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Explicit Dynamics Crash Analysis of Car for Different Materials using Ansys

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Abstract - *The strength of a vehicle is one of the most significant factors that contribute to determining its crashworthiness during an impact. During the designing process, it is essential to ensure that the structure of a car can protect or reduce the level of damage done to the driver or the car's body by absorbing the impacted load and reducing the stress values. It has been scientifically proven that the frontal side of a car is more prone to high energy impacts and deformation during a crash. A frontal accident using an explicit dynamics code is simulated and analyzed here using the ANSYS Workbench to calculate the effect of the frontal collision on various barriers. The developed stress and deformation on impact with a static concrete wall and a moving car with its speed of 20 m/s and its body structure were investigated using a car body made of aluminium, stainless steel, and composites travelling at an initial velocity of 30 m/s. The developed stress was plotted and analyzed for all three scenarios, the developed stress, and deformation resulting from the crash. The deformation caused by a collision between two moving cars was found to be the greatest, whereas that caused by static walls was the least adverse.*

Key Words: **Crashworthiness, Explicit Dynamics, ANSYS, Frontal Collision**

1. INTRODUCTION

The crashworthiness of a car determines its structural integrity. The increasing importance of the safety of a passenger car has become a relevant field of study in terms of passenger safety, frame analysis, and material selection. With the advent of Material Sciences and Composites, selecting an appropriate material has become difficult. Composites offer higher structural strength without increasing weight. The possibilities in terms of use in the automobile industry thus widen and open a broader scope of the analysis. Over the years, various studies have been conducted on the strength of frame or material analysis in different passenger car components. Studies have been mutually exclusive and are yet to offer a conclusive material for broader application in car frames and improvement of its strength. Another reason for the improvement in structural strength is the safety of the driver and pedestrian. This factor makes suitable simulations essential for better analyses of the selected material.

In 2015, it was reported that car occupant was the highest single casualty group in Europe, with 45% of death [3]. Frontal impact collisions involving cars are the single most frequent accident category resulting in a high fatality and severe injuries to the occupants. Critical fatal injury points associated with frontal impact are the head, followed by the chest, and then the abdomen, while those resulting in disability are mostly those in the legs and neck. The critical determinants of injury and its severity are travel speed, restraint use, interior occupant contact, size and weight mismatch of involved vehicles, ejection from the car, and inadequate vehicle crash protection [4].

Several vehicle design technologies have been improved to assist the driver in avoiding accident occurrences. Even if the accident occurs, the vehicle should protect both passers-by and the occupants against serious injuries. Therefore, researchers and industries are exploring all the possible options to enhance vehicle crash protective design [5]. The industries and government are striving towards producing environmentally friendly, improved, lighter cars while maintaining the rider's safety [6]. Recently, car manufacturers have used lightweight composite Aluminium, magnesium, plastics, or other steel materials of high strength to construct cars due to their strength and tensile properties [7], [1].

Aluminium material might not be durable in the car body. Still its lightweight increases the rate of acceleration and provides better fuel mileage needed for the efficient operation of Hybrid Electric Vehicles (HEVs) and pure Electric Vehicles (EVs). An essential requirement in the design process of an automobile company is the deformation zones which are meant to protect the car occupants. Its primary function is to absorb the impact through deformation while preserving the space occupied by the crew. A car crash test is one of the most important tests used to validate the deformation design strength of the vehicle. The popularly known crash tests include front, front offset, side, and rollover crash tests [6]. In addition to the cost of running a physical test, the time needed to carry out an experimental crash test is relatively high as well as the data used might be incorrect. As a result, simulation is used to eradicate such problems using numerical modelling methods such as the Finite Element Method (FEM).

2. LITERATURE REVIEW

A study presented by A. K. Picketta et al. [8], found that there is a rapid increase in more competitive modern car designs. Also, there is a need for an improved bumper system mechanism that will solve crashing problems while maintaining low cost at optimal performance. It is necessary to increase the performance of cars in terms of crashes. The factors that must be improved include materials used and energy absorbers. The energy should be absorbed or transmitted by the parts or components that are subjected to impact during a crash. However, this power intake ability of the car body is determined by its geometrical design and materials used [1]. A car should be able to resist impact during crashing, thereby keeping both the driver and the occupant safe from having any injury. This withstanding property is known as crashworthiness [7].

In a paper by Sadhasivam et al. [9], vibration and crash analysis during a frontal, side, and rear collision impact of a car body was investigated through simulation. The paper determines the natural frequency of the structure within which the safety of the car occupants is guaranteed. If the test fails, the analysis has to be repeated using different body materials, and sometimes the structure has to be re-designed and adjusted until the safety standard is achieved and guaranteed [2]. An investigation on the safety of a car passenger at reduced cost was conducted by Byeong et al. [10]. An electric vehicle was used in LS-DYNA to perform frontal crash analysis of the upper and subframe body of the car. Two crash analyses: a high-speed vehicle into a wall and a high-speed vehicle into a stationary vehicle, were simulated and presented by Lin et al. [11]. The analysis was done to determine which impact would harm the driver and be able to design a bumper model capable of withstanding the crash impact. Tejasagar et al. [12] performed frontal car crash analysis using computer simulations intending to reduce production test time and cost. Frontal and side collision car crash analysis in a transient dynamic was performed by Praveen et al. [13]. The deformations and stresses obtained from the collisions were used to determine the car's crashworthiness. The responses of a dummy driver in a four-seat modelled car to frontal and side crashing were selected and presented by Saeed et al. [14].

An SUV car was used as the hitting vehicle while the designed variables were evaluated and generated. This paper presents a crash analysis of a 3D modelled car body performed using the ANSYS workbench. In line with the quest for a lighter body for EVs and HEVs, this study uses Aluminium material which is relatively new in auto manufacturing industries. An explicit dynamic analysis of the car body at a speed of 35m/s and on collision impact for three different scenarios was conducted. The study aims to investigate the crashworthiness of the car body based on its material and structural design by measuring the amount of deformation and stress exerted on the frontal impact of the car body on a steel wall, a static and a high speed moving car.

Abolfazi Masoumi et al. [16], tested Material selection for automotive closures. The conclusion states that safety is influenced by different factors such as cost, weight, and structural performance. The paper offered an detailed analysis of the distance between engine parts and the front bumper, which is essential for head impact and highlights the importance of material selection. N. Bhaskar et al. [17] conducted a similar analysis for the design of a car bonnet. The material selected was Aluminium Alloy, a widely applied metal in the automotive industry.

J. Schulz et al. [18] incorporated composite material in car bonnets. The criteria behind choosing composite materials were stiffness and pedestrian safety. Energy absorption on frontal collision was also considered to select a suitable material. The car bonnet sandwich design was the main focus inculcating a core design. The material of the core imparted more strength to the bonnet in addition to the outer fabric. The composites used were Carbon Fiber Reinforced Plastic (CFRP) with Polyvinyl Chloride as a suitable resin.

Further analysis to reinforce the theme of this research was done by Narayana et al. [19], which further solidified the introduction of composites in Car Bonnet. Martin Mohlin et al. [20], Johan Karlsson [21], and L. Kiran et al. [22] conducted weight reduction analyses by introducing materials.

3. METHODOLOGY

3.1. Materials and Properties

The latest advancement in hybrid and pure electric vehicles has a trade-up between mileage and weight, requiring lighter bodyweight. Coupled with that, the surge in population and rapid infrastructural developments of high-speed roads and multiple lines has aggravated the need for the critical safety assessment of the vehicles produced.

3.1.1. Aluminium Alloy Properties

The properties of the aluminium are shown in Table 1.

Table -1: Aluminium Alloy Properties

Density	2770 kg m^-3
Isotropic Secant Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat Constant Pressure	875 J kg^-1 C^-1
Compressive Ultimate Strength Pa	0
Compressive Yield Strength Pa	2.8e+008

Tensile Yield Strength Pa	2.8e+008
Tensile Ultimate Strength Pa	3.1e+008

3.1.2. Stainless Steel Properties

The properties of the stainless steel are shown in Table 2.

Table -2: Stainless Steel Properties

Density	7750 kg m^-3
Coefficient of Thermal Expansion	1.7e-005 C^-1
Specific Heat	480 J kg^-1 C^-1
Thermal Conductivity	15.1 W m^-1 C^-1
Resistivity	7.7e-007-ohm m
Compressive Ultimate Strength Pa	0
Compressive Yield Strength Pa	2.07e+008
Tensile Yield Strength Pa	2.07e+008
Tensile Ultimate Strength Pa	5.86e+008

3.1.3. Composites Properties

The properties of the composite are shown in Table 3.

Table -3: Composite Properties

Density	1857 kg m^-3
Tensile Yield Strength	4.401e+008 Pa
Tensile Ultimate Strength	4.401e+008 Pa
Isotropic Secant Coefficient of Thermal Expansion	1.688e-005 C^-1
Isotropic Thermal Conductivity	0.5523 W m^-1 C^-1
Specific Heat Constant Pressure	1069 kg^-1 C^-1

3.1.4. Concrete Properties

The concrete properties assigned to the wall are shown in Table 4.

Table -4: Concrete Properties

Density	2392 kg m^-3
Tensile Yield Strength	1.095e+006 Pa
Tensile Ultimate Strength	1.196e+006 Pa
Isotropic Secant Coefficient of Thermal Expansion	1.015e-005 C^-1
Isotropic Thermal Conductivity	2.933 W m^-1 C^-1
Specific Heat Constant Pressure	936.3 J kg^-1 C^-1

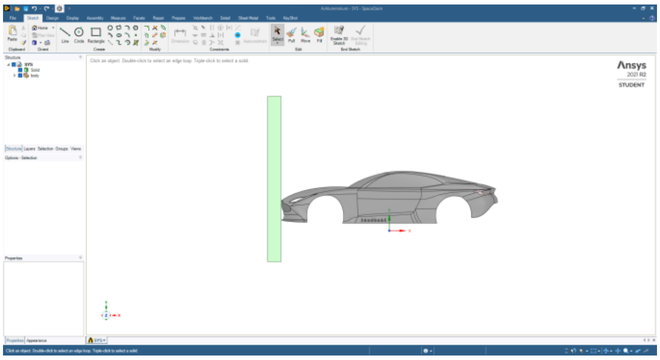
3.2. Overview

For this study, SOLIDWORKS and ANSYS were used for design and simulation, materials were added to the ANSYS directory, and the Modal Settings for Explicit Dynamics were specified. The final report was generated from ANSYS, which contained the required numerical values and graphs for each of the tested parameter. These values and graphs were inferred, and the consolidated data is presented in this study. Below mentioned are the units that are taken into consideration for the experiment.

Table -5: Units

Unit System	Metric (m, kg, N, s, V, A) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

ANSYS Explicit Dynamics was used for this study. The Engineering Data was updated. Concrete (non-linear) was chosen as additional material. Aluminium, Stainless steel, and Composite was added to the material library, and the following properties for the same were input for each material: Density, Isotropic Elasticity (Young's Modulus and Poisson's Ratio), Bilinear Isotropic Hardening (Yield Strength and Tangent Modulus), and Specific Heat.



Click an object. Double-click to select an edge loop. Triple-click to select a solid.

Fig -1: Geometry creation in SpaClaim

The geometry was imported into ANSYS and the Model was opened. Geometry settings were updated. Concrete material was assigned to the wall, and the stiffness behaviour was changed from the default ‘flexible’ to ‘rigid’. Different materials were assigned to the car, and a thickness of 10 mm was given to the car body. Table 5 mentions the initial conditions allotted to the parts.

Table -6: Initial Conditions

Definition	
Pre-Stress Environment	None Available
Pressure Initialization	From Deformed State
Input Type	Velocity
Define By	Components
Coordinate System	Global Coordinate System
X Component	-30. m/s
Y Component	0. m/s
Z Component	0. m/s
Geometry	Car

Meshing involves dividing the entire model into small pieces (elements). The element type is decided first to mesh the model. A coarse mesh was generated with 10331 nodes and 9649 elements. Velocity was added in the Initial Conditions of Explicit Dynamics. To justify the suggestion of a material, three different velocities of 30m/s were taken along the negative X-direction such that the car would collide with the wall with these velocities.

Table -7: Analysis of Settings

Step Controls	
Number Of Steps	1
Current Step Number	1
Load Step Type	Explicit Time Integration
End Time	1.e-002
Resume From Cycle	0
Maximum Number of Cycles	1e+07
Maximum Energy Error	0.1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled
Maximum Time Step	Program Controlled
Time Step Safety Factor	0.9
Characteristic Dimension	Diagonals
Automatic Mass Scaling	No

4. RESULTS AND DISCUSSION

4.1. Aluminium

4.1.1. Aluminium car v/s Concrete wall

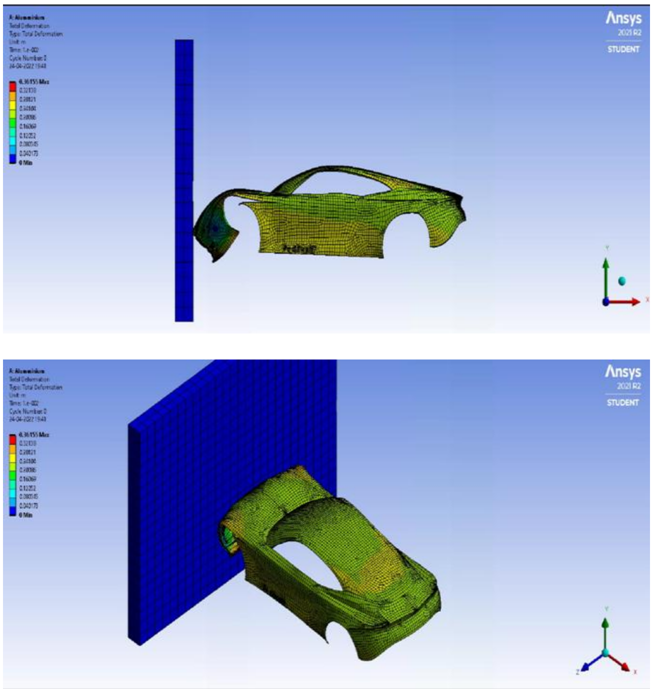


Fig -2: Total deformation of aluminium car body

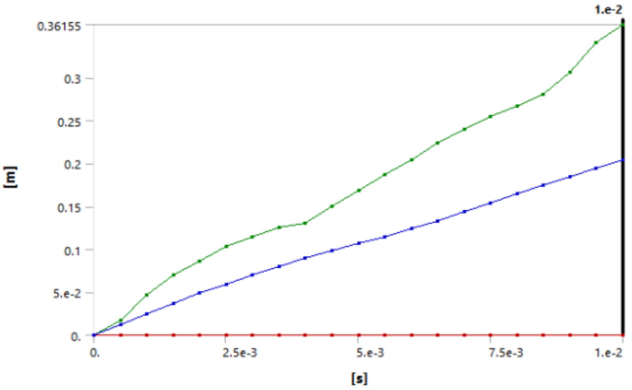


Fig -3: Total deformation graph for aluminium car body

Object Name	Total Deformation (m)	Equivalent Elastic Strain (m/m)	Equivalent Stress (Pa)
Minimum	0	3.0782e-005	1.0891e+005
Maximum	0.36155	7.2068e-002	3.7902e+009
Average	0.20467	2.5983e-003	1.4919e+008

4.1.2. Aluminium cars collision

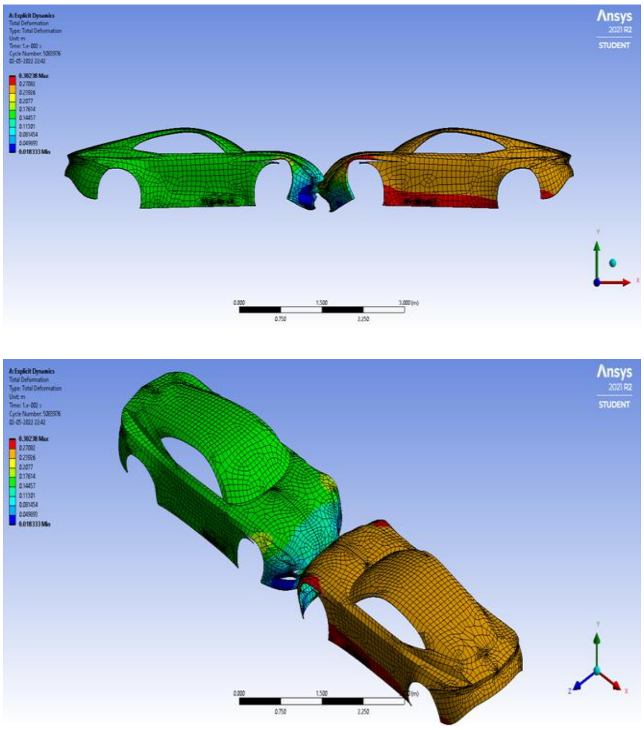


Fig -4: Total deformation of aluminium cars

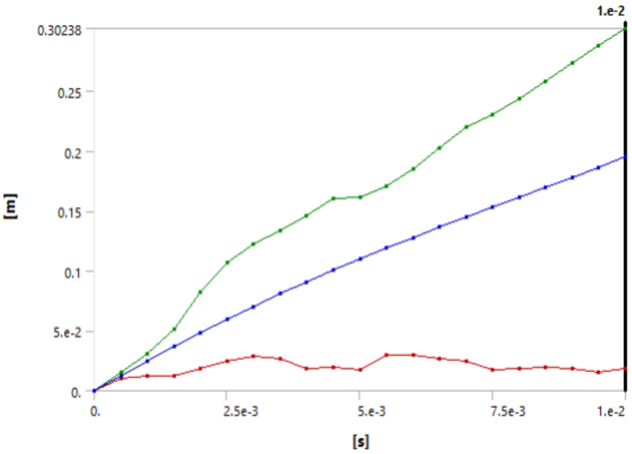


Fig -5: Total deformation graph for aluminium cars

Object Name	Total Deformation (m)	Equivalent Elastic Strain (m/m)	Equivalent Stress (Pa)
Minimum	1.8333e-002	8.8863e-005	1.945e+006
Maximum	0.30238	0.37759	2.5924e+010
Average	0.19515	2.8971e-003	1.5821e+008

4.2. Stainless Steel

4.2.1. Stainless steel car v/s Concrete wall

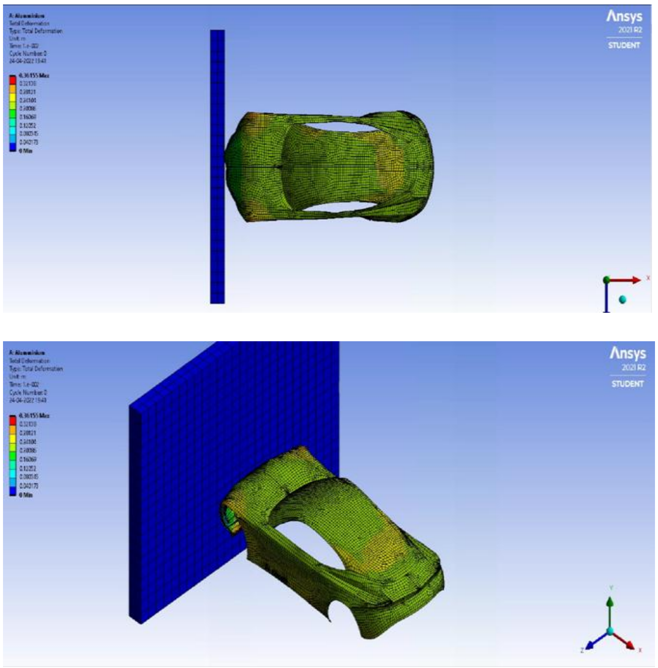


Fig -6: Total deformation of stainless steel car body

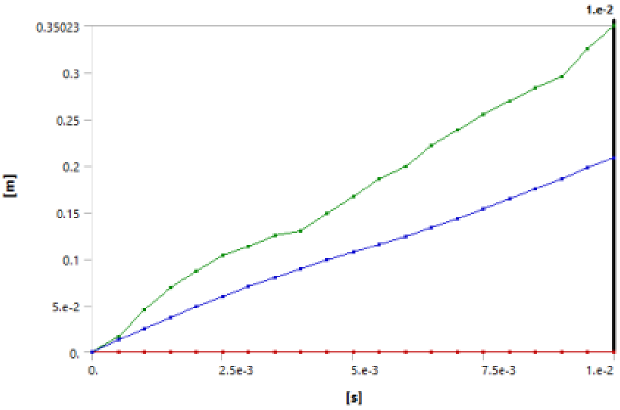


Fig -7: Total deformation graph for aluminium car body

Object Name	Total Deformation (m)	Equivalent Elastic Strain (m/m)	Equivalent Stress (Pa)
Minimum	0	0	32421
Maximum	0.35023	0.10064	8.4222e+009
Average	0.20827	0	2.7463e+008

4.2.2. Stainless steel cars

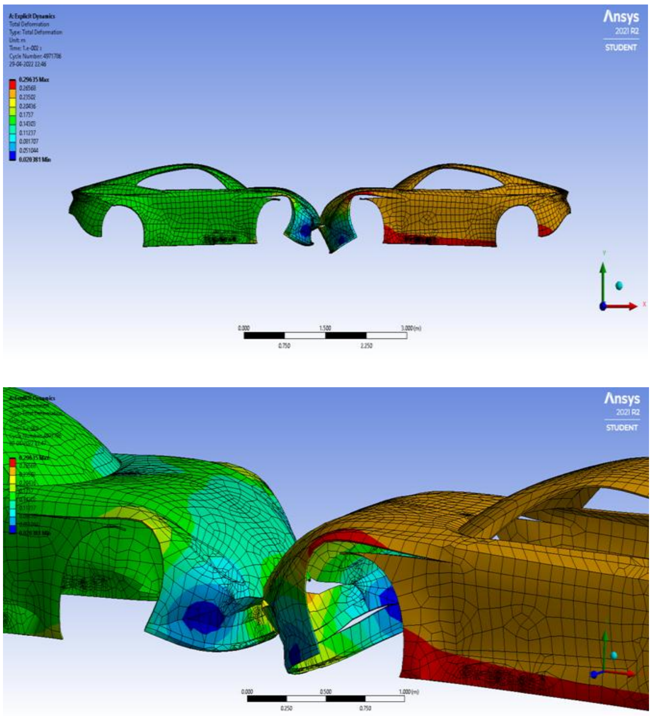


Fig -8: Total deformation of stainless steel cars

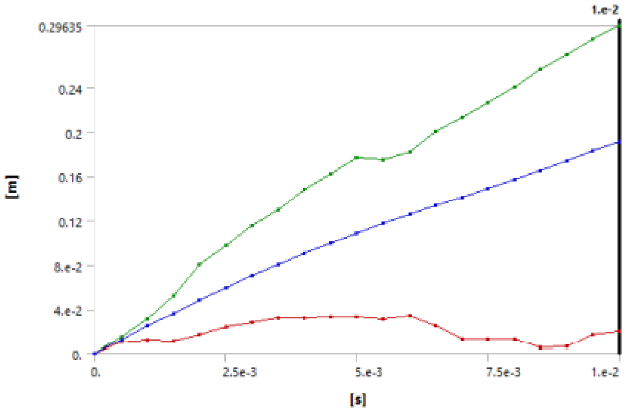


Fig -9: Total deformation graph for stainless steel cars

Object Name	Total Deformation (m)	Equivalent Elastic Strain (m/m)	Equivalent Stress (Pa)
Minimum	2.0381e-002	5.7104e-005	5.4395e+006
Maximum	0.29635	0.20751	3.7883e+010
Average	0.19188	2.9601e-003	4.2769e+008

4.3. Composite (Epoxy/glass fibre)

4.3.1. Composite car v/s Concrete wall

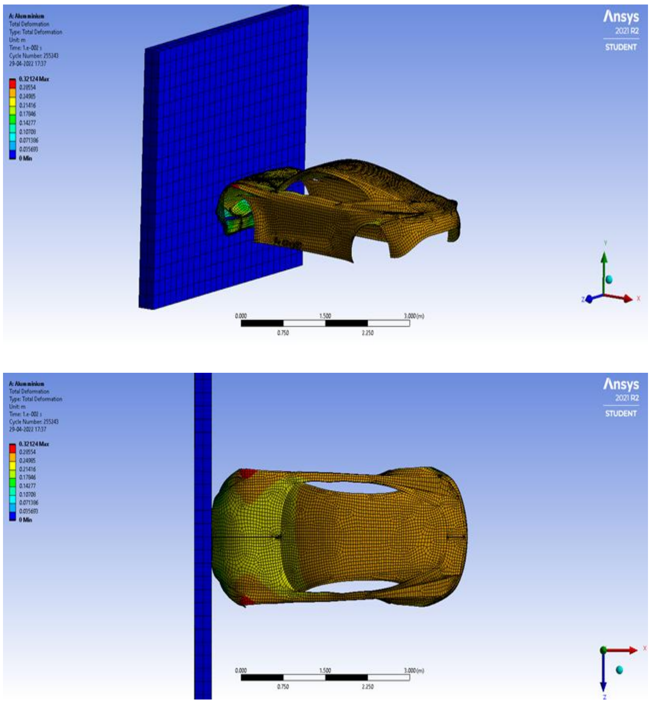


Fig -10: Total deformation of composite car body

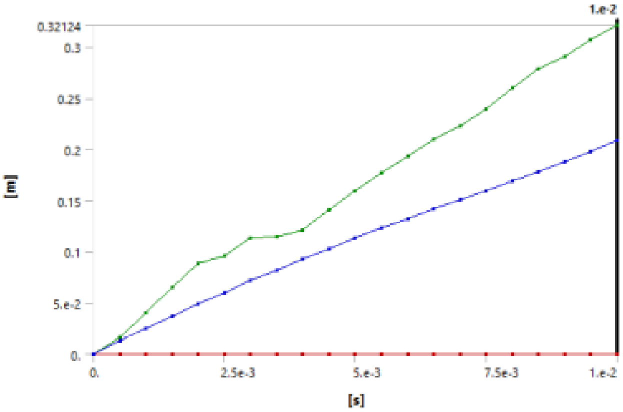


Fig -11: Total deformation graph for composite car body

Object Name	Total Deformation (m)	Equivalent Elastic Strain (m/m)	Equivalent Stress (Pa)
Minimum	0.	0	8970
Maximum	0.32124	0.1897	1.3075e+009
Average	0.20821	0	4.3012e+007

4.3.2. Composite cars

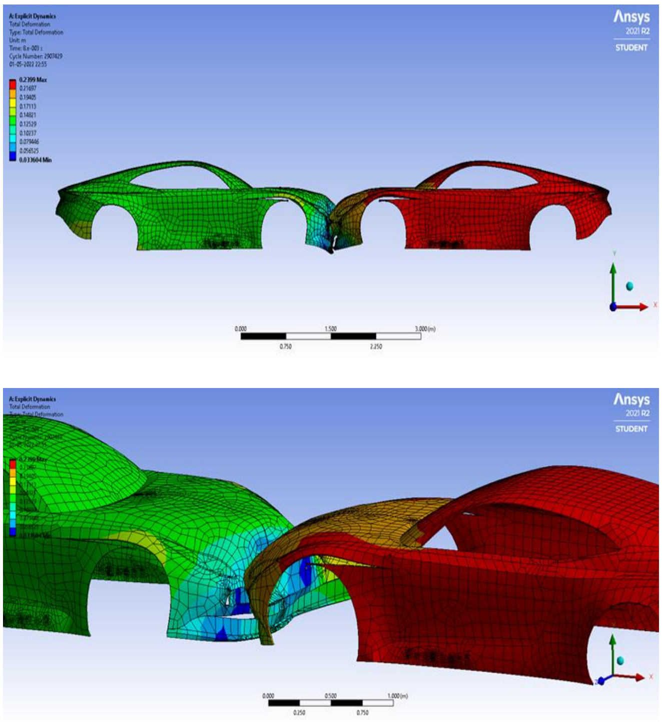


Fig -12: Total deformation of composite cars

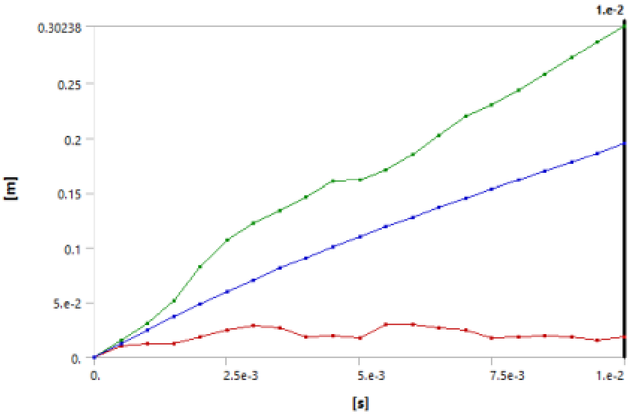


Fig -13: Total deformation graph for composite cars

Object Name	Total Deformation (m)	Equivalent Elastic Strain (m/m)	Equivalent Stress (Pa)
Minimum	3.3604e-002	1.1169e-004	1.1709e+006
Maximum	0.2399	0.36263	9.1772e+009
Average	0.17151	3.3412e-003 m	6.8928e+007

5. CONCLUSION

Recent advances in hybrid and pure electric vehicles have created a trade-off between mileage and weight, so lightweight body parts are necessary. The increase in population density and the rapid development of transportation infrastructures, such as high-speed roads and multiple lines, have heightened the need for the critical safety assessment of vehicles produced. A simple car body structure was simulated in a frontal collision using ANSYS explicit dynamic method at 30m/s. Three different materials were considered for each case. Based on the results, it can be determined that a moving car will cause more damage to the car body than a static wall.

Further, the figures illustrate the degree of deformation experienced by the vehicle in each case. The collision time and deformation are linearly related. The amount of deformation for the dynamic cars is higher, and then the deformation for the wall is next. Thus, the design obtained using aluminium sheets needs to be optimized. It experiences a high amount of stress and deformation, especially in a car-to-car collision, which is expected to be the most common scenario for vehicle accidents. It is noted that composite cars are the lightest with 264kg in mass, whereas stainless steel cars are the heaviest with 1100kg of mass. In spite of its heavy weight, it is seen that stainless steel cars have the best readings to withstand the crash, and composites have the most brittle nature. Aluminium can prove a good material if strength is increased by performing some mechanical processes. It is lighter than stainless steel and more robust than composite material. In order to determine the best body structure and materials to use for the construction of cars, it is recommended in the future study that different car body structures with hybrid aluminium material mixtures be used to model and analyze the crashworthiness of the cars and determine the best body structure and materials to use.

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