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Comparison of Crash Worthiness of Two Materials Used in Bus Skeletal Frame

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Abstract

This work is carried to improve the performance of the seat cross member for the lateral crash through Finite Element Techniques with the help of Beta-CAE ANSA for model build up and ESI PAM-Crash for solving and Beta-CAE Meta Post for extracting the solutions. A mesh convergence is carried out and the element of size 5mm in the components of study is observed as the converged. Having a good compromise between the computational time and the accuracy the element size is chosen in the range of 4mm - 8mm. The model is built with 1.2 million elements approximately for the analysis. Design combinations with an increase of altitude of the seat cross member in step sizes and through combinations like modifying individually either the front or rear member, modifying the both together are analyzed. Mass reducers such as holes and slots, gauge thickness and the strength are used to find out the feasibility for the mass saving in the same. The ECE Regulation 95 for lateral collision is followed for the test procedure with a MDB (Movable Deformable Barrier) impacting the vehicle at 55kmph. The intrusion, velocity, acceleration in B-Pillar and energy absorption locally in SCM and globally are observed as the parameters of performance for the lateral crash. The model with height increased to 33mm with mass reducers, increase of strength to 30 MPa and reduction in thickness to 1.1 mm in both front and rear members has a gain of 470 gms mass in the seat cross members without compromising the performance. The model with same design combinations and thickness change to 1.2 mm with same strength as the parent has a gain of 8mm in intrusion at middle of B-Pillar. The energy absorbing capacity of the same is increased by 250 J in seat cross member and 735 J globally is the gain achieved without increasing the expenditures. As a dual benefit producing holes and slots on the side walls of the SCM is the best way for reducing the mass and as well as improving the performance.

1. Introduction

CAE tools are very widely used in the automotive industry. In fact, their use has enabled the automakers to reduce product development cost and time while improving the safety, comfort, and durability of the vehicles they produce. The predictive capability of CAE tools has progressed to the point where much of the design verification is now done using computer simulations rather than physical prototype testing. CAE dependability is based upon all proper assumptions as inputs and must identify critical inputs. Even though there have been many advances in CAE, and it is widely used in the engineering field, physical testing is still used as a final confirmation for subsystems due to the fact that CAE cannot predict all variables in complex assemblies (i.e. metal stretch, thinning).The main objective of this thesis is to investigate the impact energy absorption of a guardrail due to impact with a vehicle in the various angles. The various angles of oblique loading are test with 20°, 45°,75° and 90°. The model of the guardrail will be built with Solidworks 2007 and the finite element model will be used to simulate the impact of guardrail with ABAQUS software. The ABAQUS software will produce some important output data for this research such as reaction force, type of energy and deformation. These data will be used to gain the energy absorb after the impact to the guardrail. The energy absorb can be obtained from two methods. Deduction between the total energy and kinetic energy will be the first method to obtain the energy absorb. The next method is the result of area under curve for reaction force versus deformation graph and the NCSS will be used to obtain the result.

1.1. CAE in Automobile Industry

CAE tools are very widely used in the automotive industry. In fact, their use has enabled the automakers to reduce product development cost and time while improving the safety, comfort, and durability of the vehicles they produce.

1.2. Ls Dyna Introduction

Vehicle crash analysis has historically been the postmortem physical test that caused engineers and manufacturers to launch a flurry of product modifications and redesign, engineering change orders, and even the eventual demise of a bus model[1]. One need only think of the Ford Pinto or Chevy Corvair as examples of models that were designed, manufactured, and sold long before the automotive industry knew how unsafe some of their buses really were. In the early 60's a number of analysis codes were developed to assist engineering in the a priori investigation of designs to better predict when a given part or assembly would fail in real life. However little was done until the mid 70's when Dr. John O. Hallquist developed the first analysis code that attempted to analyze the impact between two bodies. This early DYNA has matured into a widely used crash analysis tool that today catches many design flaws long before the first prototype is ever realized. Today, the correct use of this tool is credited with saving millions in development costs, reducing untold numbers of vehicle recalls and ultimately saving unnumbered lives by empowering engineers with the ability to virtually crash their design until they arrive at an optimally safe survival cell for the occupants.

1.3. Crash Test

Consumer crash test programs provide comparative information on the crashworthiness of new vehicles, which, in turn should predict the performance of the same vehicles in real-world crashes[3]. However, the detail and quality of available information from tests and real-world crashes differ widely, so identifying meaningful relationships between crash test results and real-world crashworthiness can be difficult. Despite these data limitations, studies in the late 1980s and mid-1990s reported positive correlations between dummy injury measures from the U.S. New Car Assessment Program (USNCAP) and real-world fatality rates. More recent analyses of results from Australian crash tests and real-world crashes also have found positive correlations. The current paper considers relationships between recent U.S. frontal crash test results from the Insurance Institute for Highway Safety (IIHS) and USNCAP, and real-world crash injury risk estimates computed from police-reported crash data from three U.S. states[6]. The frontal crash test results include dummy injury measures by body region from both IIHS offset tests and USNCAP full-width barrier tests plus measures of structural performance from the IIHS offset tests. Individually, results from the full-width and offset tests were not significantly correlated with the real-world injury risk estimates. Stronger relationships were found when a combination of overall ratings from the full frontal and offset tests was used. The current results find only weak correlations between both full front and offset frontal crash test performance and the real-world injury risk estimates. These weak relationships likely reflect the lack of detail and fundamental difference in injury information in police crash reports compared to that used in deriving crashworthiness ratings from the crash tests.

1.4. Bus Frame

A frame is the main structure of the chassis of a motor vehicle. All other components fasten to it; a term for this is design is *body-on-frame* construction.

There are three main designs for frame rails. Their cross-sections include:

1. C-shaped
2. Boxed
3. Hat

2. Methodologies

Create 3D CAD Model: Use any of the 3D CAD modeling tools like PRO-E for creating the 3D geometry of the part/assembly of which you want to perform FEA. Save the 3D CAD Geometry in Neutral Format: Save the 3D CAD geometry in neutral format like IGES, STEP, DXF etc.

Importing 3D CAD geometry to FEA Package: Import the CAD geometry into the FEA package.

Clean Up the 3D CAD Model: Some features of the 3D CAD geometry may not be that important for the FEA but increase the complexity of meshing drastically. Those features are removed from the CAD model during geometry clean up. Mid surfaces are extracted for the geometry to be used to mesh. The element chosen to mesh is Shell.

Meshing: Meshing is a critical operation in FEA. In this operation, the CAD geometry is divided into large numbers of small pieces. The small pieces are called elements.

Defining Boundary Condition: To tell the FEA package where to apply loads and where to rest the part/assembly.

Solve: In this step the FEA package solves the problem for the defined material properties, boundary conditions and mesh size.

Post Processing: The results of the solution can be viewed in this step. The result can be viewed in various formats: graph, value, animation etc.

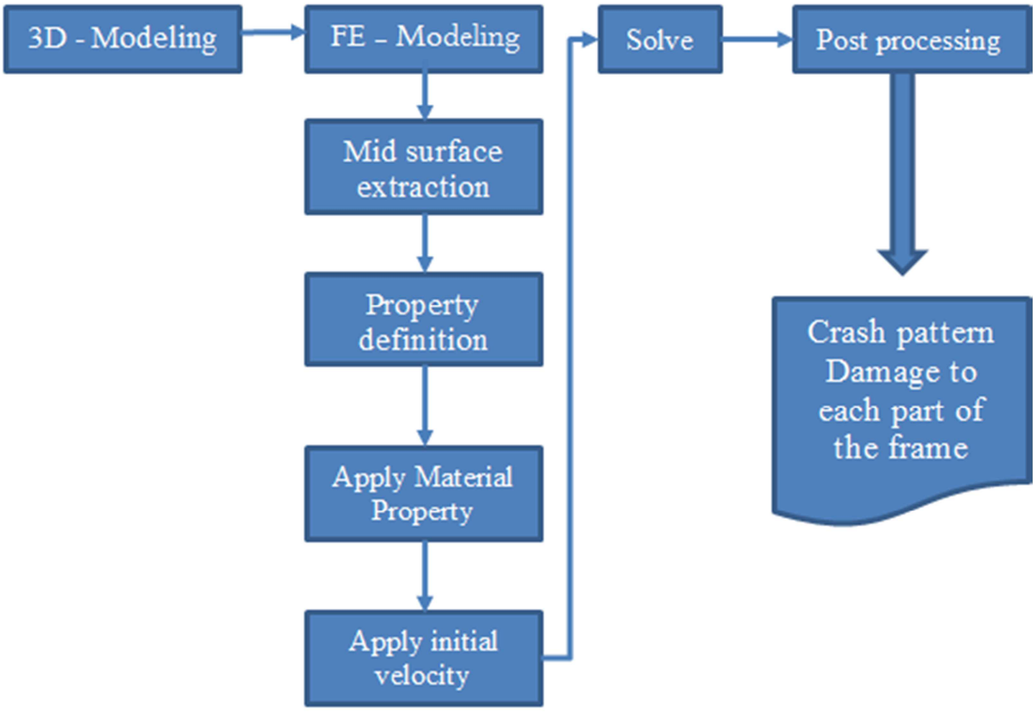

Fig. 1. *Flow Chart for methodologies.*

3. Results and Discussion

Computer-aided engineering (CAE) is the broad usage of computer software to aid in engineering tasks. Computer Aided Engineering includes the following types of analysis.

3.1. Linear Static Analysis

When structure response is linearly proportional to the magnitude of the load then the analysis of such a structure is known as linear analysis.

There are two conditions for static analysis;

1. Force is static that is no variation with respect to time.
2. Equilibrium condition.

Commonly used software's: Nastran, Ansys, Abaqus, I-deas NX, Radioss, Cosmos, UG, Pro-Mechanica, Catia etc.

3.2. Non Linear Analysis

When the load to response relationship is not linearly proportional, then the analysis falls under nonlinear analysis. Commonly used software: Nastran, Ansys, Abaqus, Radioss, Marc, LS Dyna etc.

3.3. Dynamic Analysis

Static analysis does not take into account variation of load with respect to time. Output in the form of stress, displacement etc. with respect to time could be predicted by dynamic analysis. Commonly used software's: Nastran, Ansys, Abaqus, I-deas NX, Matlab, Radioss etc.

3.4. Thermal Analysis

Heat transfer is defined as energy in transit. Analysis of a system using the laws of heat transfer is named as thermal analysis.

3.5. Fatigue Analysis

Life of the structure when it is subjected to repeated load is called as fatigue. Fatigue accounts for 90 percentage of service failure.

3.6. Optimization Analysis

Optimization is the process of avoiding or removing the unwanted parts and projections found in the structure.

3.7. Computational Fluid Dynamics

Computational fluid dynamic is the branch of fluid mechanics which uses numerical methods to analyze fluid dynamic problem.

3.8. Crash Analysis

Crash analysis is done to find the deformation, stress and energy absorbing capacity of various structural components of a vehicle hitting a stationary or moving object. The component is said to be crash worthy if it meets the plastic strain and energy targets. Crash analysis is also performed to find the effect of crash on human body and making the ride safe for driver as well as the passengers. The effect of crash and impact on structure is one problem and the second one which is of prime importance is the safety of the occupants. We find that occupant safety simulation offers today reasonably accurate results which can save a lot of testing time and overall design time. Crashworthiness also finds a lot of applications in drop test of components such as television, plastic bucket and mobile phone. Point of interest here are to check the structural integrity of the component and monitor any damage caused to the system. In mobile industry any damage caused to the antenna and the LCD displays are very important as they make the device totally useless.

Crash analysis although developed for automotive applications, crash simulation software's have also found application in train, ship and aircraft crashworthiness. Other applications in defense sector are simulating the explosive detonation process and design of weapons.Commonly used Software: LS-Dyna, Pamcrash, Radioss, Abaqus-Explict, Madymo etc.

3.9. NVH Analysis

NVH analysis concerned is very different from that of static analysis. The concept can become complex due to structural-acoustic interaction.

4. CAE

4.1. In Automobile

CAE tools are very widely used in the automotive industry. In fact, their use has enabled the automakers to reduce product development cost and time while improving the safety, comfort, and durability of the vehicles they produce. The predictive capability of CAE tools has progressed to the point where much of the design verification is now done using computer simulations rather than physical prototype testing. CAE dependability is based upon all proper assumptions as inputs and must identify critical inputs. Even though there have been many advances in CAE, and it is widely used in the engineering field, physical testing is still used as a final confirmation for subsystems due to the fact that CAE cannot predict all variables in complex assemblies.

4.2. CAE in Crash

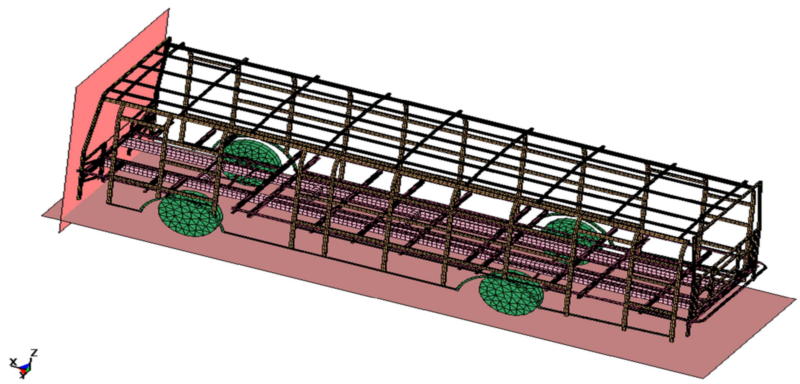

Fig. 2. CAE crash.

4.2.1. CAD Model

Before starting the project, CAD data should be thoroughly studied. Open surfaces, free edges, duplicate surfaces, interference, missing parts should be studied carefully and reported for clarification immediately.

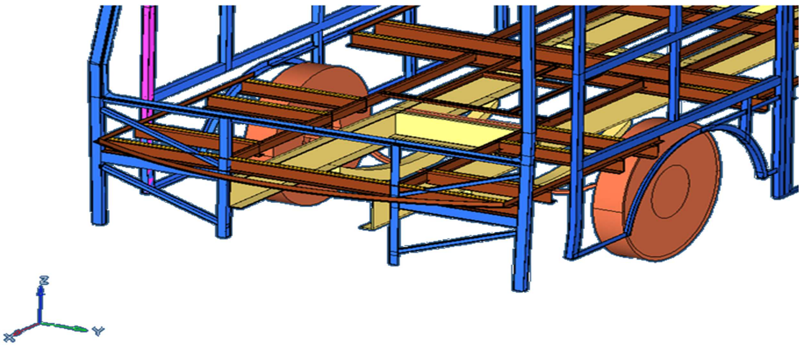

Fig. 3. CAD Model.

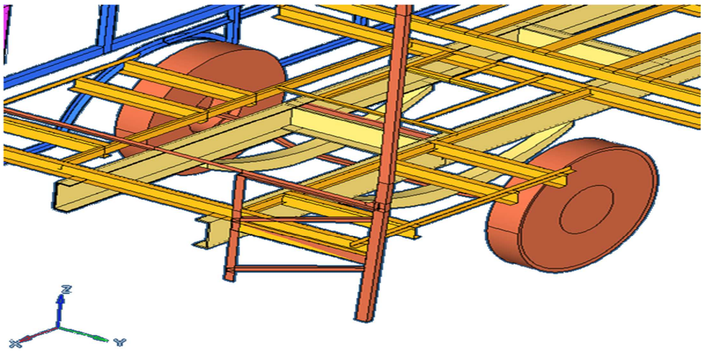

Fig. 4. Mid surface from CAD.

4.2.2. Material Data

Basic material properties details (like E, YIELD STRESS, ULTIMATE STRESS, and DENSITY) should be collected from appropriate sources.

Table 1. Properties and symbols.

SL.NO	MATERIAL PROPERTIES	SYMBOL
1	YOUNGS MODULUS	E
2	POISSON RATIO	μ
3	DENSITY	ρ
4	YIELD STRENGTH	σ_y
5	ULTIMATE STRENGTH	σ_u

To perform static analysis the list of parameters to be known are as per the given table.

4.2.3. Meshing

Basic theme of FEA is to make calculations at limited (finite) number of points and then interpolate the results for entire domain (surface or volume). A continuous object has infinite degree of freedom and it's not possible to solve for entire object. Finite element method reduces degrees of freedom from infinite to finite with help of discretization i.e. meshing (nodes and elements).

4.2.4. Mesh Quality

Obtaining accurate results meant having a good mesh. HyperMesh was used mainly to check mesh quality.

4.2.5. Mesh Quality Check

The following table represents the various parameters involved in mesh quality check.

Table 2. Meshing parameters.

SI.NO	MESHING PARAMETERS
1	1-D elements –free 1d's, rigid loops, dependency
2	2-D elements
3	Duplicate elements
4	Duplicate nodes/equivalence.
5	Delete free/temp nodes all.
6	Element normals.
7	Free edge/free faces
8	Min.element length/time step-for crash analysis
9	Flow pattern-Representing appropriate pattern of stress waves
10	Mesh penetration, deviation from geometry
11	Assign appropriate dofs for Rigid body element
12	Renumber-nodes, elements, mats, props and etc.,
13	Element summary-check element type and family, number of plot elements
14	Assign appropriate property cards ,materials,c/s,thickness dofs.
15	Free-free run for assembly of components –first 6 modes rigid, 7^{th} onwards positive deformable modes

4.3. Ls-Dyna's Contact Algorithm

- Flexible body contact
- Flexible body to rigid body contact
- Rigid body to rigid body contact
- Edge-to-edge contact
- Eroding contact
- Tied surfaces
- CAD surfaces
- Rigid walls
- Draw beads

4.4. Comparison of Two Materials

The force proceeds to the bulkhead which merely transfers the load to the monocoque. Then monocoque, being hollow and made of sheet metal, crumbles upon itself due to the inertia of the rear of the bus and also the forward transfer impact coming from the frontal bulkhead. Nonetheless correct distribution of effective stresses in and around the nose cone conclude that the bus has been designed to take as much impact as possible in the frontal portions, leaving little to transfer to the mid and rear ends of the bus. Lack of information about the material type of various components in the entire bus posed as an obstacle to correct and full model representation. We had information on several components and their material types that we obtained from PACE Partners, however were not complete in the list of materials. There was more information on the front of the bus than on the rear and hence material assumptions had to be made for the rear of the bus. Observation of the produced bus revealed that most of the components were made of aluminum and steel, with aluminum being more predominant in occurrence. Hence, 75% of the rear of the bus was assigned aluminum material properties and the remaining steel properties. Additionally it was unknown what alloy of aluminum and steel were used and hence a further assumption had to be made (Aluminum 6061 was chosen along with Stainless Steel in NX). The second assumption was the stiffness of the bus suspensions. The manufacturer rating was not available and so calculation of the spring stiffness was done both mathematically through equation solving and also through comparison with typical stiffness values for buses. An equation relating the number of turns of coil to the thickness of the coil and material properties of the spring coil was solved to get the stiffness of the suspension spring. The spring was then modeled in HyperMesh as a spring element and connected to the brackets and the rest of the bus by revolute joints as described above. Assignment of which component should be a rigid body and which other should be flexible was also a matter of judgment and assumption. For example the wheel components (wheel, wheel rotor disk, brake caliper and brake pad) were made as rigid bodies with assigned masses and combined inertial properties within the upright bar connecting the wheel to the central portion of the bus. Our analysis suggests that at high speeds the transfer of loads would proceed through the mid portion of the bus causing major injury to the human driver and hence at this stage has not passed the safety criterion required for a high speed formula one race bus. We come to this conclusion based on the simulation results and also intuitive Understanding of the monocoque and nose body which are primarily hollow that the bus is not deemed safe for high speeds. We suggest adding additional structural members to the frontal portion of the bus to prevent transfer of high velocity loads to the driver. This would mean additional weight and lower speeds but a balance would have to be attained between safety and efficiency. The results of the frame models that are compared to draw the conclusion are thevelocity,strainandinternal energy.

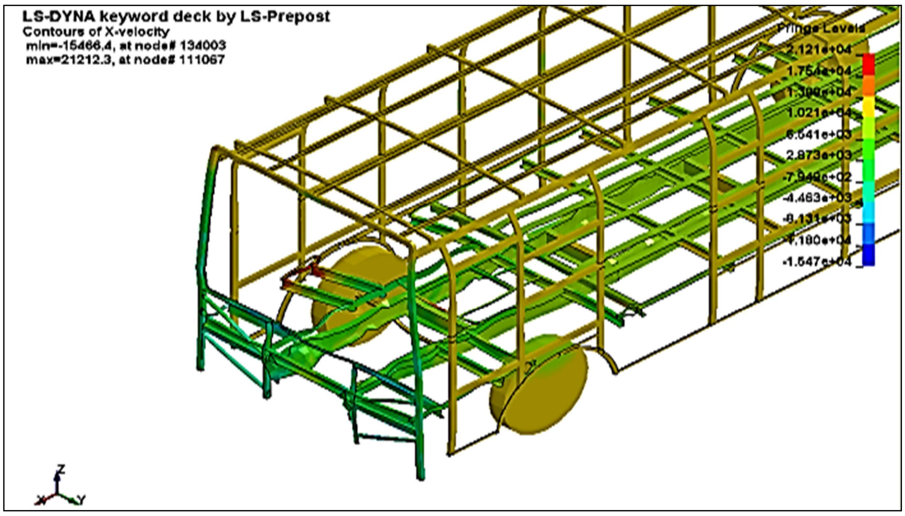

Fig. 5. *Direction Velocity for CS Frame.*

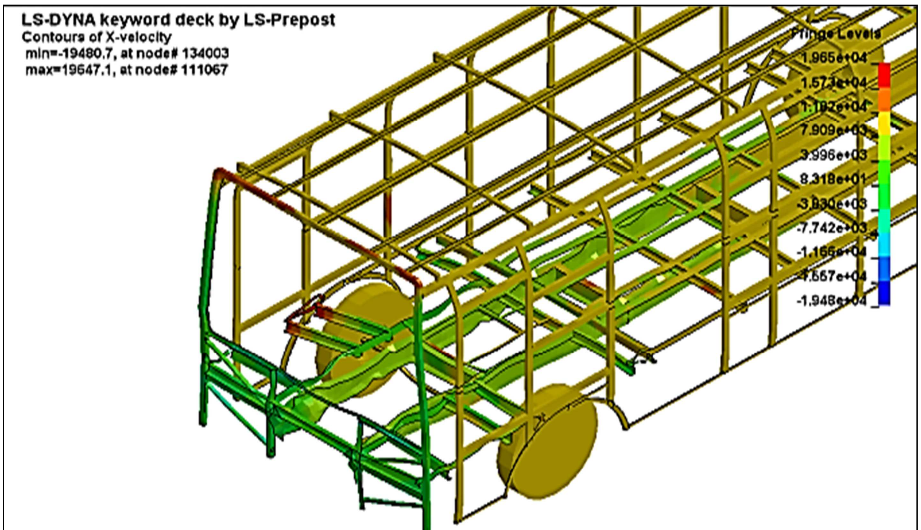

Fig. 6. *Direction Velocity for SS Frame.*

The velocity of the entire bus frame has changed from 11220 mm/s in the initial state to 10000 at most places of the frame in 30 ms using carbon steel and 9000 mm/s in stainless steel.

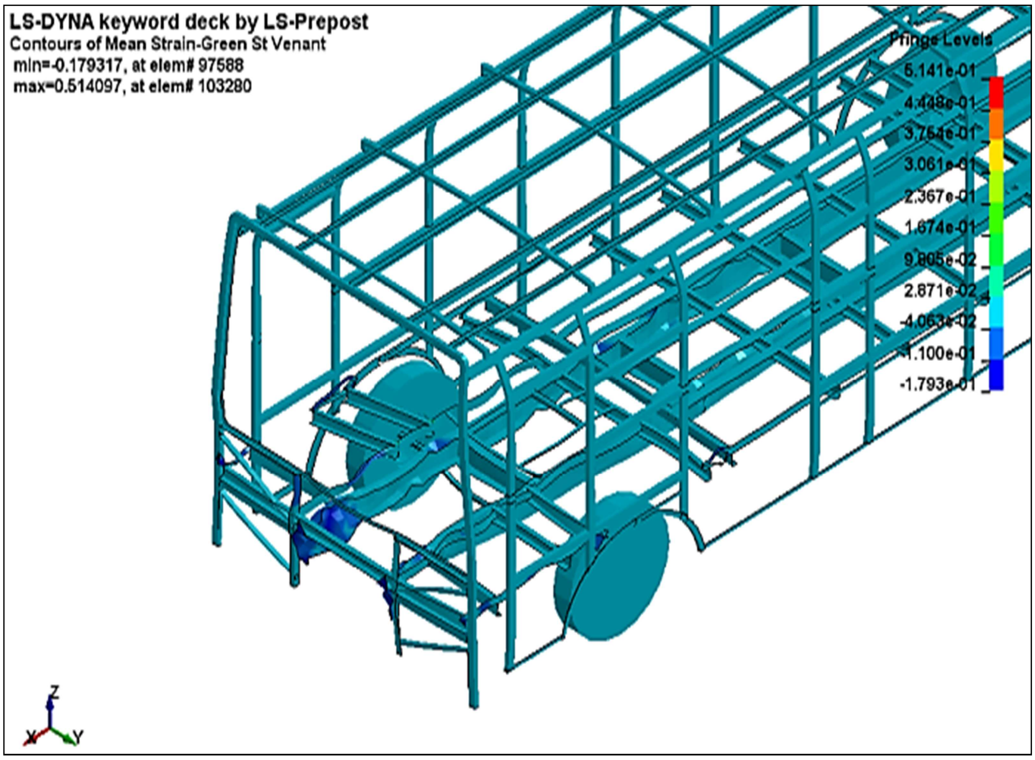

Fig. 7. *Mean Strain for CS Frame.*

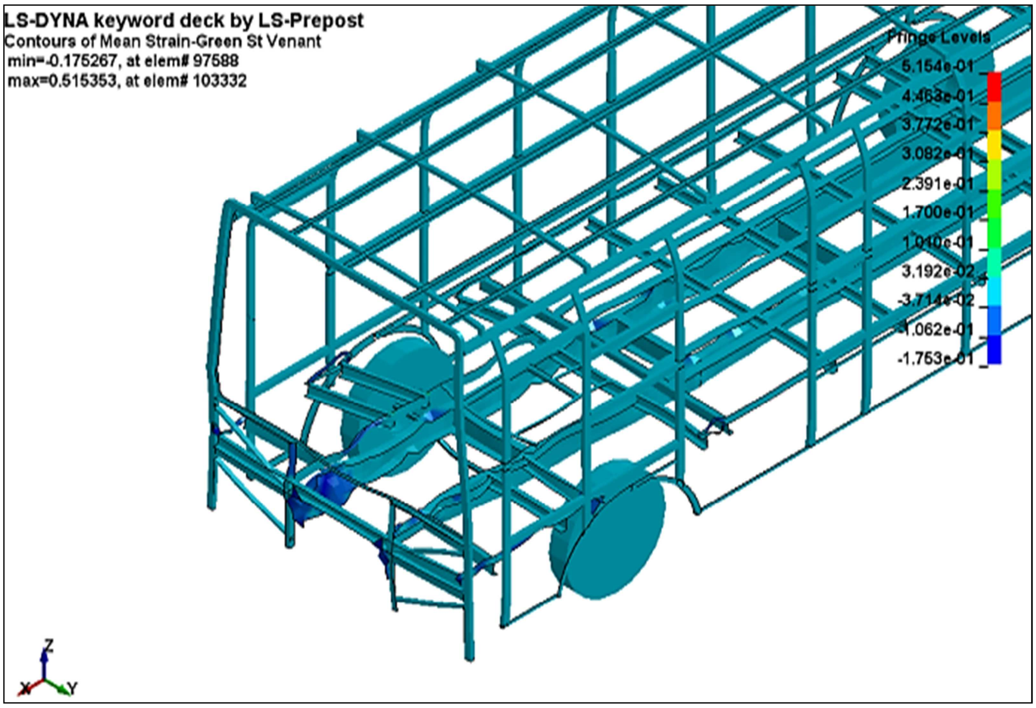

Fig. 8. *Mean Strain for SS Frame.*

The mean strain in the CS frame and SS frame are very in a very close range of 0.514 in case of CS and 0.515 in case of SS Frame.

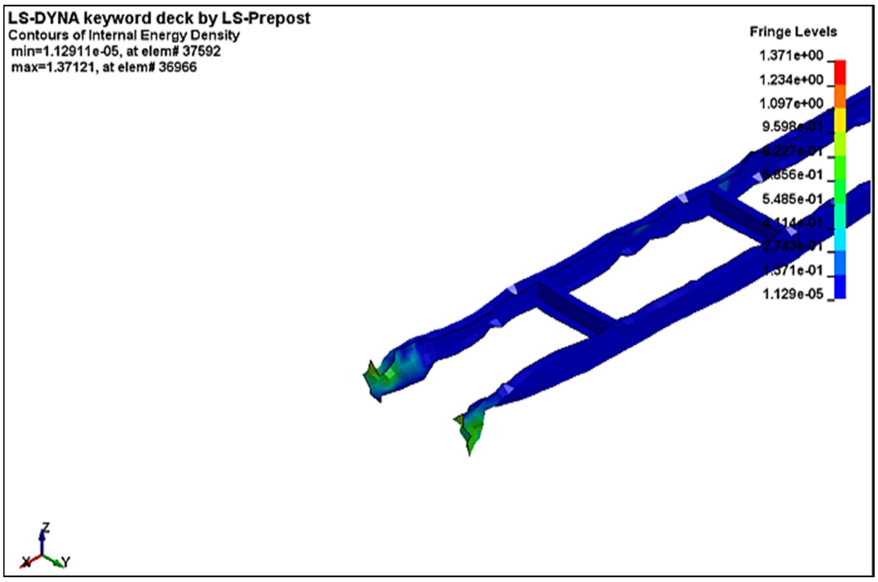

Fig. 9. *Internal Energy density for CS Frame.*

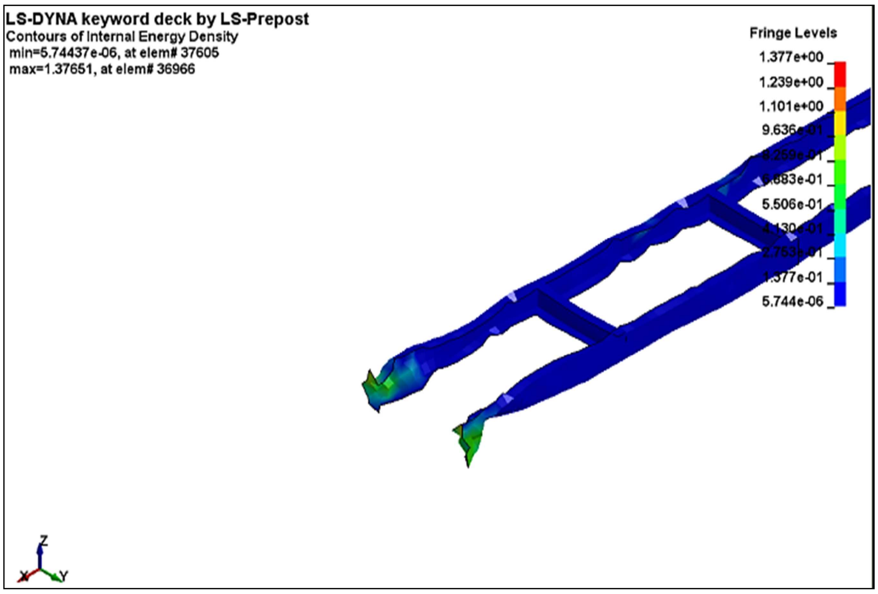

Fig. 10. *Internal Energy density for SS Frame.*

The internal energy densities of the chassis in both the cases are also in close range of 1.371 J/mm^3 in case of Cast steel frame and 1.377 J/mm^3 in case of SS. These values conclude that the SS material proposed in place of CS has similar behavior during a crash and hence considering the other properties such as corrosion resistance, aesthetic, Low Maintenance cost, Ease of cleaning, Ease of repair No painting required, Lower tare weight, High Strength to wt ratio, Higher payload, High axle load etc., it can be considered as an alternative to cast steel frames.

5. Conclusion

If provide appropriate safety levels for impact vehicles occupants, the safety barriers (frame) should be designed to absorb as much impact energy as possible through its deformation and at the same time maintain its integrity. Meanwhile, the part of the impact of energy absorption of the current safety barriers (frame) discussed in this paper. In addition to that, the comparison between the experimental results about the impact of safety barrier (frame) which was done and the simulation included. The internal energy density of the chassis in both the cases is also in close range of 1.371 J/mm^3 in case of Cast steel frame and 1.377 J/mm^3 in case of SS. These values conclude that the SS material proposed in place of CS has similar behavior during a crash and hence considering the other properties such as corrosion resistance, aesthetic, Low Maintenance cost, Ease of cleaning, Ease of repair No painting required, Lower tare weight, High Strength to weight ratio, Higher payload and High axle load. SS frames can be considered as an alternative to CS frames.

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