Comparative Finite Element Analysis of a Novel Robot Chassis Using Structural Steel and Aluminium Alloy Materials

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Abstract: This work presents a comparative finite element analysis of a 3-wheeler novel robot chassis used for uneven terrain robot applications. The chassis was modeled using SolidWorks and further analyzed in Ansys for its total deformation, equivalent stress, equivalent elastic strain and thermal strain. Two materials were taken into consideration for comparative analysis: Aluminium alloy and Structural steel. A load (force) of 500 N was distributed on the chassis uniformly and the acceleration of 5 mm/sec^2 was given. Thermal conditions were added by raising the temperature from 22^0C to 50^0C in 1 sec. The analysis performed was majorly divided into three parts: a) Only considering force, b) Considering force as well as acceleration, c) Considering force, acceleration and thermal conditions. Total deformation in Aluminium alloy was observed 1.51 to 2.79 times that of structural steel in all the cases. Both metals exhibited almost identical equivalent stress in absence of thermal effect and structural steel exhibit 1.5 times that of Aluminium alloy at elevated temperature. Aluminium alloy possess relatively more (1.86-2.63 times) equivalent elastic strain compared to structural steel. Although, distribution of thermal strain remained constant throughout the chassis for both the materials, its magnitude was 1.91 times high in Aluminium alloy. This type of analysis helps in evaluating the current design and decide whether it will sustain the required load and acceleration under given thermal conditions.

1.   Introduction

Automation is going to be the future of many fields like automobiles, farming, logistics, manufacturing sector, etc. and one of these fields is 'Robotics'. It is a very vast and fast-growing field. One of the major areas is of movable robots like vehicles with 3-4 wheels which are very much like our cars and 3-wheelers. A lot has changed in contemporary chassis design. When the automotive industry first started, the body panels and chassis frames were both composed of wood. Since 1900, chassis have been made of steel and aluminium sheets, giving designers more latitude to build shapes. It is crucial that the chassis design is solid, dependable, and long-lasting. The engineering sector possesses the expertise necessary to optimize the chassis' weight and size today. Engineers model the design to produce a prototype using industry-standard methods like Computer Aided Engineering (CAE). With the aid of simulation methods like FE modelling, the impacts of chassis input conditions can be easily calculated with minimal experimental expense. The primary goal is to ascertain the static loads as indicated by pay load and vehicle weight acting as response forces under the static load condition that was used.

CAE tools are traditionally associated with advanced research & development services related to a specialist skill in physical modelling. CAE gives analytical predictions to support automotive product designs, showing which method achieves the best performance.

Chassis serves as the structural support of a vehicle that is mounted with the suspension, steering, and drive train parts like the engine, transmission, and final drive. The suspension components would need to be supported by a sturdy and stiff chassis. [1] Chassis is typically defined in dictionaries as the framework on which the body or functional components of a car, radio, or television are

constructed. Today, the frame, unit body, and space frame construction fundamental designs are all still in use. Steel beams in the shape of channels are typically used in the frame construction and are joined by welding. All of the running gear positioned on the vehicle's frame (or chassis), as well as the engine, transmission, rear axle assembly (if rear wheel drive), and all suspension parts, are supported by the chassis. When viewed from the top, the frame resembled a ladder. The perimeter frame is made up of frame members that are riveted or welded around the border of the body [1]. A few literatures have been looked at in the current investigation. It has been determined, after carefully examining the results of the many research investigations conducted so far, that there is room for improvement in a variety of variables, including weight, stress, strain and deformation, etc. The chassis frame's cross-section and material could be altered to achieve this [2].

Integrated CAD/CAM/CAE/PLM technologies have made it possible for the industry to realize product creation, manufacturing, use, and servicing in digital settings. The main concept is to combine robotics software, mechanical CAD, and CAE capabilities into a single platform to streamline the development process with an intuitive user interface. A variety of 3D models of the robotized production work cell, including the robot and the environment in which it operates, are included on the integrated platform [3]. The study outlines an interdisciplinary strategy that combines physical and virtual (3D) modelling techniques and tools in an industrial design and high industrial undergraduate engineering school research setting. The physical modelling for many types of robotic systems, including mobile robots, manipulators, etc., was intimately related to the CAD/CAE processes. As a result, the robot's design issues are resolved in both physical and virtual settings [3]. Finite Element Method helps in understanding:

1.   The physical behavior under varied applied loads is better understood with the aid of the finite element method.
2.   To determine the performance and viability of the design.
3.   For the safety margin to be calculated.
4.   To determine the design's potential weaknesses.
5.   To determine the ideal layout [4]

Autonomous mobile robotic systems have been commonly seen in two types as legged and wheeled mobile robot. Both have advantages and disadvantages. Wheeled mobile robots have more simple mechanism, lower weight, easier to control and faster than legged ones. Wheeled mobile robots can be seen with different wheel types and drive mechanisms in academic and commercial implementations. The omnidirectional mobility, which is one of the drive mechanisms for mobile robots, is defined as having motion capability to move instantly in all directions from any configuration. Omnidirectional vehicles are capable to translate in x and y directions and rotate about its gravity centre [5].

Using CAD (Computer Aided Design) software, the mobile transportation robot was created as two modules: a mechanical wheeled locomotion module and a robotic arm module. The static structural and rigid body dynamics tools of the CAE (Computer Aided Engineering) software were used to conduct the analyses. The robot's body was subjected to the added load and the robot's weight during the structural study. In the dynamic analysis, the CAE software was used to model the operational environment and conditions [6]. The picking robot arm's modal analysis was performed using ANSYS Workbench, and the modal characteristics in various positions were obtained. We then discovered that the deformations of the arm frame's end bearing, the sub-rod, and a triangular block were larger, resulting in a smaller stiffness, which could be decreased by increasing the parts' thickness or switching out good materials [7]. Ze et al. designed frame of wall climbing robot for wall inspection of thermal power plants. The gap adsorption permanent magnet model is constructed, and its parametric simulation analysis is carried out using the Ansoft Maxwell module [7].

Overall stiffness of the car frame was determined by CAE simulations [2]. The comfort of the passengers' ride is impacted by the rigidity of the car frame, which changes with boundary conditions. In the current study, the car chassis is modelled using finite elements (FEM), and optimization is used to identify design improvements, such as bulkheads and reinforcements, on the chassis based on the

input of the road load situation. Pre-processing is used to complete the FEM modelling. To verify the modal frequency and model shape of the chassis, Nastran is employed as a solver. Virtual testing is possible. to assess the findings and confirm the frame's design adjustment. [8]

A robot manipulator CAD/CAE/CAM integrated system was created. The robot position analysis was calculated using Matlab using the D-H (Denavit-Hartenberg) coordinate transformation method in accordance with the transformation matrices. Mastercam was used to implement the cutting simulation, Pro/Mechanica was used to simulate the dynamic simulation, and a CNC milling machine was utilised to create the prototype. Pro/ENGINEER (Pro/E) was used to build the robot manipulator parametric solid models. Finally, a robot manipulator CAD/CAE/CAM integrated system was created [8, 16]. Due to the unfavourable conditions of the majority of our loads and engine operations, the automobile is subject to some loads (vibration/excitation) that, if not considered during the design stage, might harm the vehicle. Unbalance, misalignment, looseness, shaft catenary / bearing loading, resonance, rubbing, shaft bow, erroneous operating parameters, faulty bearing / bearing assembly, vibration transmission from another source, gear inaccuracies, and casing distortion are other factors that can cause vibration. Jiang et al. performed structural design and simulation of quadrupled tree climbing robot. A kinematic model was established using D-H method. Stress analysis of gripper mechanism was performed to assess stresses [9].

In mechanical dynamic systems, oscillations are known as vibrations. The term "vibration" in mechanical engineering is frequently used to refer to systems that can oscillate freely without applied forces, even though any system can oscillate when it is compelled to do so externally. In engineered systems, these vibrations can occasionally result in minor or major performance or safety issues. Using computer-aided engineering (CAE) has proved crucial for creating new automotive products. Engineering software is used in the modern automobile industry to analyse the structural, material, and crashworthiness of vehicles before they are manufactured in order to reduce manufacturing costs and material waste. In some cases, it is also used to improve an already-existing product or technology [10, 12, 15]. The types of optimisation processes include the following: Optimisation techniques include topology, topography, size/gauge, shape, and free-shape optimisation [4, 13, 14].

A Formula SAE vehicle's suspension and chassis are crucial to its structural performance. The analysis and improvement of the FSAE vehicle structure's properties, as well as the construction of the structure, are the main topics of this paper's CAE modelling and simulation study. This was done for the 2014 Formula SAE-compliant current vehicle as part of the Thapar University (TU) Formula student squad, squad Fateh [11]. To gain knowledge about the behavior of the assembly under various loading circumstances, static structural analysis is carried out. It helps the engineers identify areas where high stress is likely to occur and cause deformation, giving them the chance to adjust the design accordingly. To experience the fewest deformations during loading, a chassis must have strong structural rigidity. This characteristic guarantees that the chassis is robust for these systems to function consistently as a structure that houses numerous vehicle systems.

2. Methodology & Materials

2.1 Work and Work Material

Static Structural Analysis of three -wheeler robot chassis which includes total deformation, von mises stress, von mises strain, thermal strain, etc has been carried out. Analysis has been performed using two different materials for chassis: Aluminium 1lloy and Structural steel.

2.2 Software Used

For CAD modelling of three-wheeler robot chassis Solidworks 2018 whereas for CAE Analysis of three-wheeler robot chassis Ansys R1 were used.

2.3 Methodology

Conventional modeling and analysis procedure was adopted for the simulation. Based on input load and demission requirements, a drawing of three-wheeler robot chassis along with its dimensions was

prepared. Further, CAD model of the chassis was prepared in solidworks according to the dimensions. Weldments were used for the body of the chassis.

Thereafter, the model was imported into Ansys Workbench. Engineering data which includes the materials for chassis was assigned. Two materials from the existing material library Aluminium alloy and Structural steel were used considering weight and load criteria.
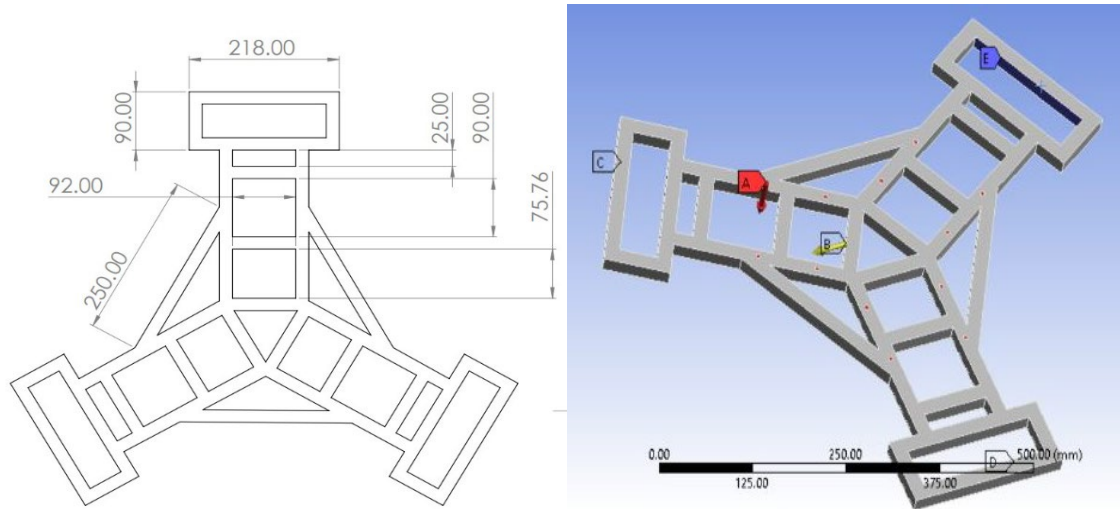

Fig. 1. (a) Chassis Drawing, (b) application of forces, acceleration and fixed support on the chassis

2D drawing of the chassis alongwith its 3D representation has been shown in Fig 1(a)-(b). Specification of the materials used for simulation are tabulated in Table 1 and 2.

Table 1. Aluminum Alloy Specification used in Ansys

Property	Value	Property	Value
Young's Modulus	71000 MPa	Compressive Ultimate Strength	0 MPa
Poisson's Ratio	0.33	Compressive Yield Strength	280 MPa
Bulk Modulus	69608 MPa	Tensile Ultimate Strength	310 MPa
Shear Modulus	26692 MPa	Tensile Yield Strength	280 MPa
Isotropic Secant Coefficient of Thermal Expansion	2.3 e^{-05} /°C		

Table 2. Structural Steel Specification used in Ansys

Property	Value	Property	Value
Young's Modulus	200000 MPa	Compressive Ultimate Strength	0 MPa
Poisson's Ratio	0.3	Compressive Yield Strength	250 MPa
Bulk Modulus	166700 MPa	Tensile Ultimate Strength	460 MPa
Shear Modulus	76923 MPa	Tensile Yield Strength	250 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.2 e^{-05} /°C		

3.   Results & Discussion

3.1   Behavior of chassis under applied load only

Under load only condition with three-wheel support, maximum deformation was observed at the center of the chassis. This is obvious due to lack of support the center. Aluminium alloy shows more total deformation as compared to structural steel as its ultimate tensile strength is less than structural steel (Fig 2 & Fig 5). Equivalent stress is almost similar for both the materials, with structural steel having slightly higher value (Fig 3 & Fig 6). The equivalent elastic strain is more in Aluminium alloy as compared to structural steel which is due to more deformation (Fig 4 and Fig 7). Maximum and average values of deformations, equivalent stresses and strains for Aluminium alloy are shown in Table 3 and for structural steel in Table 4.
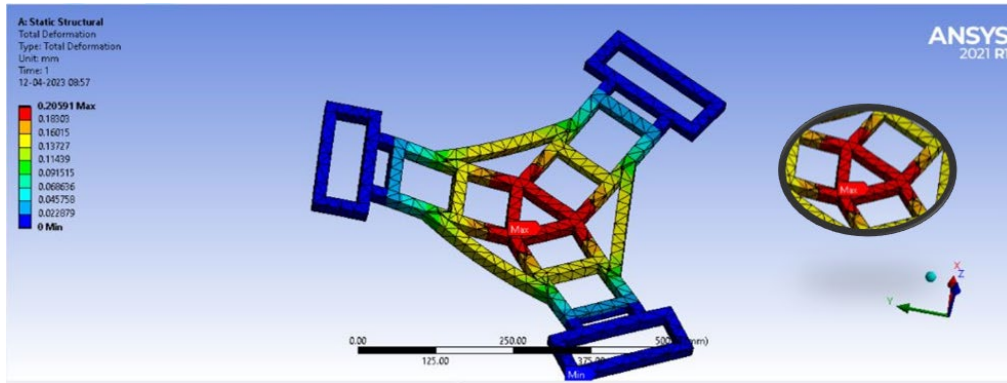
Fig. 2. Total deformation on aluminum alloy chassis without thermal and acceleration aspects
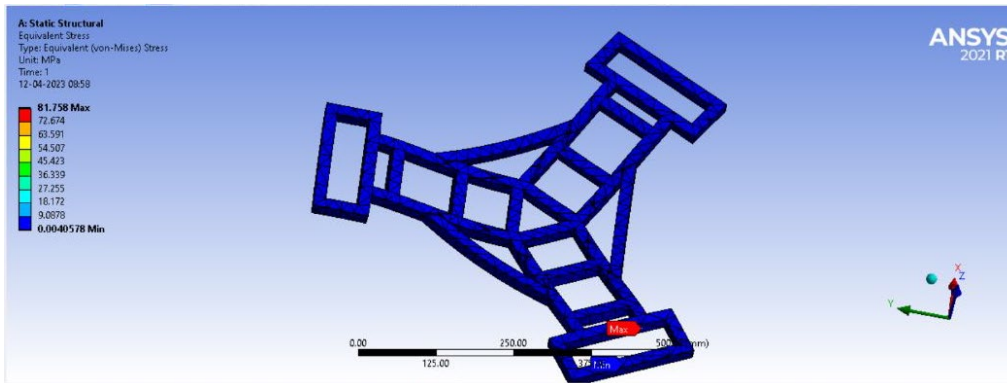

Fig. 3. Equivalent Stresses on aluminum alloy chassis without thermal and acceleration condition
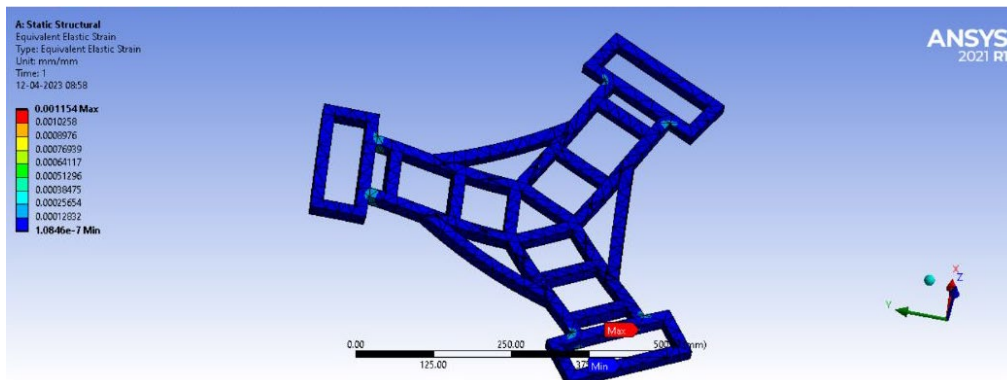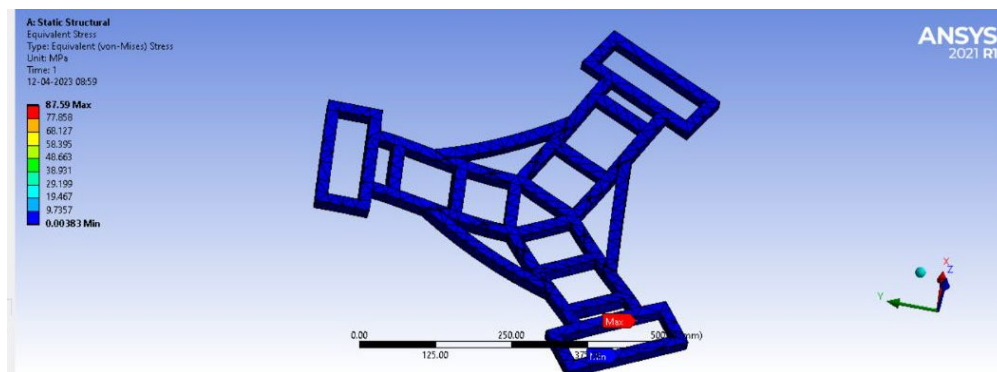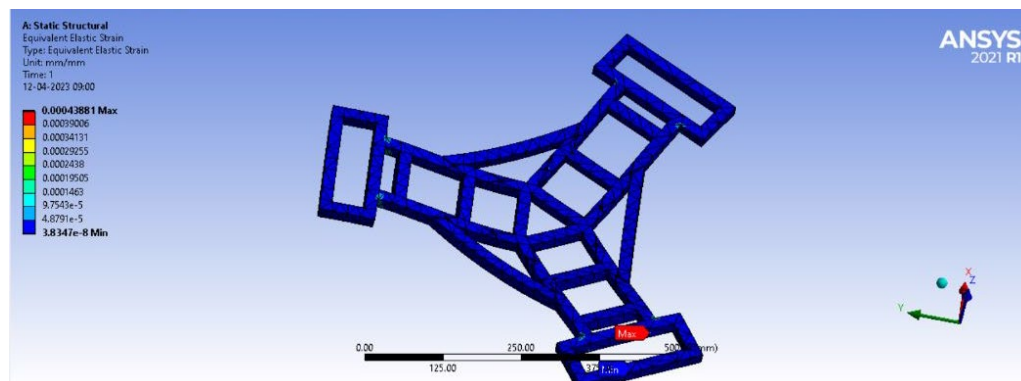

Fig. 4. Equivalent Elastic Strain on aluminum alloy chassis without thermal and acceleration conditions

Table 3. Aluminum Alloy without thermal and acceleration condition

	Maximum Value	Average Value
Total Deformation (mm)	0.20591	0.077836
Equivalent Stress (MPa)	81.758	2.8966
Equivalent Elastic Strain	0.001154	0.0005807
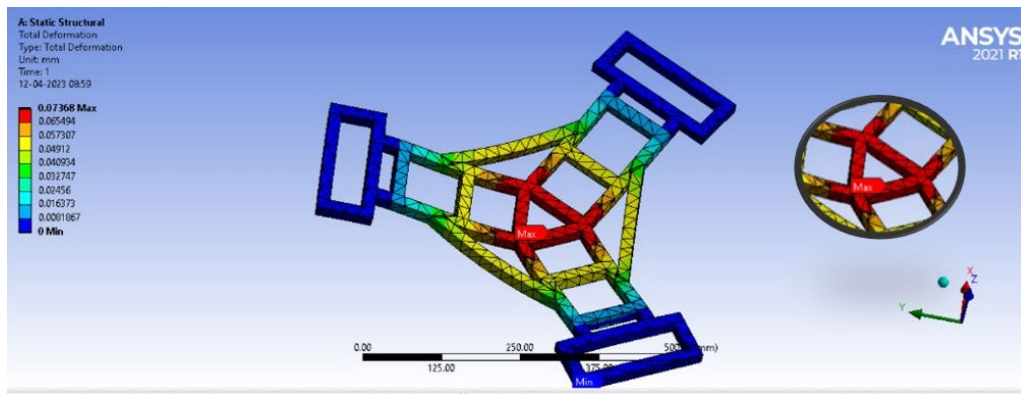
Fig. 5. Total deformation on structural steel chassis without thermal and acceleration conditions

Fig. 6. Equivalent stresses on structural steel chassis without thermal and acceleration conditions

Fig. 7. Equivalent elastic strain on structural steel chassis without thermal and acceleration conditions

Table 4. Structural Steel without Thermal and Acceleration conditions

	Maximum Value	Average Value
Total Deformation (mm)	0.07368	0.027879
Equivalent Stress (MPa)	87.59	2.9261
Equivalent Elastic Strain	0.000438	0.000209

3.2   Behavior of chassis under applied load and acceleration

Total deformation of structural steel chassis was found to be less compared to aluminium alloy chassis as its ultimate tensile strength is higher (Fig. 8 and Fig. 11). The equivalent stress is slightly high in the case of structural steel (89 MPa) as compared to Aluminium alloy (81 MPa) (Fig 9. and Fig. 12). The equivalent elastic strain is less for structural steel as compared to Aluminium alloy (Fig. 10 and Fig. 13). Application of acceleration has had no effect on total deformation, equivalent stress, and equivalent elastic strain. Maximum and average values of deformations, equivalent stresses and strains for structural steel are shown in Table 5 and for Aluminium alloy in Table 6.
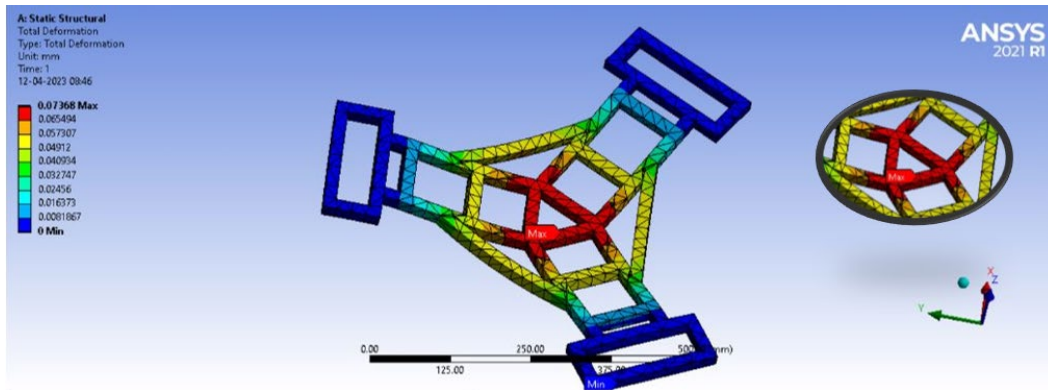
Fig. 8. Total deformation of Structural Steel chassis without thermal conditions
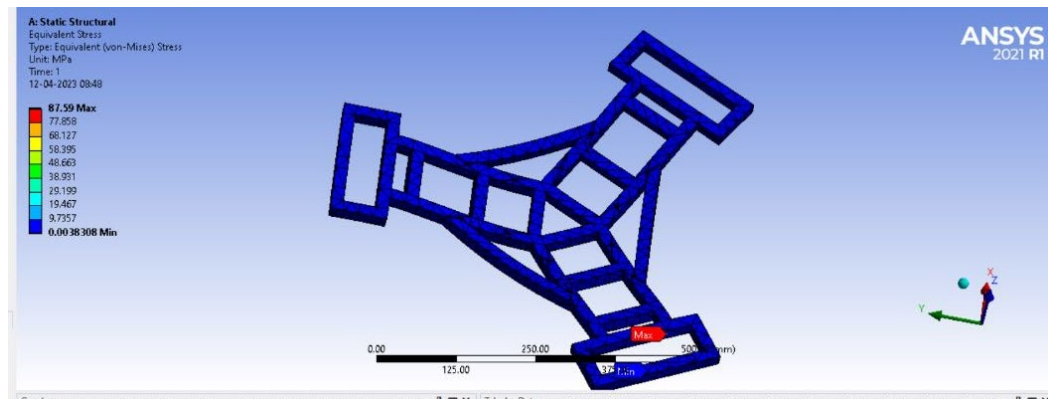

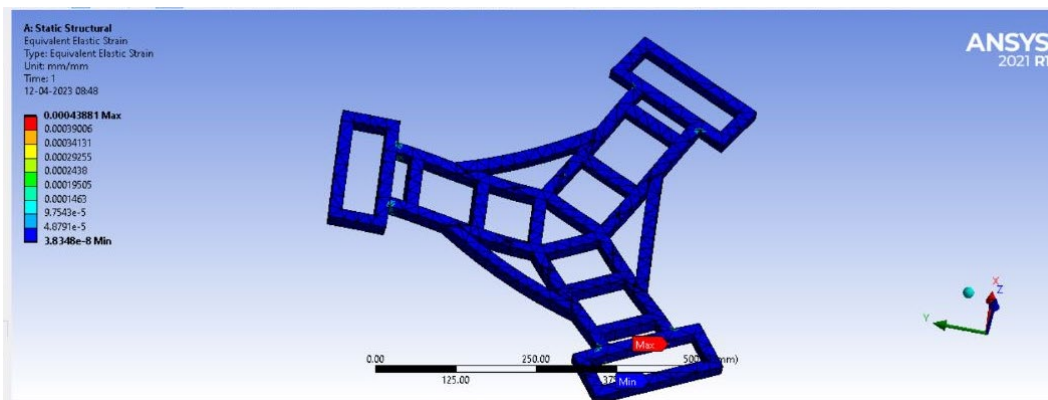Fig. 9. Equivalent stress of Steel chassis without thermal conditions

Fig. 10. Equivalent elastic strain of Steel chassis without thermal conditions

Table 5. Structural Steel with application of acceleration

	Maximum Value	Average Value
Total Deformation (mm)	0.07368	0.027879
Equivalent Stress (MPa)	87.59	2.9261
Equivalent Elastic Strain	0.000438	0.000209
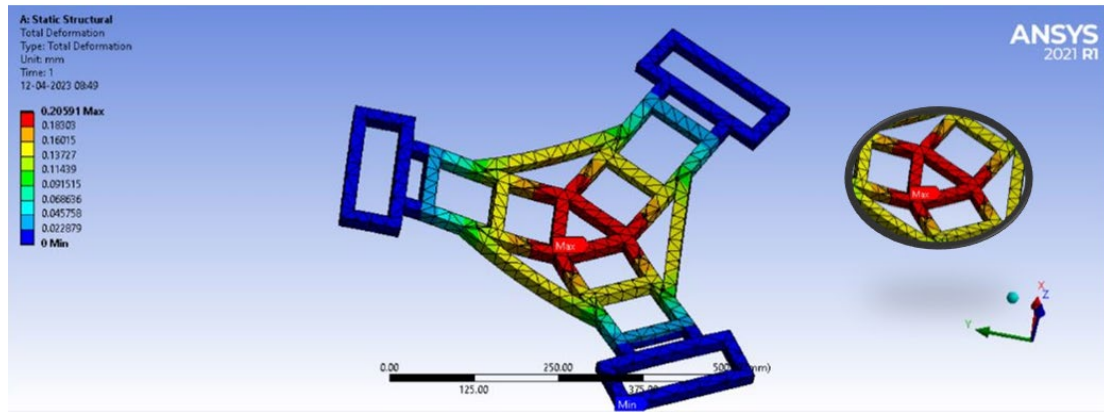
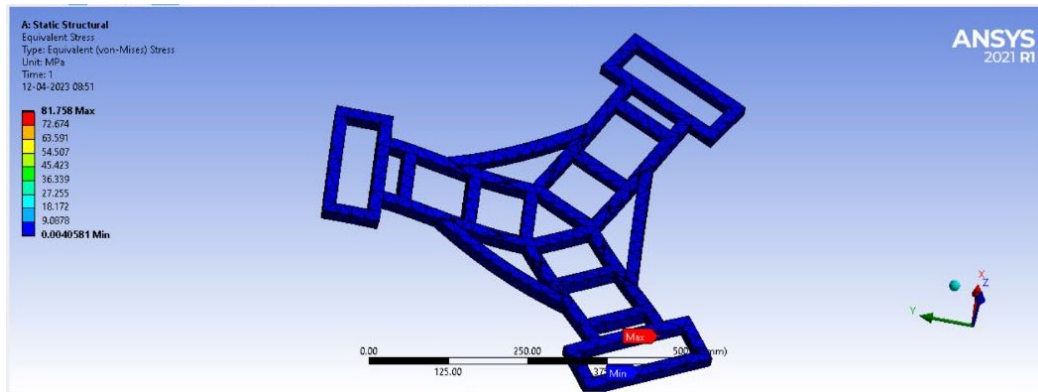Fig. 11. Total deformation of Aluminium alloy chassis without thermal conditions

Fig. 12. Equivalent Stress acting on Aluminium alloy chassis without thermal conditions
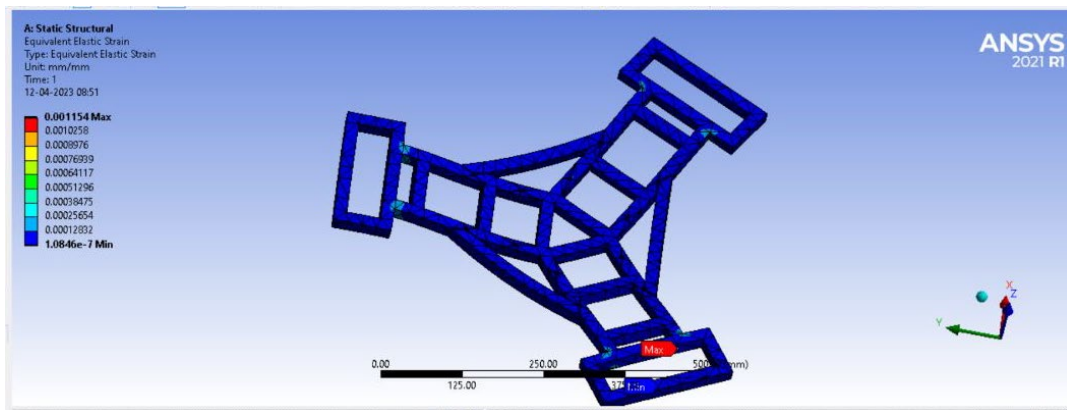

Fig. 13. Equivalent strain experienced by Aluminium alloy chassis without thermal conditions

Table 6. Aluminium Alloy with application of acceleration condition

	Maximum Value	Average Value
Total Deformation (mm)	0.20591	0.077836
Equivalent Stress (MPa)	81.758	2.8966
Equivalent Elastic Strain	0.001154	0.0005807

3.3   Behavior of chassis under load, acceleration, and 50^0C temperature condition

In the case of aluminium alloy as chassis material when load, acceleration and temperature is raised to 50^0C, the total deformation is more as compared to structural steel since its ultimate tensile strength is less and thermal coefficient is more as compared to structural steel (Fig. 14 & Fig. 18). The total deformation is maximum near the center of the chassis as the fixed supports in the form of wheels would be present at the edges. Least deformation is seen near the fixed supports.

The equivalent stress in this case is less in the case of aluminium alloy as compared to structural steel, but equivalent elastic strain is more in aluminium alloy because the structural steel has undergone less deformation (Fig. 15 & Fig. 19). Thermal strain is more in the aluminium alloy as its isotropic secant coefficient of thermal expansion is higher than structural steel (Fig. 17 & Fig. 21). Maximum and average values of deformations, equivalent stresses and strains for Aluminium alloy are shown in Table 7 and for structural steel in Table 8.
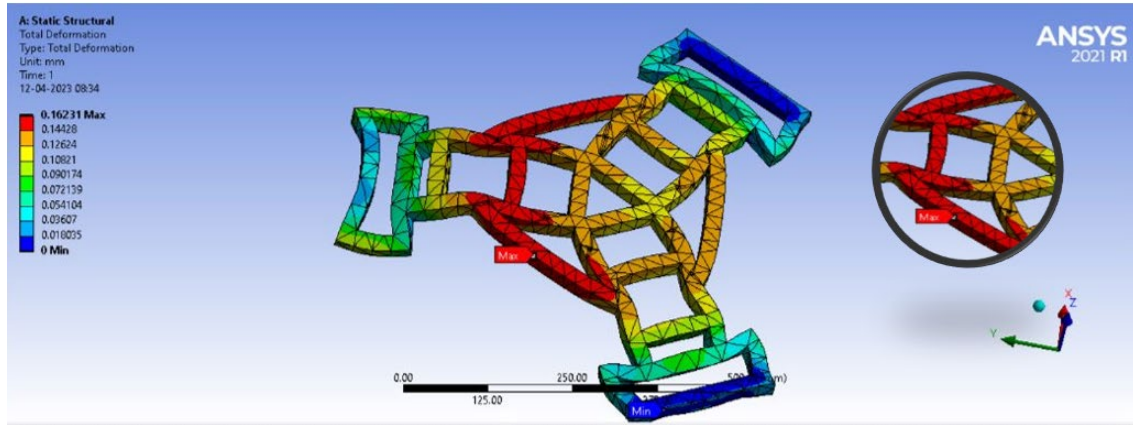

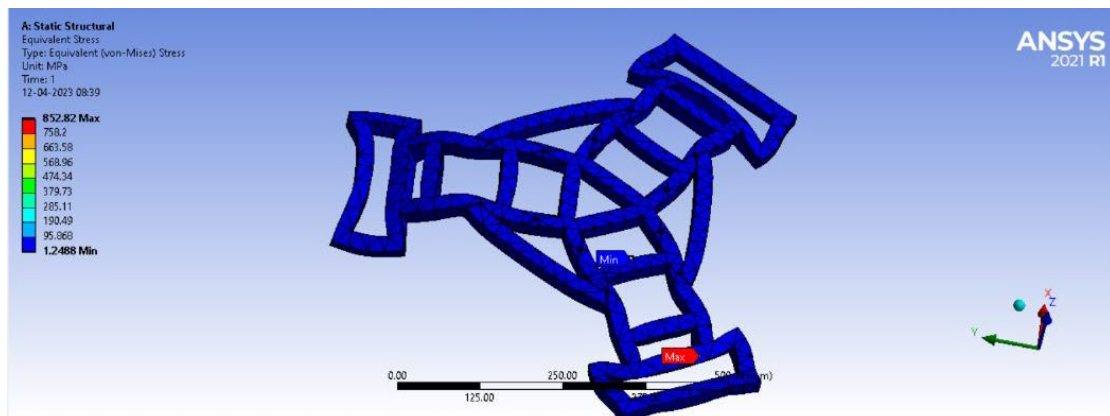Fig.14. Total Deformation on aluminium alloy chassis

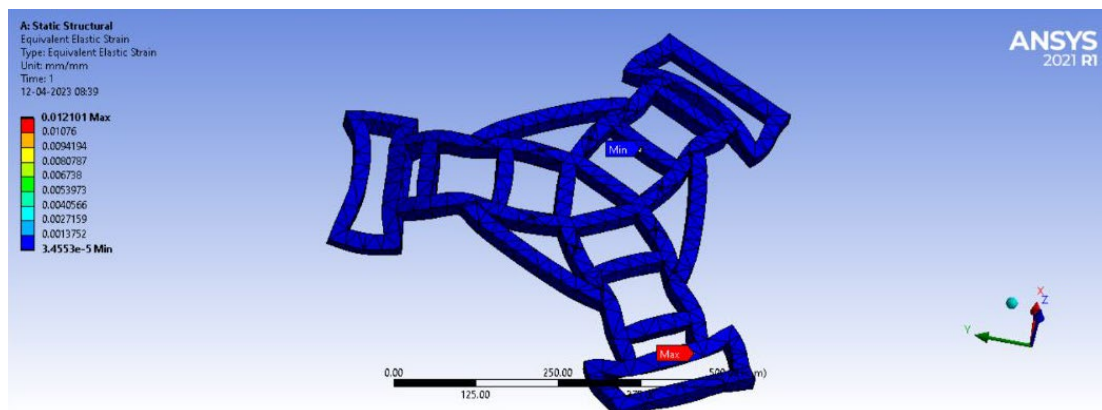Fig.15. Equivalent stresses on aluminium alloy chassis

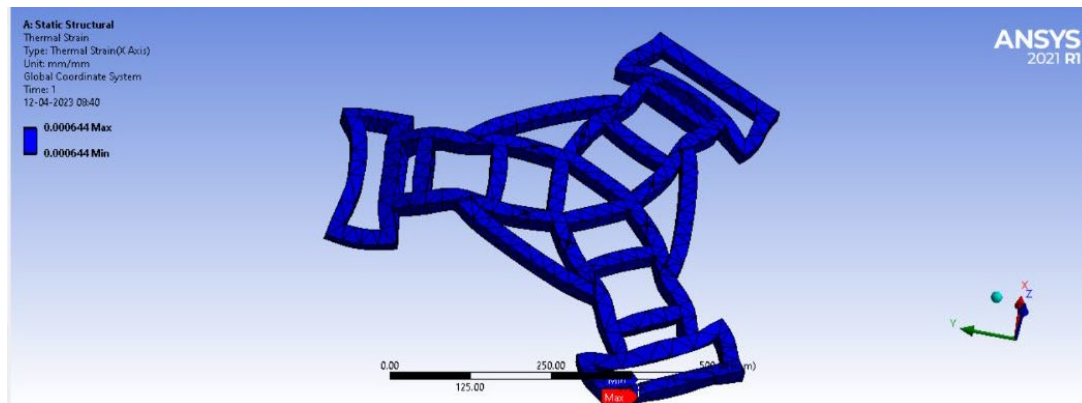Fig. 16. Equivalent strain on aluminium alloy chassis

Fig. 17. Thermal strain on aluminium alloy chassis

Table 7. Aluminium Alloy with application of thermal and acceleration condition

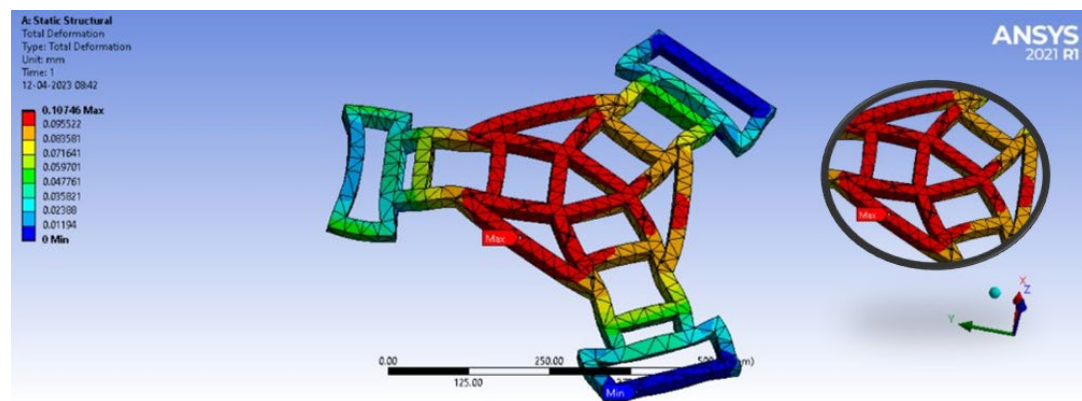|	Maximum Value	Average Value
Total Deformation (mm)	0.16231	0.089
Equivalent Stress (MPa)	852.82	34.639
Equivalent Elastic Strain	0.012101	0.00062308
Thermal Strain	0.000644	0.000644

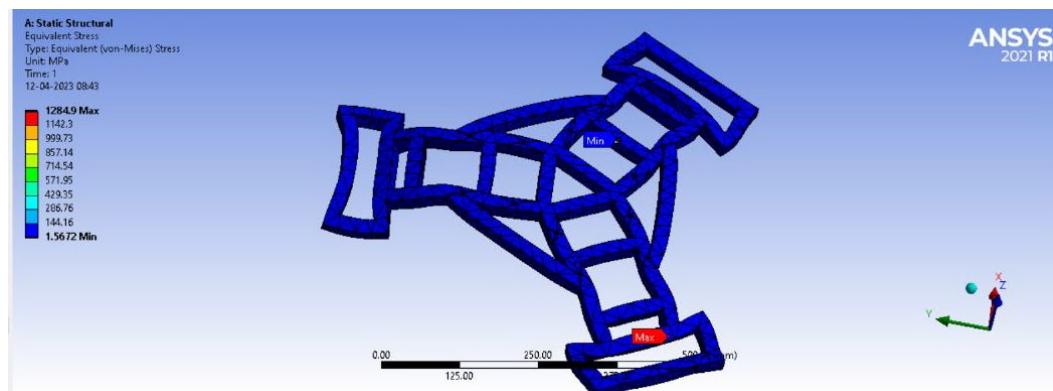Fig. 18. Total deformation on structural steel chassis

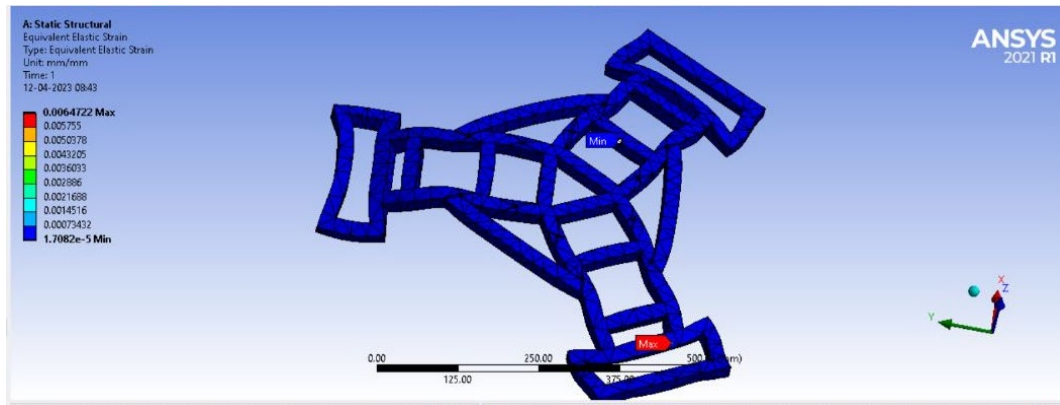Fig. 19. Equivalent stresses on the structural steel chassis

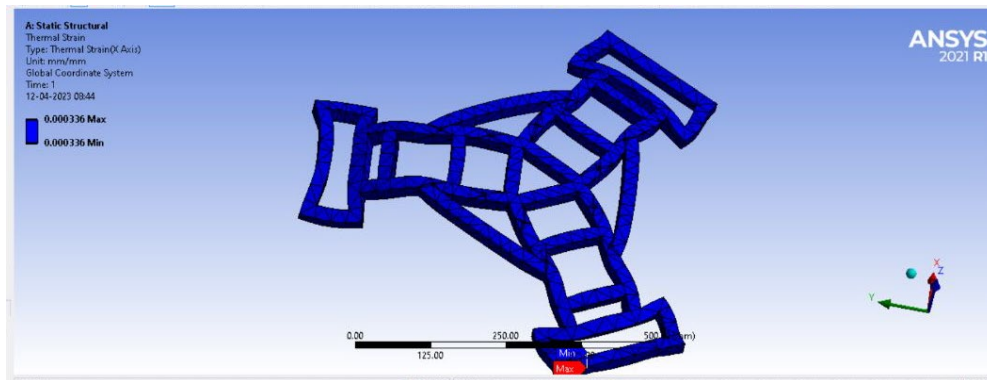Fig. 20. Equivalent elastic strain on the structural steel chassis

Fig. 21. Thermal strain on the structural steel chassis

Table 8. Structural Steel with application of thermal and acceleration condition

	Maximum Value	Average Value
Total Deformation (mm)	0.10746	0.0589
Equivalent Stress (MPa)	1284.9	50.65
Equivalent Elastic Strain	0.006472	0.00032561
Thermal Strain	0.000336	0.000336

4. Conclusions

A comparative static structural analysis of a novel robot chassis for structural steel and Aluminium alloy materials has been carried out for a novel robot chassis. The conclusions of the simulation are highlighted as follows:

1) Total deformation in Aluminum alloy model is more than structural steel model for all the cases. Maximum total deformation in Aluminium alloy when only load is applied is 2.7946 times (279.46%) as compared to structural steel. Total deformation increases with the application of thermal condition but remains constant even when acceleration condition is applied. Under 50^0C temperature, Aluminium alloy deforms 1.5104 times (151.04%) more compared to structural steel.

2) Distribution of equivalent stress is almost same for both materials in absence of thermal conditions. Whereas, equivalent stress in structural steel shows 1.5066 times (150.66%) rise as compared to aluminum alloy at 50 ^{0}C.

3) Equivalent elastic strain is more in Aluminum alloy as compared to structural steel in all the cases. When only load is applied, Aluminium alloy shows 2.6347 times (263.47%) more equivalent elastic strain as compared to structural steel. Equivalent elastic strain increases by 1.8697 times (186.97%) for Aluminium alloy as compared to structural steel when thermal condition is applied.

4)   Thermal strain distributions are constant throughout the chassis for both the materials. Whereas, it is 1.9166 times (191.66%) more in magnitude for aluminum alloy model compared to its counterpart.

Thus, while working in higher temperature ranges of around 50^0C, structural steel should be preferred as chassis material as it undergoes lesser total deformation and also the equivalent stress and strain developed are less as compared to Aluminium alloy. When working in normal room temperature range, despite undergoing more total deformation, Aluminium alloy should be preferred as chassis material as there is no significant change in equivalent stress and strain. Moreover, Aluminium alloy is lighter in weight and economically cheaper.

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