CRASH INVESTIGATION ON FRONTAL VEHICLE CHASSIS FRAME USING FINITE ELEMENT SIMULATION

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ABSTRACT

Car chassis can be considered the primary protective shield for the safety of the passenger during rear-end crashes. This study focuses on the deformation and failure behaviour of the frontal car A-pillar chassis frame when subjected to collision with a heavy vehicle. Two different angles of the A-pillar chassis frame used are 45-degree and 70-degree. The crash simulation is conducted by using Finite Element software under the explicit dynamic. The car chassis frame geometries are designed by using SolidWorks 2021 and imported to the finite element software while a rigid block is designed in the finite element software as a rigid body to replicate the heavy vehicle. The chassis body is simulated for two types of materials, Aluminum alloy, and steel. The car speed impacted at 60 km/h. Results show that the intrusion of a rear barrier for 45 degrees of aluminum alloy will stop at 0.03 s but for 70 degrees it will intrude the car frame until the end. For the steel car frame, 45 degrees design is capable to withstand the intrusion of a rear barrier from a serious deform but for 70 degrees the intrusion will continue until the end. Car frame crush behaviour, energy dissipation, and vehicle decelerations from the crash simulation were observed.

Keywords: rear-end, crashworthiness, A-Pillar, finite element simulation, aluminium alloy.

1. INTRODUCTION

A crash is defined as an accident that takes place when a moving vehicle violently hits something, whether it is between the vehicle and another vehicle or between the vehicle and any obstacles [1]. Vehicle collisions have become one of the leading causes of rising human mortality rates throughout the globe. As a result, the car industry has been subjected to severe vehicle safety regulations [2]. Serious traffic accidents may occur resulting from the car-strike-truck in rear-end collisions, and the effects of these catastrophes are frequently severe, resulting in fatalities or serious injuries, in addition to huge economic losses [3]. Since certain accidents are unavoidable, it is critical to increasing the safety of automobiles when it comes to rear-end collisions. As a result, research into the crashworthiness of vehicle rear-end collisions is of significant practical value.

The frontal underrun protection system must be able to stop the vehicle from going under the truck in the event of a head-on collision between a car and a truck and be able to absorb the energy from the collision [4]. A rear-end collision involving a car and a truck is one of the most common types of road traffic accidents. Some frontal vehicle bodies will have plastic deformation during a rear-end crash and absorb energy from the impact. The most advanced techniques to simulate crashes allow for the structural optimization of vehicles (crashworthiness) to enhance occupants' safety, as well as for the reconstruction of road accident dynamics [1]. A crash simulation is a virtual recreation of a destructive crash test of a car by using computer simulation software to examine the level of safety of the car and its occupants [5]. An increase in simulated crash testing is being carried out at a variety of institutes to research the results of a rear-end collision under a variety of circumstances [6].

Atahan *et al.* did research on a rear-end protection device for heavy vehicles and also designed a special underride guard [7]. Finite element models of these specific designs are developed, and the models are then tested to see how affected of passenger car model going at two speeds of 48 and 64 km/h. Numerous aspects, including vehicle deceleration, vehicle crush characteristics, change in kinetic energy, and occupant injury potential, were examined using simulation studies [8]. They have noticed that vehicle damage and injury to its occupants become more likely when the height of the underride guard is raised to 500 or 600 (mm). It can be seen that the frontal area and also the A-pillar area of the vehicle had a serious impact from the collision. Balta et al. successfully finished the constrained optimized design of the rear underride guard, which increased the device's energy-absorption ratio [4][9]. Yang *et al.* successfully performed the research on crashworthiness optimization of an A-pillar in a passenger car in rear-end collision with a truck [10]. A reduction of 33.19 % in the maximum intrusion of the car's A-pillar was achieved as a result of the optimization, and a reduction of 46.98 % in intrusion speed was achieved without affecting the car's body mass from their research. The underride guard of trucks is the matter of the majority of domestic and international research related to car-truck rear-end collisions. The brain damage is mostly caused by the A-pillar in the passenger compartment and the occupant's head colliding with the A-pillar. In general, the A-pillar is a crucial load-bearing element in the frame of every automobile. It is often a spot-welded, closed-section, thin-walled construction with the roof support structure on either side of the windscreen of a car. As part of the validation process, the A-pillar may be experimentally loaded at quasi-static rates till failure [10]. The A-pillars are provided by the manufacturer on both sides of the vehicle. Cao *et al*. performed research on car crashworthiness in car-to-truck offset rear-end collisions [11]. They simulated the car front-deformable barrier crashing process under different offset rates and analyzed the variation of car acceleration, intrusion volume, and invasive procedure under different offset rates. According to the results, the underrun protection capability of the truck is reduced in the offset condition, and the A-pillar of the automobile is more susceptible to being invaded by the truck.

In addition, very little research has been done on the crashworthiness of automobiles in rear-end collisions involving A-pillars. This study will aim at the frontal car chassis frame of an A-pillar crash simulation against rear-end of the truck conducted by using ABAQUS Finite Element Simulation under the explicit dynamics. Two types of materials are compared for the chassis while the angle of the A-pillar used is 45 and 70 degrees.

2. MATERIALS AND METHODS

The geometry model of the car chassis frame was designed using SolidWorks Version 2021. Figures 1 and 2 illustrate the projection view of the unibody car chassis frame with two different angles of the A-pillar which are 45 and 70 degrees. The design model from SolidWorks 2021 will be converted to Initial Graphics Specification (IGES) format. This file format was developed for a model that generates a specific software package that can be imported and is ready to be analysed in its entirety. To design the form or geometry of a truck's rear barrier, numerical simulation software was utilised, and the barrier was given the dimensions of length, width, and thickness. The rigid barrier has dimensions of 1050 mm by 1750 mm by 200 mm.

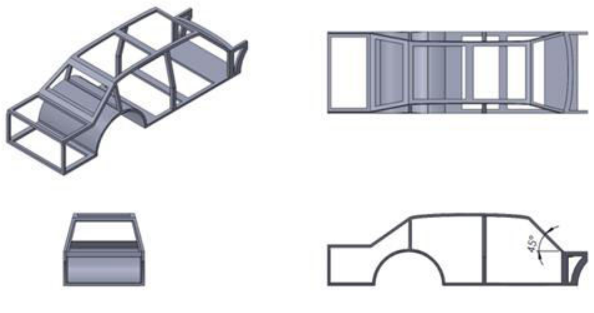


Figure-1. Projection view of the car frame for 45-degrees A-Pillar.

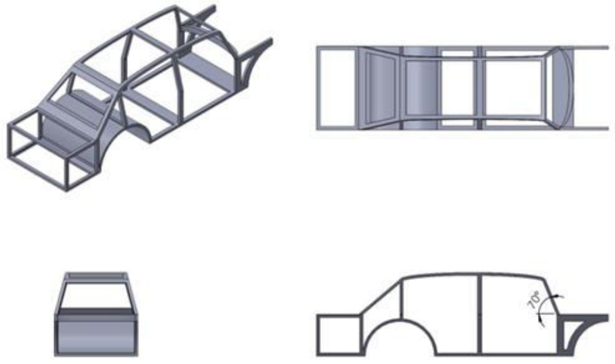


Figure-2. Projection view of the car frame for 70-degrees A-Pillar.

2.1 Mechanical Properties

The material used for the unibody car chassis frame is aluminium alloy and steel. The rear barrier of a truck is considered rigid in simulation. Table-1 and Table-2 depict the properties of the aluminium alloy and steel that were employed in this research and other material properties that were altered for a portion of the car's components including, which was determined by the mechanical behaviour that was necessary.

Table-1. Properties of aluminium alloy**.**

Mechanical Properties	Value
Density	2700 kg/m3
Young’s Modulus	70,000 MPa
Poisson’s Ratio	0.33

Table-2. Properties of steel**.**

Mechanical Properties	Value
Density	7800 kg/m3
Young’s Modulus	210,000 MPa
Poisson’s Ratio	0.3

2.2 Model Arrangement

One of the most significant factors to consider in numerical simulation software is the model arrangement, which will influence the time required to solve the simulation analysis. Setting a part's behaviour to rigidity drastically simplifies the representation of the part to a single-point mass, resulting in a large reduction in the time required to solve the problem. When the simulation begins, the chassis frame of a car and the rear barrier of a truck will come into instant contact.

2.3 Boundary Condition

The middle of a truck's rear barrier was assigned a reference point where a fixed ENCASTRE boundary condition was applied and also the fixed x, y displacement boundary condition was applied to the car frame. The boundary condition also assumed that the rear barrier is clamped, preventing the rear barrier's location from changing until the effect is applied. The boundary condition's displacement was set.

2.4 Meshing

Meshing is part of the simulation process that affects how accurate the results are because it sets up how each point on a model is placed. To improve the model's outputs, fine meshing is used across the impact area relative to the A-pillar area and front of the car frame to generate a smooth variation in stress in the impact zone. The number of nodes, on the other hand, may have an impact on the outcome of each result. The quadrilateral-dominated mesh was generated for the rear barrier of a truck and for the car frame. Figure-3 shows an arrangement of meshing at a car chassis frame while Figure-4 shows the mesh arrangement at a rear barrier of a truck.

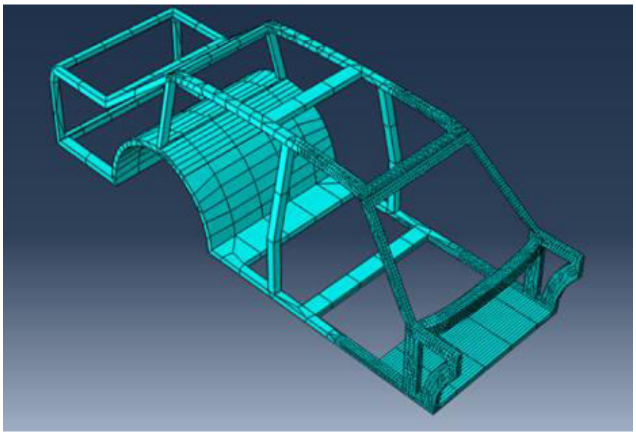


Figure-3. Arrangement of meshing at a car chassis frame.

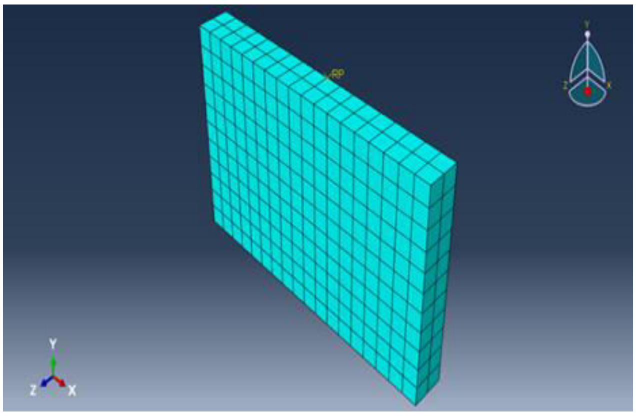


Figure-4. Arrangement of meshing at a rear barrier of truck.

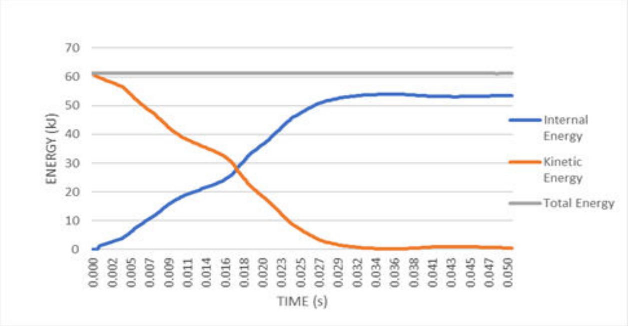
3. RESULTS AND DISCUSSIONS

The results presented in terms of change in kinetic energy, velocity dissipation of the car frame, crash sequence, and behaviour obtained from the crash simulation in this study.

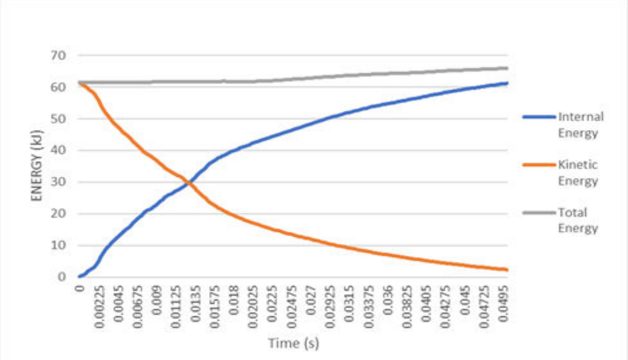
3.1 Results for Aluminium Alloy

3.1.1 Energy balance

The simulation started with initial kinetic energy and external work was applied which is the car will crash the rear barrier directly to get the optimum result for the intrusion of the frame car in the crash investigation. It can be seen that in the graph for 45 degrees, the maximum kinetic energy of the car frame is 61.2 kJ. The kinetic energy then starts to decrease and increase over time until the energy constantly starts at 0.033 s. The constant value of the energy is caused by the car frame being bounced back from hitting the rear barrier and stopping the intrusions and thus the kinetic energy of the car frame dissipated faster due to higher energy dissipation by the car frame features. However, for 70-degree the maximum value for the kinetic energy of the car frame is 61.5 kJ. As increasing in the time of the simulation, the kinetic energy will decrease until it reached the minimum value of 2.32 kJ at 0.05 s. Based on the result obtained; the kinetic energy value for the aluminium alloy with 70 degrees is much higher than 45 degrees. This can conclude that the car frame for 70 degrees had absorbed much energy due to the impact that deforms the shape of the vehicle. When the car frame model hits the rear barrier, the kinetic energy is absorbed by the car frame and converted into internal energy. So, in the graph, the internal energy starts to increase until it reaches its maximum value at the maximum deformation. The total energy remains constant until the simulation stops.



(a) Energy Balance for car 45-degree A-pillar angle

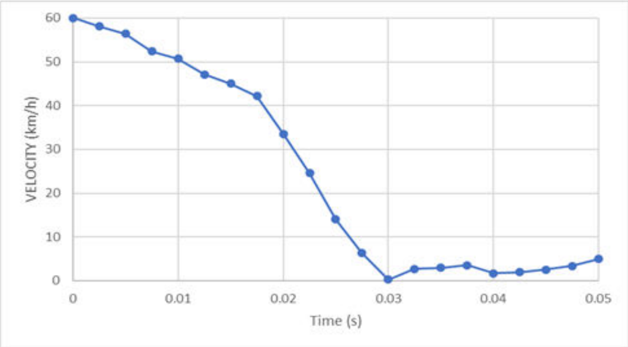


(b). Energy Balance for car 70- degree A-pillar angle

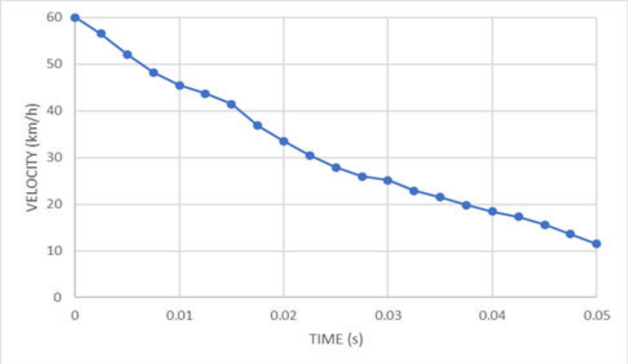
Figure-5. Graph for energy balance of Aluminium Alloy.

3.1.2 Car frame velocity dissipation

The initial velocity of the car frame before striking the rigid rear barrier is 60 km/h. From the velocity graph of 45 degrees, after the rear barrier intruded the A-pillar of the car frame, the value of the velocity directly decreases until 42.15 km/h at 0.017 s. At 0.03 s, the velocity of the car frame constantly fluctuated a bit until the end of the simulation at 0.05 s with 4.9 km/h. unfortunately, for 70 degrees after the impact with the barrier, the velocity is immediately dissipated to 36.87 km/h at 0.017 s. Then, starting from 0.015 s velocity continued to decrease until the end of the simulation at 0.05 s. decreasing of the velocity is because there is a large resistance passed by the car frame affected by the rear barrier. The graph clearly shows that the velocity of the car for 70 degrees at the end of the simulation is higher than 45 degrees. It can be analysed that the car frame had serious damage due to the intrusions of a rear barrier of a truck onto the car frame causing the velocity dissipated earlier and slower down the car frame to move.



(a) Velocity for car at 45-degree A-pillar angle.



(b) Velocity for car at 70-Degree A-pillar angle.

Figure-6. Velocity against time for aluminium alloy.

3.1.3 Crash behaviour

Several analyses could be made based on the crash sequence from both angles of the A-pillar. At 0.01 s, the A-pillar for both angles which are 45 degrees and 70 degrees had a deformation after the rear barrier invaded the car frame. The intrusion of a rear barrier into the car frame continued for both angles at 0.02 s and 0.03 s. As can be seen from Figure-7 and 8 at 0.02 s, the A-pillar of the car for both angles had total damage. This can be predicted that there is a high probability of serious injury to the occupants of the front seats of the passenger vehicle in a real crash situation. At increasing time of the simulation, the intrusion of the rear barrier of the car frame for 45 degrees is stopped at 0.04 s and the car bounced back from the rear barrier at the B-pillar. But, for the 70 degrees in Figure-8, the car frame again slid under a rear barrier with serious damage until the simulation ended at 0.05 s. From the discussion, it has been proved that to acquire high strength, aluminium can be alloyed and strengthened through cold working and/or heat treatment. This allows for the metal to attain a high strength-to-weight ratio. Aluminium alloy is now used in vehicle structures, power trains, and accessories, which makes it possible to manufacture vehicles that are lighter, safer, and have higher performance in terms of acceleration, handling, and braking distance [12].

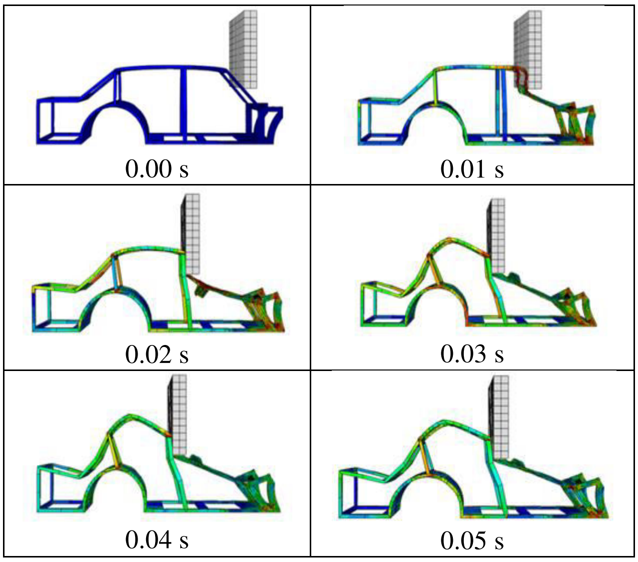


Figure 7. Crash sequence for 45 degrees.

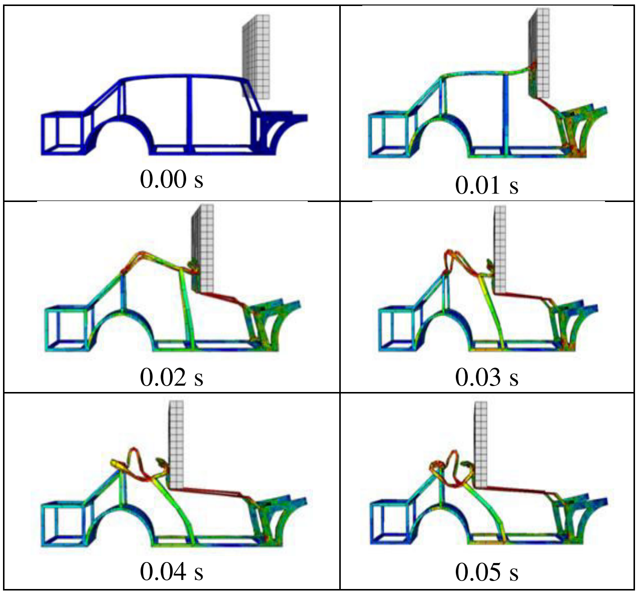
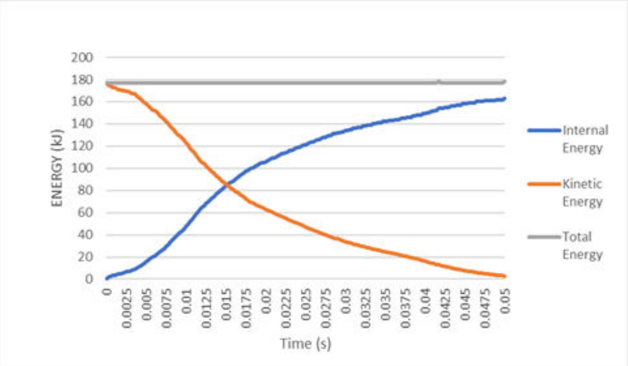


Figure-8. Crash sequence for 70 degrees.

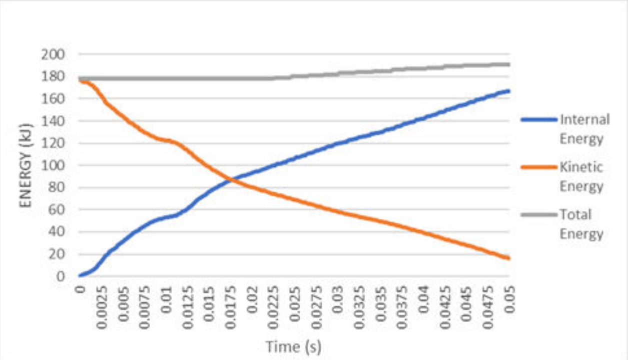
3.2 Results for Steel

3.2.1 Energy balance

As shown in Figure-9, it obtained the energy balance against time at the end of the simulation. From the kinetic energy graph, it can be seen that the initial kinetic energy for both angles starts to decrease immediately at the beginning of the simulation when strikes the rear barrier of a truck. From the 45-degree graph, the maximum value of the kinetic energy computed when 60 km/h velocity impact is applied is 178 kJ. The kinetic energy will decrease increasing over time and does not stop until the end of the simulation which is at 0.05 s as 2.90 kJ is the minimum value of the kinetic energy. While for 70-degree the maximum kinetic energy for the car frame is 178 kJ and decreases along the time of the simulation until reached the minimum value of 16.1 kJ. Based on the graph, the car frame of steel with 70 degrees has much kinetic energy from the car frame from starting of the A-pillar intrusions to the back side of the car. The higher value of the kinetic energy and internal energy obtained shows that the car frame of steel for 70 degrees had serious damage from the collisions with a rear barrier compared with 45 degrees. At 0.04 s, kinetic energy for 70 degrees is still higher compared to 45 degrees had dissipated a bit of the kinetic energy from the impact of the car frame with a barrier.



(a) Energy balance for car 45-degrees A-pillar angle.

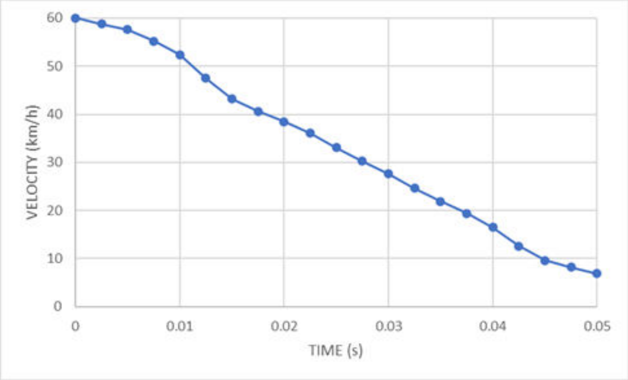


(b) Energy balance for car 70-degrees A-pillar angle.

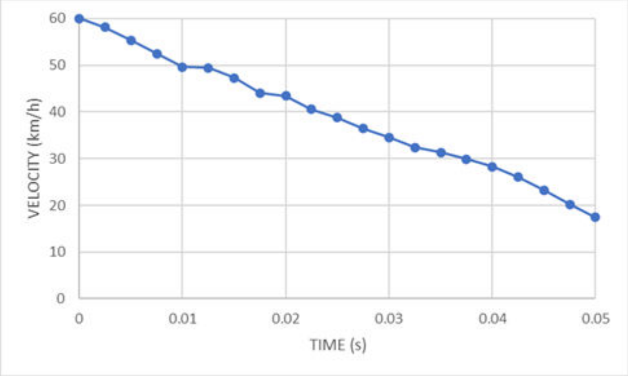
Figure 9. Graph for energy balance of steel.

3.2.2 Car frame velocity dissipation

When the angle of the A-pillar increased, the interaction between the rear barrier and car frame was different concerning the damage occurring in the occupant compartment. Figure-10 provides an illustration of the velocity plot for a steel car structure inclined at 45 to 70 degrees that significantly influenced the outcome of the test. It is possible to see that the simulation began with an initial velocity of 60km/h before the car frame hit the barrier. Unfortunately, as soon as the car frame collides with the barrier, its velocity immediately decreases to 38.49 km/h in 0.02 seconds for 45-degree. The dissipation of the velocity demonstrates that the rear barrier is responsible for slowing the velocity of the car frame, which in turn causes the frame to deform. But for 70 degrees, after hitting the barrier, the speed drops to 43.44 km/h in just 0.02 seconds. This lowers and remains constant for a while before decreasing proportionally with time until the simulation is complete. Despite this, the velocity rises above 45-degree at 0.05 s. It is possible that the steel car frame of 70 degrees was further deformed by the incursions of the rear barrier of a truck against the car frame, causing the frame to have a significantly deformed shape from the 45-degree crash.



(a) Velocity for car 45-degree A-pillar angle.



(b) Velocity for car 70-degree A-pillar angle.

Figure-10. Velocity against time for Steel.

3.2.3 Crash behaviour

When a rear barrier of a truck invaded the car after the simulation started at 0.01 seconds, as seen in Figure-11 and Figure-12, the A-pillar of the car frame became noticeably deformed. According to the examination of the data for 70 degrees, the A-pillar of a vehicle's frame experienced a more severe deformation as a result of the incursion of a barrier than it did for 45 degrees. The fact that the A-pillar for 70 degrees had to go through elongation up until the very end of the simulation may be demonstrated by the outcome that was attained. Despite this, the A-pillar for the bottom side of a rear barrier that invaded the car frame does not experience a deformation when the angle is 70 degrees, in contrast to 45 degrees, which had a full distortion when the barrier invaded the car. When compared to a circumstance in which the situation was 70 degrees, it is possible to predict that the risk of injury to the people sitting in the front and back seats of the passenger vehicle was significantly lower when the was 45 degrees.

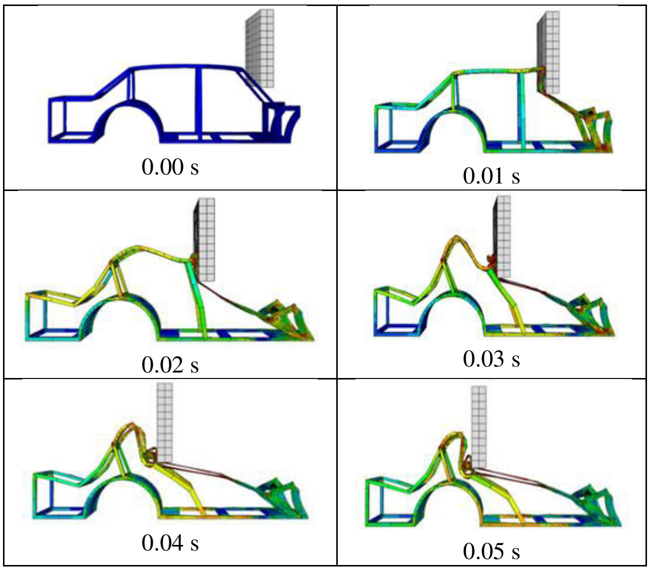

0.00 s
0.01 s
0.02 s
0.03 s
0.04 s
0.05 s

Figure 11. Crash sequence for 45-degree.

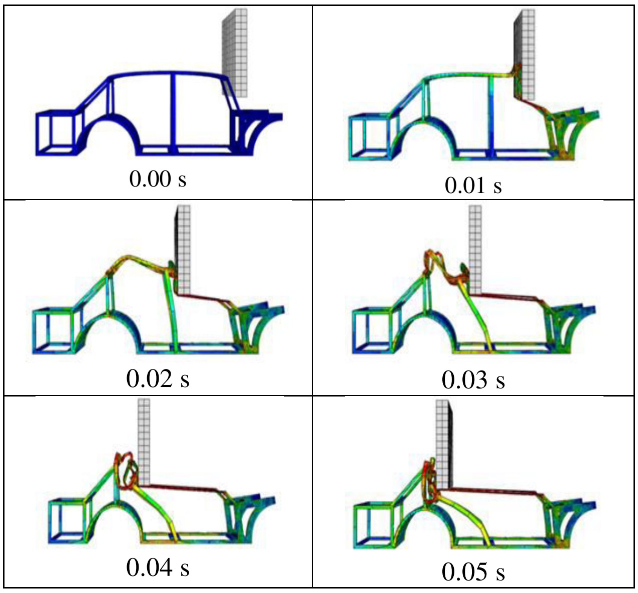

0.00 s
0.01 s
0.02 s
0.03 s
0.04 s
0.05 s

Figure 12. Crash sequence for 70-degree.

4. CONCLUSIONS

Based on the result for aluminum alloy, a car frame with 45 degrees can barely withstand the deformation by a rear barrier. At 0.03 s, the rear barrier stops from invading the car frame until the end of the simulation. Unfortunately, the A-pillar had to deform seriously from the collision and turn to plastic deformation. For the 70-degree, the result has shown that it had a serious permanent deformation at the A-pillar area as well as the area of the car roof. From the result for steel, the car frame for 70 degrees had a serious elongation for the A-pillar. For 45-degrees, it also indicates that the A-pillar of a car frame had a permanent deformation beyond expectation. This is due to the material used having a lower strength to withstand the rigid barrier from invading the A-pillar of a car. The findings of the research indicate that the strength of the A-pillar should have to be improved, and the crash evaluation system would need to take into account the form of offset collisions. In the meantime, the crashworthiness of the car frame should be purposefully improved to reduce the risk of rear-end collisions.

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