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Composite Solutions for Sustainable Mobility: Aluminum Alloy, Carbon Fiber, and Graphene in Chassis Frame Design

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Abstract

This study describes the design and analysis of a chassis frame made of carbon fibre, graphene, and aluminium alloy composite materials. A frame must be able to sustain vibration, shocks, and bending and torsional pressures. This piece of work uses a rectangular cross-sectional area to design a frame. After that, the simulated chassis is taken for investigation using composite materials such as aluminium alloy and carbon fibre reinforced with graphene. Given the significant role that vehicle chassis play, structural analysis must be used to the design to check against all potential scenarios of load application and design failure. Using front, side, and rear impact force assessment of the chassis frame, we will conduct impact test analysis in the explicit dynamic's module of Ansys to identify places with maximum pressures and deformation. Ansys 2021 R2 and Solidworks 2021 are used for the simulation.

Keywords: Structural analysis, Rectangular hollow cross section, SolidWorks, Ansys, Graphene.

INTRODUCTION

In the field of car engineering, finding lightweight yet durable chassis designs is a never-ending challenge. In order to meet the increasing demands for safety, performance, and fuel efficiency, engineers are always looking for new materials and manufacturing methods. An exciting new direction in automobile design and analysis is the incorporation of graphene, carbon fibre, and aluminium alloy as composite materials in chassis construction. The word "chassis" means "base frame of an automobile" in French. The fundamental framework of an automobile is its chassis. It provides structural stability and support for all the vehicle's pieces that are attached to it. The primary purpose of a chassis is to protect the vehicle's occupants in the event of a collision in addition to maintaining the structure, hence material selection is quite important. A chassis frame needs to be robust enough to bear any and all bending, torsional, dynamic, and static forces placed on it. The chassis of a car is a crucial component. The body and other components of the car are supported by the chassis, which acts as a framework. It must also be sufficiently stiff to bear loads such as twisting, vibration, and shock. Adequate bending stiffness is a crucial factor in chassis design, in addition to strength, for improved handling qualities. Thus, rigidity and strength are two crucial factors in the chassis' design.

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GRAPHENE TRENDS AND DEVELOPMENT

When graphene is stacked one on top of the other, it forms three dimensions. Graphene is a two-dimensional sheet of graphite structured in a honeycomb hexagonal configuration. Graphene, often known as the wonder material, possesses exceptional mechanical, electrical, and chemical capabilities, making it the strongest substance yet measured. However, 3D printing cannot be done with just this amazing material. Scientists at Pennsylvania State University developed a novel method for producing graphene-reinforced carbon fibre, a material that has gained recognition in recent years. Graphene-reinforced carbon fibre was developed by a team of scientists at Pennsylvania State University. They devised a novel method of producing the material that not only reduces production costs but also fortifies the fibres. Researchers incorporated graphene into carbon fibre and examined its characteristics through a combination of in-lab tests and computer models. When compared to PAN-based carbon fibres, the researchers saw a 225% increase in tensile strength and an 184% rise in young's modulus when they introduced tiny amounts of graphene (0.075 to 0.1 weight percent) to conventional carbon fibre.

Although carbon fibre is a great material, it is currently exceedingly expensive to introduce PAN-based carbon fibres into mass production due to the $15 USD per pound manufacturing cost. However, with this discovery, the cost is predicted to drop to $5 USD per pound.

Graphene: The Material of Miracles

Due to its remarkable features, graphene, which is a single sheet of carbon atoms organised in a two-dimensional honeycomb lattice, has attracted a lot of attention. Graphene, one of the toughest materials ever discovered by humans, possesses remarkable electrical conductivity, stiffness, and tensile strength. Because of its exceptional mechanical qualities, it is a great option for strengthening the structural integrity of car chassis.

Engineers can greatly increase the material's strength-to-weight ratio and increase the crashworthiness and longevity of the chassis by adding graphene into the composite matrix. Additionally, the superior heat conductivity of graphene can help dissipate heat produced during operation, enhancing the vehicle's overall longevity and efficiency.

Finite Element Analysis

A simulation programme called finite element analysis, or FEA, is used to numerically solve large engineering models in a virtual setting. The purpose of static analysis for mechanical parts is to determine the effects of constant loads on the structure without accounting for the effects of shock and inertia, which are frequently observed when applied loads change quickly. The areas of deformation and corresponding stresses in a structure caused by the application of impact force are computed using an Explicit Dynamics analysis. We will obtain the minimum, average, and maximum deformation along with equivalent stresses upon completion of the analysis. Fundamentally, finite element analysis divides large, complicated systems into smaller, easier-to-manage units known as finite elements. These components form a mesh that depicts the complete system since they are joined at distinct locations known as nodes. Through the application of mathematical formulas to every component and their combined solution, finite element analysis (FEA) enables engineers to forecast the overall system's behaviour under different scenarios. The potential of Finite Element Analysis is anticipated to increase tremendously with the advancement of simulation techniques and computing capacity. Further enhancing FEA's usefulness and efficacy in engineering design is its integration with other simulation tools, like computational fluid dynamics and optimisation methods.

Important Steps in Analysis of Finite Element:

Preprocessing: In this step, the system's geometry is defined, the material properties are specified, and the finite element mesh is created.

Analysis: The system's controlling equations, such as those derived from conservation equations or Newton's laws of motion, are solved to mimic the behaviour of the system.

Postprocessing: After the analysis is finished, engineers visualise and analyse the data to learn more about how well the system is working.

Related Study

The conceptualization and evaluation of a chassis frame made of graphene, carbon fibre, and aluminium alloy was represented by Maideo et al. [1] A book was referred for the ANSYS study [2]. Markus created a novel motorbike suspension system with changing geometry based on the driving circumstances [3]. The structural analysis and optimisation of a vehicle's chassis with limitations on the maximum shear stress and the chassis's deflection at maximum load were described by Patil et al. [4] Yagyansh Mishra demonstrated the TATA LPT 1618 truck, which was used to construct the chassis with the C, I, and Rectangular Box (Hollow) types of cross-sections [5]. Vijaykumar et al. worked to optimise the vehicle chassis while keeping in mind the maximum shear stress, equivalent stress, and chassis deflection at maximum load [6]. The improved FE truck chassis model, as proposed by Chintada et al., is meant to minimise vibration, enhance strength, and optimise the truck chassis' weight [7]. Babu et al. discussed automotive chassis design material selection for both road and race vehicles [8]. For an Eicher E2 TATA Truck ladder chassis, Kumar et al. determine the optimum material and most appropriate cross-section while keeping in mind the maximum shear stress, equivalent stress, and chassis deflection under maximum load conditions [9]. Using FEM, Patil et al. provided the stress study of a ladder-type low loader truck chassis structure made of C-beams designed for 7.5 tonnes of application [10]. Cavazzuti et al. presented a methodology for designing car chassis using optimisation techniques [11]. The work done in preparation for the truck chassis' static structural analysis was presented by Patel et al. [12]

Reinforcements Made of Carbon Fibre: Increasing Structural Stiffness

For a very long time, carbon fibre composites have been highly valued for their outstanding rigidity and unmatched strength-to-weight ratio. The chassis structure can be strengthened with carbon fibre reinforcements, allowing engineers to achieve significant weight savings without sacrificing structural integrity.

By using carbon fibre components, the mechanical characteristics of the chassis may be precisely tailored to improve ride comfort and vehicle handling by optimising damping and rigidity. Furthermore, carbon fibre offers durability and long-lasting performance throughout the vehicle's lifecycle due to its resistance to corrosion and fatigue.

Aluminium Alloy: Harmonising Density and Tensile Power

For many years, aluminium alloys have been a mainstay in the automobile industry due to its low density, ability to withstand corrosion, and malleability. Engineers can further reduce weight while preserving robustness and rigidity in the composite chassis design by selectively integrating aluminium alloy parts. Because of its inherent qualities, aluminium is a great choice for structural elements like chassis frames that are subjected to dynamic loading situations. Because of its versatility in forming processes, it can be used to create lightweight yet intricately built chassis constructions with complex geometry.

Problem Definition

Traditionally the most used material for manufacturing chassis frame has been steel. Steel has some decent properties, it's cheap and is readily available but over the years a lot of automobile manufacturers are experimenting with new and improved material technologies such as carbon fiber, aluminium, graphene, glass epoxy etc. conventional materials like steel are heavy and during high speed head on collisions they may deform beyond their crumple zones so we wanted to compare latest generation material technologies to previous generation materials and see how they perform when subjected to forces which they experience during realistic high speed crashes.

OBJECTIVE

- To determine Deformation using comparable stresses.
- To determine the chassis's weight using various materials.

- To create a straightforward yet sturdy chassis frame.
- To evaluate analysis results and choose the most suitable material.

Challenges in Design and Analysis

Although the combination of graphene, carbon fibre, and aluminium alloy presents exciting opportunities for chassis design, there are a number of obstacles that need to be overcome in the course of development.

First and foremost, to optimise load transfer and structural integrity, it is critical to ensure optimal bonding between the various components inside the composite matrix. Automated fibre placement and resin infusion are two examples of advanced production procedures that can help create smooth integration and get rid of any delamination problems.

Second, to verify the composite chassis's performance under varied operating situations, thorough computer analysis and simulation are necessary. Engineers can evaluate structural integrity, forecast failure modes, and optimise material distribution to satisfy performance and safety requirements by using finite element analysis (FEA) as shown in Figure 1. Moreover, during the production process, factors like cost-effectiveness, scalability, and environmental impact must be considered. Although composite materials have unmatched performance advantages, their widespread use depends on their ability to be produced at scale and at a cost that is competitive with that of traditional materials as mentioned in Table 1 and Table 2.

Design

We used the frame of the Jeep Wrangler as inspiration while designing the ladder frame chassis for this project. The majority of ladder frame members have C or I cross sections, but for this project, we're going to use a rectangular section type as it's easier to design and has greater strength and stiffness than the other two. The frame's measurements will resemble those of a Jeep Wrangler in general. The ladder frame has two long side members, a few cross members, and connection plates, just like a conventional ladder frame. It was designed using the SolidWorks 2021 programme.

Table 1. Details of Chassis Frame

State	Fully Defined
Length @ X axis	3440 MM
Length @ Y axis	278 MM
Length @ Z axis	1225 MM
Mass	Mass (kg)
AA7075 T6	45 Kg
Carbon fiber	38 Kg
Graphene	24 Kg
Graphene reinforced CF	30 Kg

Table 2. Material Selection

Properties	AA7075 T6	Carbon fiber	Graphene Reinforced CF	Graphene
Density	2810	1780	2000	2267
Poisson's ratio	0.33	0.38	0.396	0.456
Youngs Modulus	71700	155000	233000	1000e3
Shear Modulus	26955	56159	83453	3434e5
Ultimate Strength	542	1000	3250	130e3
Yield Strength	485	600	1916	14000

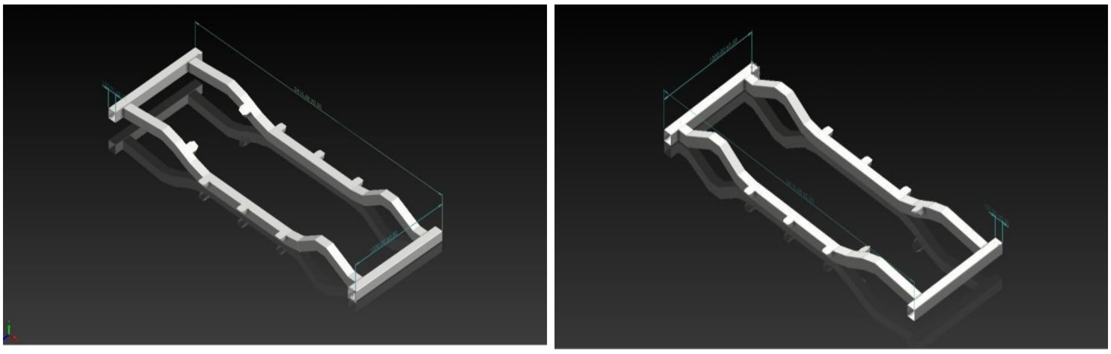


Figure 1. Structure analysis of chassis framework.

Explicit Dynamics Analysis

Ansys' Explicit Dynamics assessment module aids users in examining and simulating the impact forces acting on a body—in this example, a chassis framework. It is employed for determining material harm or malfunction in terms of displacement and pressures by simulating short-duration events.

Meshing

The elements' sizes are kept to a minimum, and a tetrahedron mesher is employed for meshing. To obtain precise results, the mesh quality is maintained at a fine level.

Delineation Conditions

Boundary conditions must be used for this kind of study. The following are a few of the border conditions:

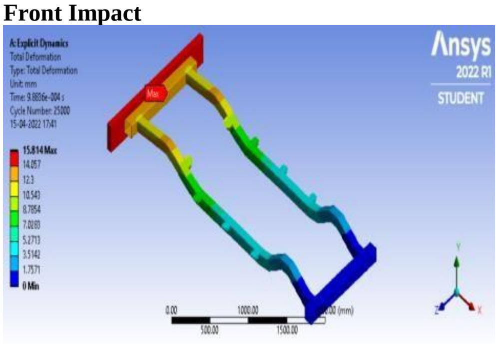
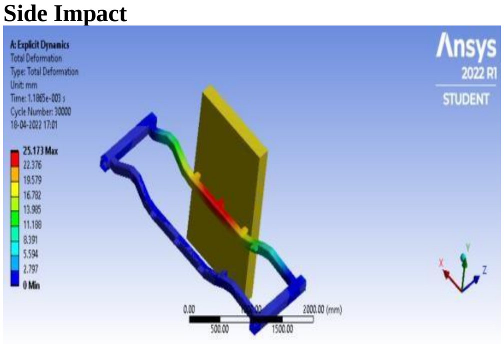
1. A fixed foundation is utilised at the back of the chassis frame for front impact evaluation, and a 60 km/h velocity is imposed on the wall at the X-axis for the analysis.
2. A rigid support is placed at the opposite end of the opposite side of the chassis frame for side impact study, and a velocity of -60 km/hr is applied to the wall at Z axis.
3. The analysis parameters maintain a maximum duration of 100,000 cycles and a completion time of 0.03 seconds. Results shown in Table 3.

RESULTS AND DISCUSSIONS

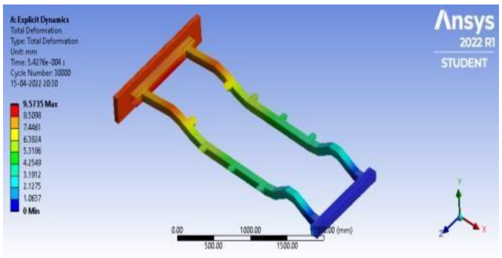
Automobile Chassis Design's Future

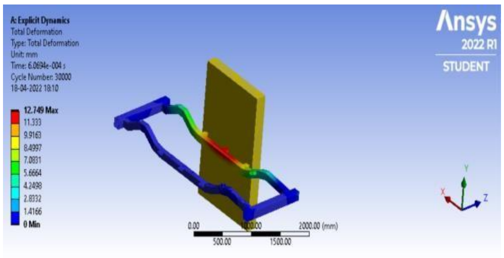
Front Impact Results and side impact results discussed in Table 4 and Table 5. In automobile chassis design and analysis, the integration of graphene, carbon fibre, and aluminium alloy as composite materials marks a paradigm change. In future vehicle architectures, engineers can attain previously unheard-of levels of performance, efficiency, and safety by utilising the distinctive qualities of each component material. We should expect more advancements in materials science, computer modelling, and composite manufacturing techniques as research and development efforts continue, which will open up new avenues for the creation of robust yet lightweight chassis designs.

Table 3. Impact Force Comparison

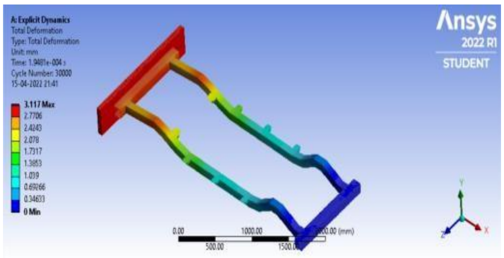
Material	Front Impact	Side Impact
AA7075		

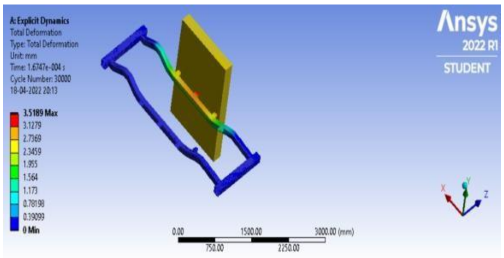
Carbon fiber



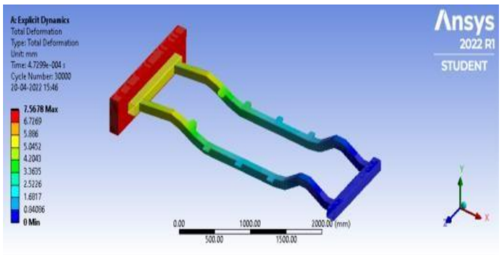


Graphene





Graphene reinforced Carbon fiber



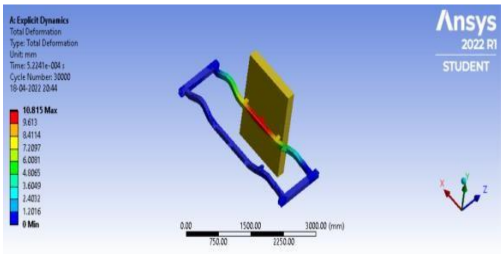


Table 4. Front impact results.

Materials	Range	Deformation	Equivalent Stresses
AA7075	Minimum	0	0.002 Mpa
	Average	7.907 mm	269.7 Mpa
	Maximum	15.81 mm	606.8 Mpa
Carbon fiber	Minimum	0	0
	Average	4.254 mm	358.5 Mpa
	Maximum	9.573 mm	
Graphene	Minimum	0	0
	Average	1.385 mm	880.6 Mpa
	Maximum	3.117 mm	1638 Mpa
Graphene reinforced CF	Minimum	0	0
	Average	3.363 mm	446.5 Mpa
	Maximum	7.56 mm	887.6 Mpa

Table 5. Side Impact Results

Materials	Range	Deformation	Equivalent Stresses
AA7075	Minimum	0	0
	Average	11.18 mm	147.79 Mpa
	Maximum	25.17 mm	337.04 Mpa
Carbon fiber	Minimum	0	0
	Average	5.66 mm	379.8 Mpa
	Maximum	12.7 mm	675.6 Mpa
Graphene	Minimum	0	0

	Average	1.564 mm	823.2 Mpa
	Maximum	3.518 mm	1652 Mpa
Graphene reinforced CF	Minimum	0	0
	Average	4.8 mm	254.72 Mpa
	Maximum	10.81 mm	570.87 Mpa

CONCLUSION

Tables shows that aluminium alloy has had the most deformation, whereas graphene has experienced the least and shows the similar pattern, with graphene experiencing the least amount of deformation at 3.5 mm and aluminium alloy experiencing the highest at 25.17 mm. Graphene reinforced carbon fibre, which has seen the least degree of distortion following graphene, can be utilised as an alternative to graphene as it cannot be utilised alone to create a chassis frame. Weighing every chassis frame, we discovered that carbon fibre and graphene-reinforced carbon fiber-made chassis frames weighed less than carbon fibre and aluminium alloy chassis frames. With emerging material trends like carbon fibre reinforced graphene, the automotive sector appears to have a bright future.

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