isotropic and homogenous
- The effect of heat is neglected.
- The analysis performed is linear and independent of time and displacement.
- Road roughness effect is not considered
- Air resistance is neglected

The material properties such as the ultimate strength, yield strength, Poisson’s ratio, modulus of elasticity and rigidity considered in the analysis are shown in Table 1[6-9]. From the table it can be seen that HSSS possesses better mechanical properties than the conventional materials. It has a lesser density and high resilience. The composition of the material is given in Table 2 and its microstructure is shown in Figure 2 [10,11].

| Material       | Ultimate tensile strength (MPa) | Yield strength (MPa) | Poisson’s ratio | Modulus of elasticity (GPa) | Modulus of rigidity (GPa) |
|----------------|---------------------------------|----------------------|-----------------|-----------------------------|---------------------------|
| Low carbon steel | 440                             | 370                  | 0.29            | 205                         | 80                        |
| Medium carbon steel | 565                             | 310                  | 0.29            | 200                         | 80                        |
| Grey cast iron  | 310                             | 200                  | 0.29            | 180                         | 50                        |
| HSSS           | 2000                            | 1400                 | 0.3             | 210                         | 75                        |

Figure 2. HSSS Microstructure
Table 2. Composition of HSSS

| Element | Percentage composition | Actual weight (g) |
|---------|------------------------|------------------|
| Iron    | 68.474                 | 3423.7           |
| Silicon | 0.02                   | 1                |
| Manganese | 16.1                | 16.1             |
| Aluminium | 9.6                   | 480              |
| Titanium | 0.042                 | 2.1              |
| Niobium | 0.004                 | 0.2              |
| Nickel  | 4.9                    | 245              |
| Carbon  | 0.86                   | 43               |

5. Results and discussion
The chassis is subjected to various dynamic forces and the stress and deformation are analyzed and tabulated. Here, Von Mises stress is used to predict yielding of materials under complex loading from the results of uniaxial tensile tests. It is a theoretical measure of stress used to estimate yield failure criteria in ductile materials and is also popular in fatigue strength calculations.

The chassis is driven at a constant velocity of 120kmph and is made to crash into a structural steel plate or wall to check the induced stresses and deformation in each of the chosen materials and different cross sections of chassis. Considering the capacity of the truck with 1.25 factor of safety (306562.5 N) and the weight of body and engine (70926.3 N), the total load acting on the chassis is estimated to be 377488.8 N. So, the load acting on one beam will be 188744.4 N which corresponds to a mass of 19240 kg. The total force acting at the assumed driven velocity will be 1282666.667N.

The final results are taken after $10^5$ iterations so that the accuracy can be improved. The total deformation and equivalent stress for grey cast iron, low carbon steel, medium carbon steel and high specific strength steel are obtained as in Figures 3 to 6.

Figure 3(a). Total deformation in Grey Cast Iron
Figure 3(b). Von-mises stress in Grey Cast Iron

Figure 4(a). Total deformation in Low Carbon Steel
Figure 4(b). Von-mises stress in Low carbon Steel

Figure 5(a). Total deformation in Medium Carbon Steel
Figure 5(b). Von-mises stress in Medium Carbon Steel

Figure 6(a). Total deformation in HSSS
A comparison of the deformation produced and the stress generated as a result of the collision for different chassis material is given in Table 3.

**Table 3.** Comparison of deformation and stress for different chassis material

| Material       | Deformation (mm) | Stress (MPa) |
|----------------|------------------|--------------|
| Low carbon steel | 10.805           | 488.8        |
| Medium carbon steel | 10.8          | 487.7        |
| Grey cast iron | 33.372           | 491.1        |
| HSSS           | 10.547           | 484.7        |

From Table 3, it is clear that HSSS has the least deformation and least stress when compared to the other materials. Hence HSSS stands as an exemplar alternative material for the currently used materials.

**Table 4.** Comparison of weight of materials

| Material       | Density (g/cm³) | Weight (N) |
|----------------|-----------------|------------|
| Low carbon steel | 7.85            | 18646.55   |
| Medium carbon steel | 7.87       | 18694.03   |
| Grey cast iron  | 7.2             | 17102.55   |
| HSSS           | 6.85            | 15867.38   |
It is depicted clearly from the Table 4 that the weight of chassis made from HSSS is the least when compared to the other materials used in the industry.

6. Conclusion
From the analysis carried out for the comparison of different materials, HSSS is found to have the least deformation amongst the other materials chosen for the study. Thus, it has been concluded that HSSS used as the material has the least deformation and hence it has the best properties among the other analyzed combinations. Since the material is having lower density and weight also, selecting HSSS as the chassis material will contribute in weight reduction which in turn increases the overall performance of the vehicle. Hence, it can be proposed as an alternative for the existing chassis materials.

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