Automotive Chassis Design Material Selection for Road and Race Vehicles

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ABSTRACT: Automotive chassis design, development is quite important in today's environment. This work is oriented towards analysis of a ladder chassis and space frame chassis design. The analysis of the designed models involves the use of three different materials. In this investigation two different conditions of vehicle loading are considered namely un-laden (without passengers that is the KERB weight of the vehicle) condition and the laden (with passengers and miscellaneous weight also called gross weight) condition. Analysis had resulted with various variables of stress indicating the stress levels minimum in unladen case as 3.00E-17 and maximum in laden case as 29.8662, in case of space frame analysis the stress in minimum for steel with laden chasis as 0.001558 and maximum in case of composite material as 7.8447. These results would be useful with in selection of material for automotive frames.

KEYWORDS: Aluminum; Automotive; Chassis; Composites; FEM; laden; Material; Steel; Unladen.

INTRODUCTION

Automotive chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering etc. are bolted. The chassis is considered to be the most significant component of an automobile [1]. It is the most crucial element that gives strength and stability to the vehicle under different conditions. The backbone of any automobile, it is the supporting frame to which the body of an engine, axle assemblies are affixed [8]. Tie bars, that are essential parts of automotive frames, are fasteners that bind different auto parts together. Automotive frames are basically manufactured from steel [1,6]. Aluminum is another raw material that has increasingly become popular for manufacturing these auto frames. Automobile chassis helps keep an automobile rigid, stiff and unbending [7,9]. Auto chassis ensures low levels of noise, vibrations and harshness throughout the automobile [12,15-16]. In this work the discussion will confine to the ladder chassis and the tubular space frame chassis which is used currently in many of the race cars as of today, with the material specifications given in table 1. Both of these frames have their own advantages and disadvantages.

Table 1. Material Properties

Properties	Low carbon Mild Steel	Aluminum Alloy 6000 Series	Fiber Glass
Young's Modulus	29.5E6	10.5E6	12.3E6
Poisons Ratio	0.26	0.33	0.10

MATERIAL SELECTION AND GEOMETRIC DETAILS

Today mostly all the cars incorporate mainly three base materials for manufacturing sheets of the car body and these are steel, aluminum alloys and composites [9,12]. Various grades of the above given materials are available for use and they have their own advantages and The best way to select material for chassis design is based on application and load distribution.

Steel

Traditionally the most common material used for manufacturing the vehicle chassis has been steel, in various forms. Steel is easy to get and the machinery required to manipulate steel is also easy. The primary reason of steel widespread use in the chassis construction industry [3,7]. There are many grades of steel which may be used for the sheet preparation of car bodies. In this current work carbon steel material adopted.

Low Carbon Mild Steel

Mild steel also known as plain carbon steel is the most common form of steel, and is relatively low. It also provides material properties that are acceptable for many applications, more so than iron. Low carbon steel contains approximately 0.05 – 0.320 % carbon making it malleable and ductile. This property of carbon steel is useful because it gives good surface wear characteristics the only problem being that it leaves the core tough. These properties easily suggest that low carbon mild steel is a suitable material for fabrication of car body sheets.

Aluminum

The Aluminum chassis provides the best of both worlds when it relates to chassis design and manufacturing. A chassis, being the frame of the vehicle has to be rigid to absorb and retain movements and vibrations from the engine, suspension and axles. It should also be as light as possible to improve the vehicle's performance and fuel efficiency. Aluminum provides both strength and lightweight properties. It also assists the vehicle in having better power to weight ratio as the weight is reduced considerably. After alloying the yield strength is increased by a good amount but not much effect has been observed on the stiffness. Despite a much higher cost than steel and additional problems in working with it Aluminum does have a secure place in chassis building. It is also less likely to suffer from corrosion as compared to steel [1]. The positive environmental impact during the use phase plays a much bigger role in the environmental assessment than in the automotive sector.

Aluminum Alloys

Aluminum alloys typically have an elastic modulus of about 70Gpa which is about one third of the elastic modulus of most kinds of steels and steel alloys [3,5]. In automotive engineering cars made of aluminum alloys employ space frames made of extruded profiles to ensure rigidity. This represents a radical change from the common approach for current steel car design, which depend on the body shells for stiffness, known as uni-body design.

Table 2. Geometric details of the model

Chassis type	Length (mm)	Width (mm)
Ladder	3000	750
Space Chassis	2667	750

Composite Materials

The creation and use of composite materials is a fairly simple concept to understand. Basically a composite is the mixing of separate materials designed to create one material [10]. Role of composites, it play key role in automotive industry, it's important to understand how composites can benefit us in other ways [5,7,9]. Composites can be environmentally friendly [12]. The use of composite materials in vehicles has become extremely popular, if not necessary in producing vehicles that can withstand the speed they are pushed to. Composites are popular in their use in not only vehicles, but also on construction of sites, dental offices and other applications.

CHASSIS DESIGN

Two types of chassis design adopted in this work are explored in fig 1 and fig 2 which are modelled using CATIA tool. C channel has been used instead of the box tubing as shown in fig 1 and fig 2 and geometric details are given in table 2. Box tubing can prove to be stronger than the C channel but the latter is more user friendly and also costs less compared to the box tubing. The box frame is better for twisting loads for four-wheeling over a rough terrain whereas the C channel frame is stronger (for a given weight of frame material) with straight vertical loads like loading a ton of gravel in the box but isn't so good at twisting [4,14]. Big trucks and large SUV'S tend to use the C channel frame.

Figure 1. Ladder chassis [12]
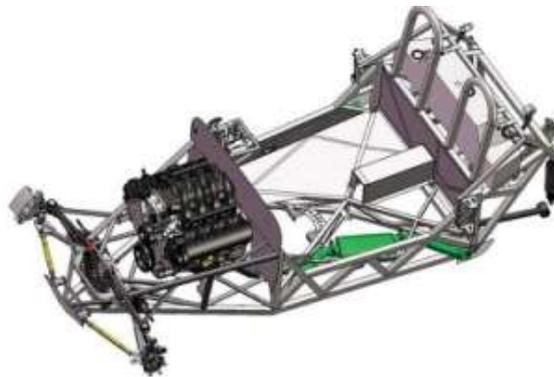
Figure 2. Space frame chassis [12]

METHODOLOGY

The ultimate purpose of a finite element analysis is to recreate mathematically the behavior of an actual engineering system [2,11,13]. In other words the analysis must be an accurate mathematically model of a physical prototype. In the broadest sense, this model comprises all the nodes, elements, material properties, red constants, boundary conditions as detailed in table 3 are adopted in current work by considering all loads are uniformly applied in the vertical downward direction. The original body or structure is considered as an assemblage of these finite elements connected at a finite number of joints called nodes or nodal points. The concept of discretization used in finite difference is adopted here. The properties of the elements are combined and formulated to obtain the solution of the entire body or structure. The concept used in functional approximation method but the difference, is that the approximation to the field variable is made at the elemental level [12,15]. The stresses and strains within the element will also be in terms of nodal displacement. The necessary boundary conditions and the equations of equilibrium are solved for the nodal displacement [11,12]. Having thus obtained the values of displacements at the nodes of each element, the stresses and strains are evaluated using the element properties and pressure values are calculated from the area of application of load for each design and other features that are used to represent the physical system.

Table 3. Boundary Conditions

Chassis type	Gross Weight (kg)	Pressure Applied (Mpa)	
		Laden	Un-laden
Ladder	1500	0.0065	0.0052
Space Chassis	1350	0.0066	0.0058

STRESS OPTIMIZATION

Different practices are available for chassis modification. In optimization methods suitable changes are to be made in the design of the chassis. There are mainly two standard methods used to observe a reduction in stress values

Optimization by boxing technique

Boxing is the addition of 3 mm or thicker plate by welding it into the opening of C channel to form a box section. Here boxing is done using plates of 90mm x 90mm dimension on both sides of cross member where maximum stress intensity is found. It has been found that due to the boxing technique the stress values are reduced by around 30 percent and the deformation value is also reduced by a small but considerable amount.

Optimization by using reinforcement technique

Reinforcement is the practice of providing a cover plate either internal or external on the side members at the highly stressed regions. Here reinforcement of 3 mm thickness and 180 mm length is provided on the side members where the stress is maximum. It has been found that due to the reinforcement technique the stress values are reduced by around 45 percent and the deformation is reduced even further as compared to the boxing technique. Hence it is necessary to incorporate the above given methods to optimize the stress values and the deformation of the body.

RESULTS & DISCUSSION

A Comparison has been made between the un-laden and laden conditions for three types of materials which are adopted in the current design and are presented in figure from fig. 3 to fig. 14. For ease of comparison a detail formulation of results are presented in table 4 and table 5 which outlines the displacement and stress variations over different designs these material properties are adopted in the current work.

From the plot shown in fig. 15 above it is noted that steel and fiberglass are the materials that show proportionality in both the laden and un-laden conditions whereas aluminum did not obeyed the proportionality, hence a selection has to be made between steel and fiberglass. Fiberglass has impressed with better proportionality than steel and also adds to the weight reduction aspect of the vehicle chassis hence this material is a good choice as far as maximum deflection of the vehicle chassis under structural loads is concerned.

In the plot shown in fig. 16 aluminum shows the minimum load carrying capacity for the minimum stressing value. Even if a small load is placed on the chassis the vehicle is subject to deformation. So aluminum must be ruled out. Composite material shows the highest load carrying capacity whereas the traditionally used low carbon mild steel shows moderate properties. This means steel may be still in use in the future for some applications but composite materials will form the majority.

From fig. 17 it is noticed that aluminum alloy does not exhibit good load carrying capacity for the maximum stress intensity as well. This shows that aluminum alloys cannot be used for the manufacture of high end vehicle chassis because of poor load carrying properties. Also the material being highly expensive is not suggestible for this use. However when it comes to weight reduction Aluminum may be a good choice. For trucks and SUV'S however weight reduction is not of much importance hence selection can be made from steel and fiberglass material in case of ladder type frames.

In the plot shown in fig. 18 above all three materials show good proportionality. Fiberglass shows the best characteristics for maximum deflection again like in the ladder chassis case. Steel shows the minimum amount of deflection as expected due to the high modulus of elasticity. The aluminum alloy again shows decent proportionality but highest amount of deflection due to its light weight. For a space frame vehicle deflection is an important criteria but the stress values are of more importance. Therefore aluminum alloys with modifications still

may be used for such vehicles.

In the plot shown in fig 19 above steel shows minimum load carrying capacity and the aluminum alloy shows a high load carrying capacity for minimum stressing values. This means aluminum alloys can be used to make lightweight racing cars.

In the plot shown in fig 20 it is seen that steel shows poor load carrying capacity for maximum stressing values and fiberglass shows the best load carrying capacity amongst the three materials. It is known that racing cars are subjected to large amounts of stresses due to their high speeds hence this factor is the most important for such vehicles. Thus selection can be made between fiberglass and aluminum alloys for such vehicles. In all three cases (maximum displacement, minimum stress and maximum stress) the composite materials have shown best results in both laden and un-laden conditions whereas aluminum is not preferable as presented in table 5 and table 6 as per current methodology adopted.

CONCLUSION

Material selection is artful balance between production and customer. The automotive industry's adoption of many materials interrelationships among objectives, such as fuel economy and safety are sufficiently strong that materials are very essential in manufacturing and fabrication. This work designates the process of selecting a material for chassis design. The conclusions drawn on two designs three materials have resulted Ladder chassis can be mainly used for long passenger vehicles or trucks that carry more load than the other types hence the material used should be of considerable stiffness and should be able to withstand the loads exerted. Weight reduction is not of much importance in such cases. In case of space frame chassis which is the type of chassis used for high end road vehicles and some race cars weight reduction is also an important factor which adds to the better handling of the vehicle. Stiffness of material is not of much importance in such cases. In these vehicles aluminum alloys may be used and composite materials like fiber glass can be used without a doubt. Changing materials involves changing processing operations. This can be achieved by demonstrating that light weight design does not lead to any loss of robustness in the daily operation of the road and race vehicles. Analysis suggest that the cost of vehicle decrease with weight-optimized commercial vehicles.

FUTURE SCOPE

In this paper analyses has been confined to c channel frames for the ladder chassis. However there are various structural modifications that can be done to alter the results for both types of designs. Analyses can be done after changing the geometry and by changing the thickness of the chassis frame. In this paper thickness has been taken to the minimum value.

Table 4. Ladder chassis design variables of stress and displacement

Ladder Chassis Material	Displacement		Minimum Stress		Maximum Stress	
	Laden	Unladen	Laden	Unladen	Laden	Unladen
Steel	1.66E-04	1.24E-04	0.001558	0.001159	6.4886	4.8268
Aluminium alloy	6.71E-04	3.31E-04	7.36E-04	0.001353	5.5372	4.2838
Composite	3.98E-04	4.05E-04	0.002487	0.003607	7.8447	5.6515

Table 5. Space frame chassis design variables of stress and displacement

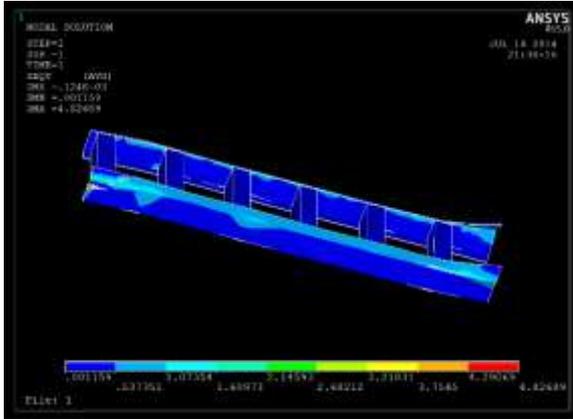| Space frame Chassis Material	Displacement		Minimum Stress		Maximum Stress	
	Laden	Unladen	Laden	Unladen	Laden	Unladen
Steel	0.003675	0.00326	1.13E-15	1.01E-15	29.0092	26.2459
Aluminium alloy	0.01024	0.008991	6.65E-15	5.96E-15	29.5168	25.796
Composite	0.008619	0.007583	3.35E-15	3.00E-17	29.8662	27.7048

Ladder Frame Chassis

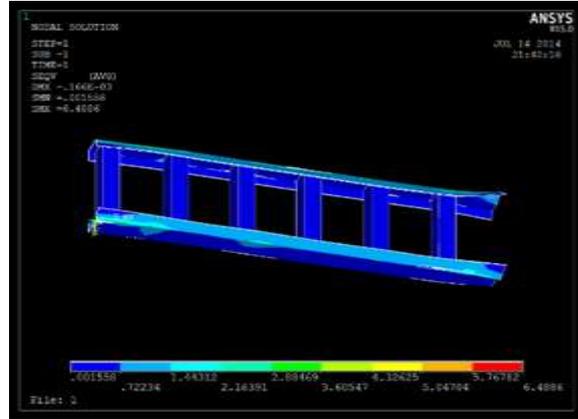**Figure 3.** Unladen chassis of steel

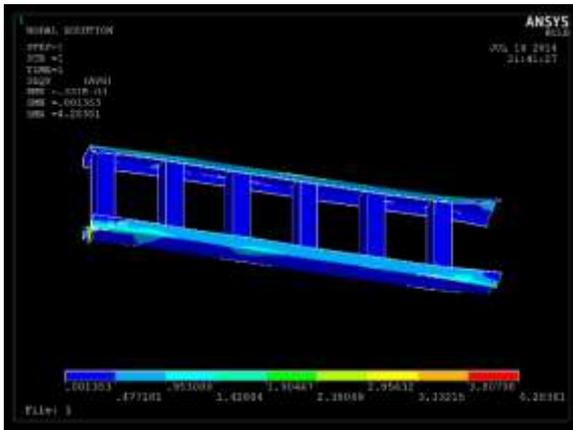
Figure 4. Laden chassis of steel

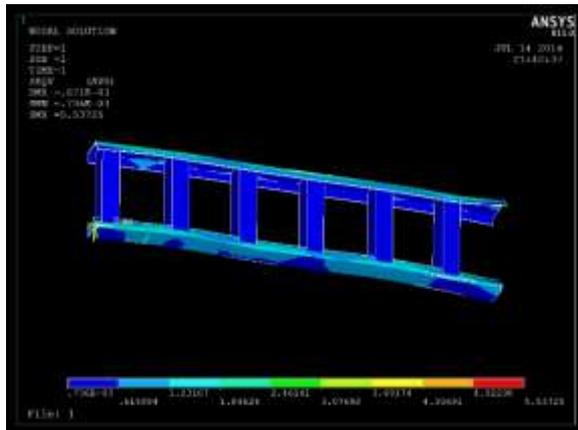**Figure 5.** Unladen chassis of Aluminum Alloy

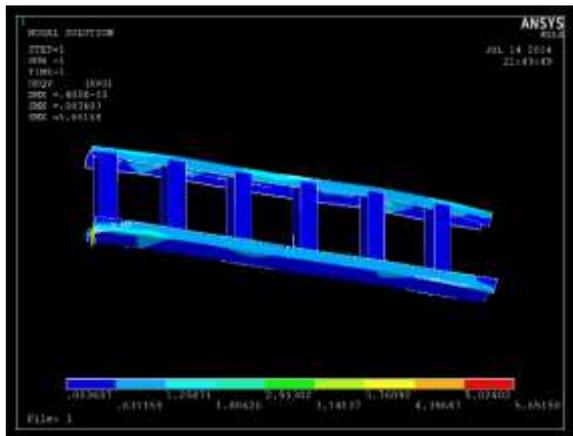**Figure 6.** Laden chassis of Aluminum Alloy

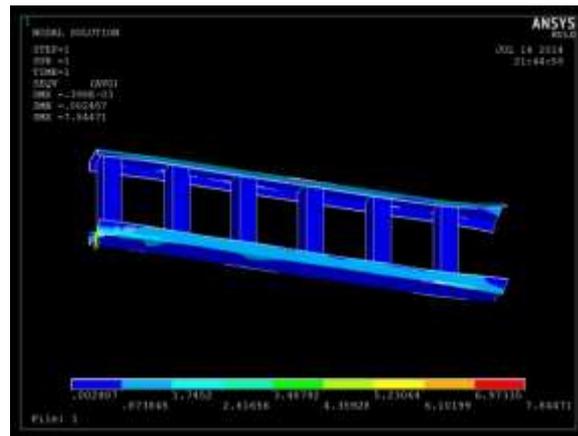**Figure 7.** Unladen chassis of fiber glass

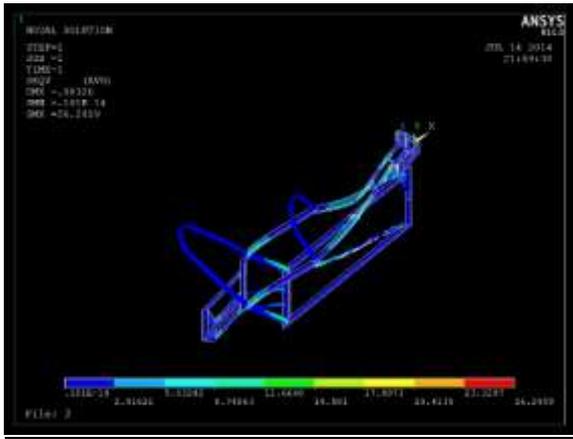**Figure 8.** Laden chassis of fiber glass

Space Frame Chassis – Steel

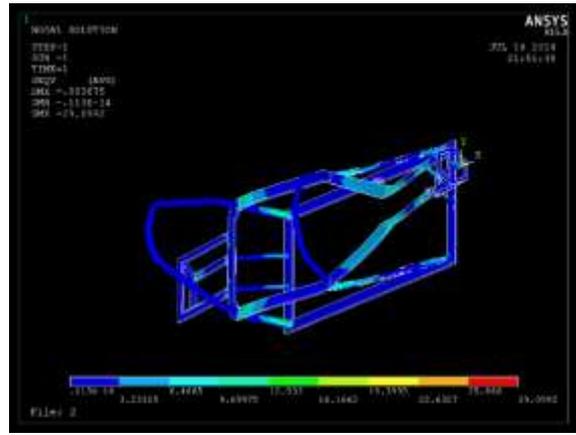**Figure 9.** Unladen chassis of Steel
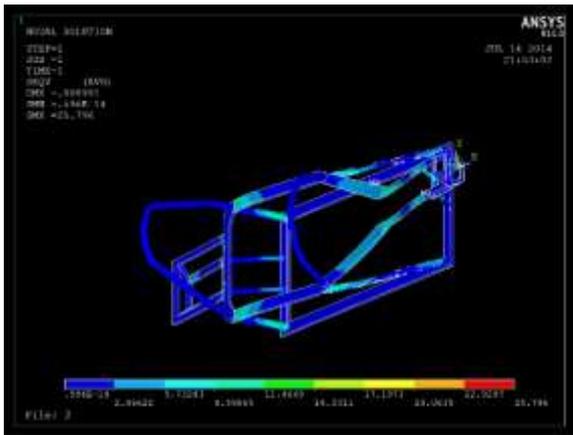

Figure 10. Laden chassis of Steel

Figure 11. Unladen chassis of aluminum
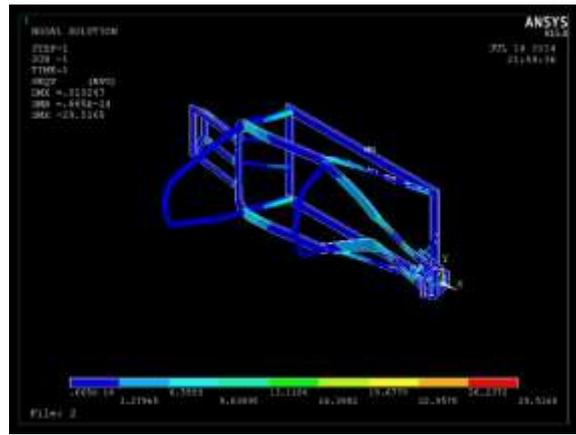
Figure 12. Laden chassis of aluminum
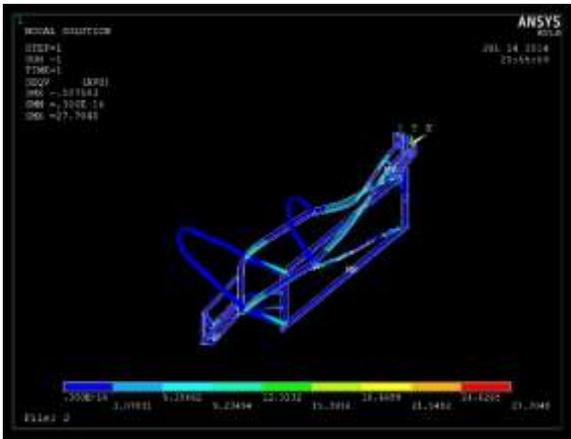
Figure 13. Unladen chassis of fiberglass
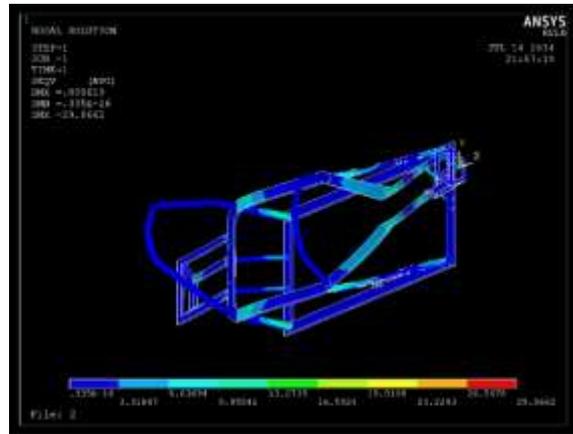
Figure 14. Laden chassis of fiberglass

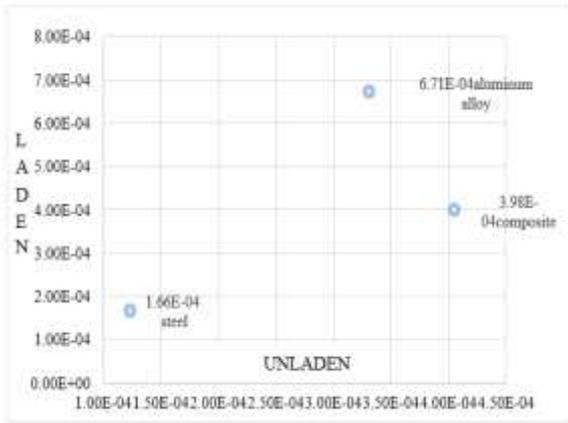Plots showing the different material properties analyzed by using FEM tool

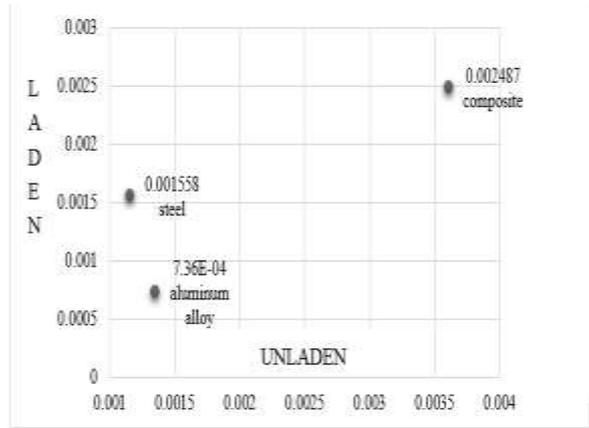**Figure 15.** Plot for maximum displacement-ladder chassis

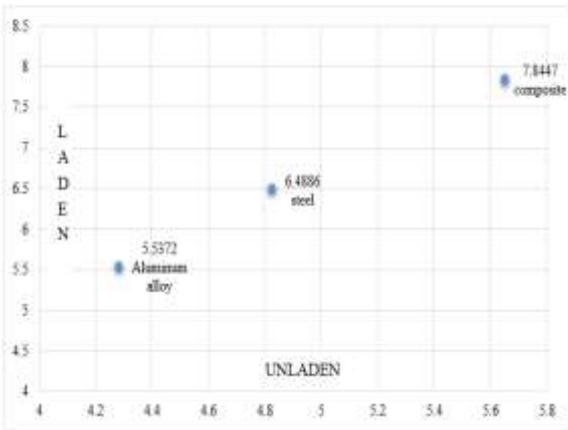**Figure 16.** Plot for minimum stress-ladder chassis

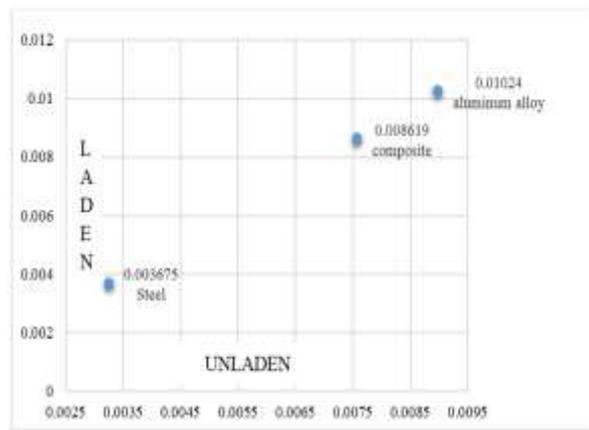**Figure 17.** Plot for maximum stress-ladder chassis

Figure 18. Plot for maximum displacement-space frame chassis
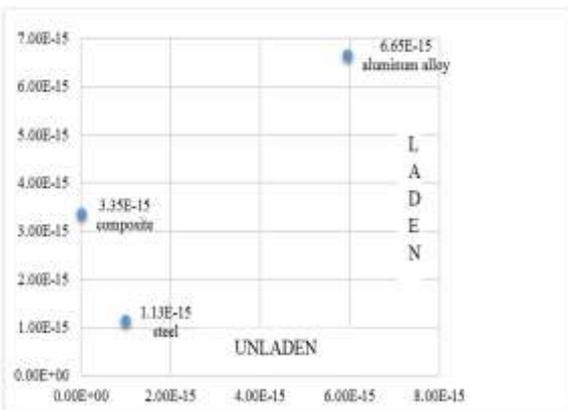

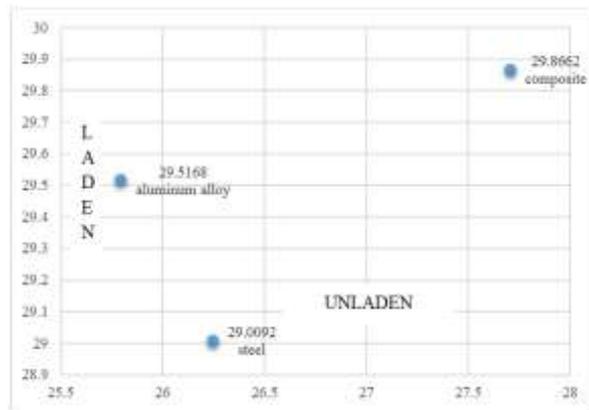**Figure 19.** Plot for minimum stress – space frame chassis

Figure 20. Plot for maximum stress-space frame chassis

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