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Crash Analysis of Car Body Structure under Quasi-Static Condition

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Abstract: ***The crashworthiness enhancement of vehicle structures is a very challenging task during the vehicle design process due to complicated nature of vehicle design structures that need to comply with different conflicting design task requirements. Although different safety agencies have issued and modified standardized crash tests to guarantee structural integrity and occupant survivability, there is continued rise of fatalities in vehicle crashes especially the passenger cars. This research envisages the application of various materials in manufacturing of car body. Quasi-static analysis is performed using ANSYS software. Analytical models for both cases are also presented. The model used for analysis is Ford 2002 explorer.***

Keywords: Crashworthiness, ANSYS, LS DYNA, weight reduction

1. Introduction

In automotive design, the occupant and structural behavior in the event of a crash is of special interest. Non-linear finite element and rigid body analysis is applied to predict the responses of the structure or of the occupant. Decisions based on these computations can lead to significant design modifications. Usually, intuition leads the iterative process of finding the best design. It is often hard to determine necessary design modifications from the analysis results only. In some cases many variations are tried before a satisfactory designs found.The first motor vehicle fatality occurred in 1889 in New York City. Arguably this event led to the birth of automotive safety as a field of study. Over the past century, occupant safety has become an important design objective among all the performance criteria of ground transportation vehicles. Manufacturers realized early on the need to demonstrate occupant protection before the public accepted the automobile as a viable means of transportation. There are three distinct periods in the development history of automotive safety. The vehicle structure should be sufficiently stiff in bending and torsion for proper ride and handling. It should minimize high frequency fore-aft vibrations that give rise to harshness. In addition, the structure should yield a deceleration pulse that satisfies the following requirements for a range of occupant sizes, ages, and crash speeds for both genders:

2. Literature Review

Don O. Brush and Bo O. Almroth [1] demonstrate the classic buckling behavior of identical structural members subjected to axial crash loading in the book "Buckling of Bars, Plates, and Shells." In this book, the authors discuss common buckling problems and develop the equilibrium and stability equations for bars, plates, and shells. The authors also provide some particular examples that demonstrate how to determine the critical load using the stability equations. They include the direct numerical solution of the governing nonlinear equations.

Ishiyama, Nishimura, and Tsuchiya [2] report a numerical study of the impact response of plane frame structures with thin-walled beam members to predict the deformation and absorbed energy of automobiles under crash loading. The researchers investigate the collapse characteristics of thin-walled beam members under crashing loads, describe the inelastic deformations of the frame structure, and verify the important assumptions and conclusions via crash tests.

E. Haug and A. De Rouvray [3] illustrate the numerical simulation and prediction of the crash response of metallic components and structures. The algorithms of the numerical crashworthiness simulation and prediction are developed in their research. To validate the developed numerical algorithms, a full car crash simulation is performed using the numerical method. The reliability of the numerical method is verified by comparing the results of the simulations and the experiments.

A. G. Mamalis, D. E. Manolakos, G. A. Demosthenous, and M. B. Ioannidis [4] study the crashworthy behavior of thin-walled structural components subjected to various loading conditions, i.e. static and dynamic axial loading and bending. The authors describe the loading and deformation characteristics of the collapsed shells and discuss the influence of the shell geometry and the material properties on these characteristics. Also, the structural features related to vehicle collisions are introduced and useful conclusions for vehicle design and manufacture are provided.

H. S. Kim and T. Wierzbicki [5] investigate the rush response of thin-walled prismatic columns under combined bending-compression collapse loading. They construct the initial and subsequent failure loci representing the interaction between the axial forces and the bending moment. In their work, the researchers formulate a problem in which rectangular cross-section beams with different aspect ratios are subjected to a prescribed translational and rotational displacement rate. They then generate numerical results after solving the problem. From the numerical results, they continue developing the corresponding initial and subsequent failure loci, which describe the anticipated crush behavior of thin-walled columns under combined loading.

3. Problem Definition

When creating a car, it is very important to reduce its mass. This allows maintaining the basic characteristics of the car, using less powerful engines that consume less fuel and emit less harmful substances into the atmosphere. In addition,the inertia of the car decreases and for its acceleration or breaking it is necessary to spend less energy. Lowering the weight of the car also reduces the load on the suspension parts, which increases their lifespan. With increase in fuel cost and demand for more mileage from vehicle it has become more important for vehicle manufacturers to search for materials which are lighter in weight and absorb more crash energies as compared to conventional steel of carbon steel material. The new category of composites named MMC (Metal Matrix Composites) are getting popular due to low cost and improved mechanical properties. The current research is intended with the application of MMC material (Aluminum ceramic matrix composites) in manufacturing of car body.

4. Methodology

The analysis of car body is performed using Finite Element Method using ANSYS software. The CAD model of ford explorer is developed using Creo 2.0 software which is sketch based parametric 3d modelling software developed by PTC.

Figure 1: CAD model of Ford Explorer

The dimensions of Ford Explorer is 71”x190”x71” (W x L x H) [6]. The CAD model developed in Creo software is imported in ANSYS for meshing and applying with loads and boundary conditions. The model is meshed with tetrahedral elements and fine sizing.

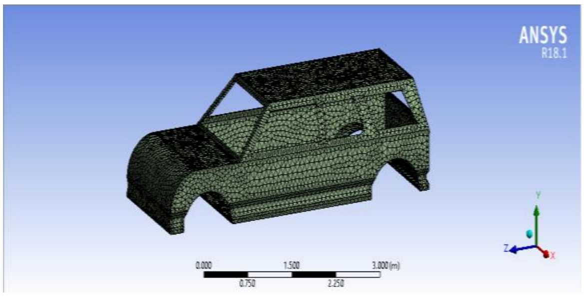

Figure 2: Meshed model of Ford Explorer

In current research crash investigation is performed using 2 different approaches which are discussed in detail in subsequent section. First approach is using quasi-static method and second approach is using dynamic analysis.

Quasi-Static Analysis

For quasi-static analysis the impact force is calculated using conservation of linear momentum, Equation (1) below was used to solve for the time averaged force F that would be distributed at each node on the front of the car.

$$F * \Delta t = - mV1 \qquad (1)$$

where Δt= .001s is the duration of impact,
m is the car mass, and
V1 is the incoming speed of car before impact.

Table 1: Impact Force at various velocities

Velocity (Km/hr)	Mass of vehicle (kg)	Δt (duration of impact)	Force(N)
32	2327.84	.001 secs	74490880
64	2327.84	.001 secs	148981760
96	2327.84	.001 secs	223472640
128	2327.84	.001 secs	297963520
160	2327.84	.001 secs	372454400

For quasi-static analysis loads and boundary conditions applied is shown in figure 3 below. The front face is applied with impact force as calculated in table 1 above.

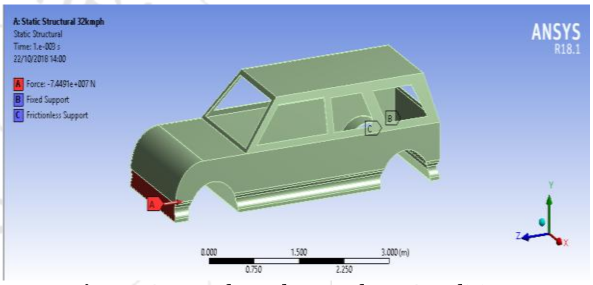

Figure 3: Loads and Boundary Conditions

After applying loads and boundary conditions, the solver is run to calculate deformation and other parameters. The results are calculated at nodes and interpolated for entire element edge length. The deformation and equivalent stress plots are generated and shown in figure 4 and figure 5 for 128Km/hr.

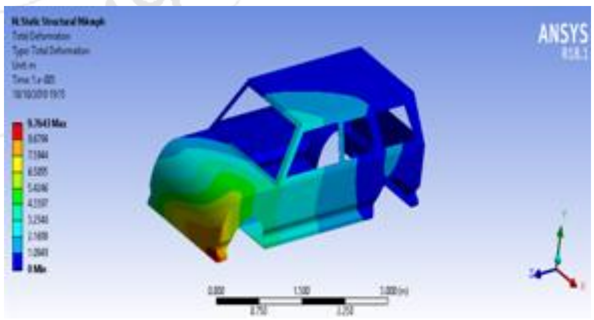

Figure 4: Deformation at 160Km/hr using carbon steel material

The deformation plot shown above shows maximum deformation on frontal portion of car body with maximum value of 9.6m completely crushing car body.

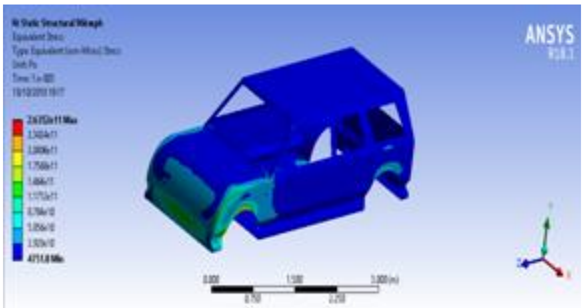

Figure 5: Equivalent stress at 160Km/hr using carbon steel material

Figure 5 above shows equivalent stress generated from collision. The maximum value of equivalent stress is seen on frontal portion of car and quarter panels with maximum value of $3.29*10^{11}$ Pa. Table 2 below shows equivalent stress and deformation developed on car body.

Table 2: Equivalent stress and deformation at different velocities of impact using carbon steel

Velocity (Km/hr)	Equivalent stress (Pa)	Deformation (m)
32	$6.58 * 10^{10}$	2.44
64	$1.31 * 10^{11}$	4.88
96	$1.97 * 10^{11}$	7.32
128	$2.63 * 10^{11}$	9.76
160	$3.29 * 10^{11}$	12.05

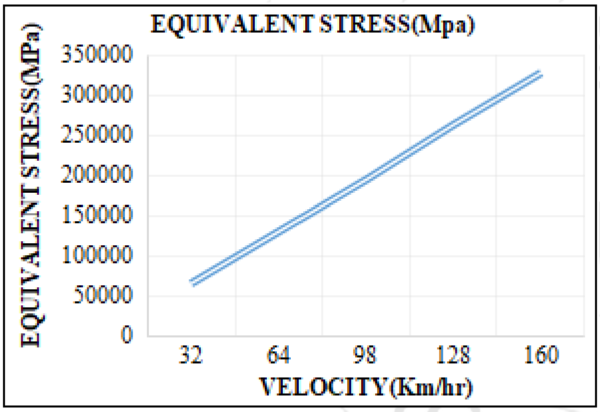

Figure 5: Equivalent stress vs velocity using carbon steel

The equivalent stresses increase linearly with velocity as can be seen in figure 5 above. The increase in stress can be attributed to increase in impact force on vehicle. The equivalent stress value is minimum for 32Km/hr and maximum for 160Km/hr.

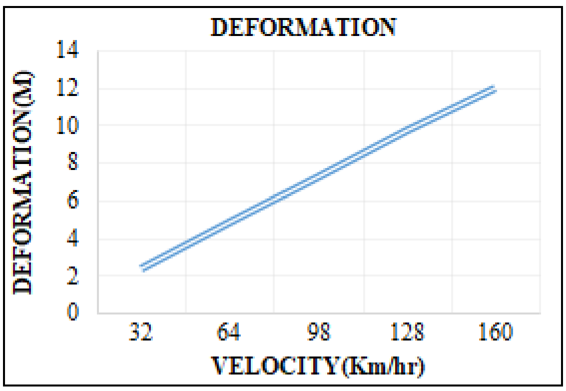

Figure 6: Deformation vs velocity using carbon steel

The deformation increase linearly with velocity as can be seen in figure 6 above. The deformation value is minimum for 32Km/hr and maximum for 160Km/hr.Similar tests are conducted using Aluminum Ceramic composite material applied for entire body structure and results are shown below.

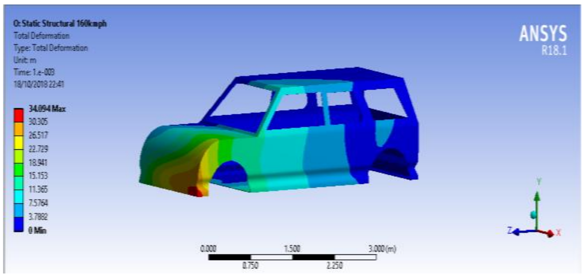

Figure 7: Deformation at 160Km/hr using Aluminum ceramic composites

The deformation plot shown above shows maximum deformation on frontal portion of car body with maximum value of 34.03m completely crushing car body.

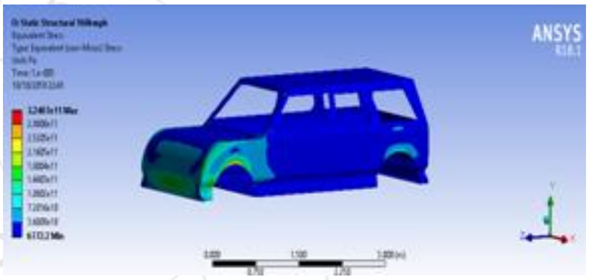

Figure 8: Equivalent stress at 160Km/hr using Aluminum ceramic composites

Figure 8 above shows equivalent stress generated from collision. The maximum value of equivalent stress is seen on frontal portion of car and quarter panels with maximum value of $3.24*10^{11}$ Pa.

Table 3: Equivalent stress and deformation at different velocities of impact using composite

Velocity (Km/hr)	Equivalent stress (Pa)	Deformation (m)
32	$6.48 * 10^{10}$	6.81
64	$1.29 * 10^{11}$	13.63
96	$1.94 * 10^{11}$	20.45
128	$2.59 * 10^{11}$	27.27
160	$3.24 * 10^{11}$	34.09

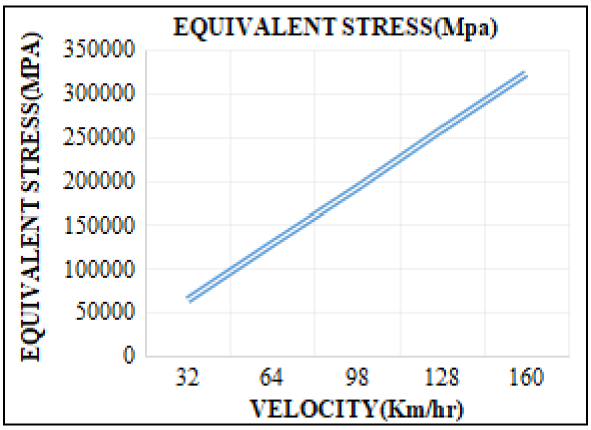

Figure 9: Equivalent stress vs velocity using Aluminum ceramic composite

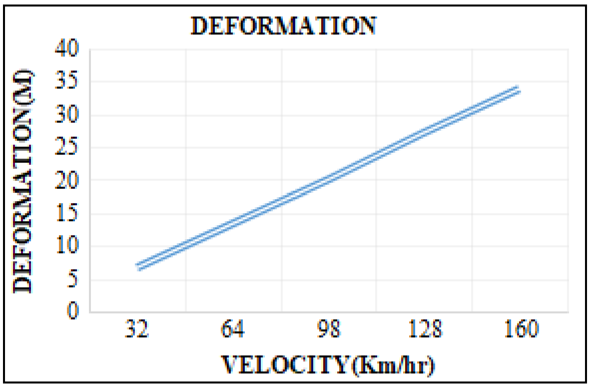

Figure 10: Deformation vs velocity using Aluminum ceramic composite

Both deformation and stresses increase linearly with velocity. This is due to increase in impact force. The deformation signifies complete crushing of vehicle along the length and maximum stress generated is 3.24 * 10^{11} Pa. which is lower than that of carbon steel.

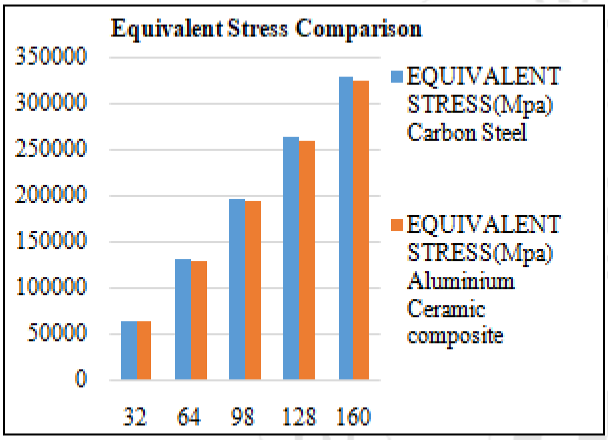

Figure 11: Equivalent stress comparison using different materials

The equivalent stress plot obtained from analysis is shown in figure 11 above. The equivalent stress for carbon steel is found to be more than Aluminum ceramic composite for all velocities of impact.

5. Conclusion

The crash analysis performed under quasi-static condition shows larger deformation of car body made from aluminium ceramic composite material, thereby resulting in complete distortion of body structure. Use of carbon steel for car body shows lower deformations in car body and higher stresses with better energy absorption characteristics.

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