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Usage of Finite Element Method and Analysis of Car Hood Model with Different Material and Speed for Crash Test by using Abaqus Explicit Software in Automotive Application

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Abstract: The most important variables to analyze the crashworthiness are material, speed, and different car hood thickness. This study compares two different types of material aluminium and steel on car hood by different speeds. It determines the response elements in terms of hood deformation, energy absorbed, Von-Mises stresses, kinetic energy, internal energy, and strain energy of hood. Next is to investigate the potential of Abaqus/-Explicit as the tool to simulate vehicle crashes into a rigid wall in general. Based on the results, the lowest deformation at 84.90 mm is by aluminium material at a thickness of 1.50 cm. The stresses in both the material increases with the increase in speed and structural steel have a high value of stress than aluminium. The equivalent stresses in aluminium material are only 5.00-13.00 % of the structural steel body and deformation is almost the same. The maximum value of the hood energy absorption is 5.31E+06 for aluminium material. The minimum energy absorption is 4.61E+06 for steel at high speed of 100 km/h. Aluminium exhibits the minor deflection because the energy nearest turns to zero and the atom completely absorbs the kinetic and internal energy. Steel material absorbs maximum internal energy of 30271 J followed by steel 15007 J. The conclusion from the results is that Abaqus/Explicit is a suitable finite element software for simulating crashes.

Keywords: Abaqus, Speed, Hood, Deformation, Kinetic energy, Energy absorption, Aluminium, Steel

1. Introduction

Hood or bonnet is one of the main parts used to protect passengers from the front and rear collision [1]. Car hood is one of the essential components in passenger cars for which should consider the material and car speed to reduce the impact of the crash [2]

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In this study, the most important variables like material, speed and hood thickness, are studied to analyze the car hood to improve the crashworthiness. In this paper, material changes and car, speed are applied to the hood for the same design and finally show a frontal crash collision. The car hood is the part of the car that contributes to passengers' protection in any crash. According to NCAP (European New Car Assessment Program), crash tests verify material selection's correctness for the car body's deformation zones [3]. The most important cases that influence the inner hood body's material are hood performance for high speed and low-speed crashes [4]. The structure and the material of a car hood constitute a significant factor in the degree of injury resulting from a hood collision; therefore, research on car hood material selection may lead to innovations that will reduce incidence and severity of car accidents [5]. According to Untaroiu JS, Crandall JR [6] the vehicle hood is the area most likely to affect the accidents. A good design of car hood must provide safety for passengers [7].

There are several types of finite element software in the market such as Algor, Nastran, Abaqus, Cosmos, I-Deas, Radioss and Ls-Dyna.[8]. Abaqus/Explicit is an analysis product used in special-purpose. This product uses an explicit dynamic finite element formulation. It is suitable for brief, transient dynamic events, such as impact problems. It is also preferred for problems involving large deformations, i.e., highly nonlinear problems [9].

Energy absorption can be determined using real-time test, but due to the high cost of conducting real-time tests, finite element analysis (FEA) is used in the automotive industry before conducting real-time test. [1]. The measurement of energy absorption of a system requires calculating the forces during the collision, which are needed to assess the passenger's structural damage and survivability. The energy absorption is a useful measure for comparing the capabilities of different materials and structure in which weight is an important consideration [10].

Elastic behaviour under tension or compression of the slope for the initial part of the stress-strain curve determines Elasticity's the Module (Young's Modulus). Mostly, the rounded value of E = 70.000 MPa is used for aluminium and its alloys. It is 1/3 the value of steels. Under torsion, the Shear Modulus or Modulus of Rigidity is G = 26.000 MPa for aluminium compared to 82.700 MPa for steel [11]. The lower E-modulus aluminium can absorb the 3-fold amount of energy elastically before plastic yielding compared with steel. This property is significant for crash-relevant components, like bumpers, hood and car body [12]. Vehicle safety considerations have led to a conceptual approach where the front and rear crash management systems are part of the structural load path. The specific properties of aluminium offer the possibility to design cost-effective, lightweight structures with high stiffness and excellent crash energy absorption potential. The impact of energy is typically distributed between the following standard elements of the crash management system [13]:

- The hood where the impact energy results in elastic and plastic deformation behaviour.
- The crash boxes which absorb energy by plastic deformation behaviour.

Table 1 summarizes several conclusions from selected past researches on frontal crash

Table 1: Selected previous studies on car crash simulation

Author	Title/Year	Aims	Method	Finding	Sources
Vivek Dayal, Ashwani Sharma, M.A. Murtaza	Crash Simulation of a Car Body (2018)	This paper presents the simulation of frontal crash of a car for various speeds	Ansys software	The Equivalent (von-Mises) stress in both the material increases with the increase in speed	[14]
Rimy, M.M. & Abdul	Simulation of Car Bumper	To analyze and study the structure and material	Abaqus Software	The most important variables like material, structures, shapes and	[1]

Aziz, Faieza	Material using Finite Element Analysis (2010)	employed for car bumper in one of the national car manufacturers Studied by impact modelling to determine the kinetic energy, potential energy and strain energy	impact conditions are studied for analysis in order to improve the crashworthiness. Materials were studied by impact modelling to determine the kinetic energy, potential energy and strain energy.

2. Materials and Methods

The method of this study, followed by the flowchart in Figure 1. The simulation steps encountered for this study shown in Figure 2. The significant parameter and variables for simulation need to be defined for the simulation design.

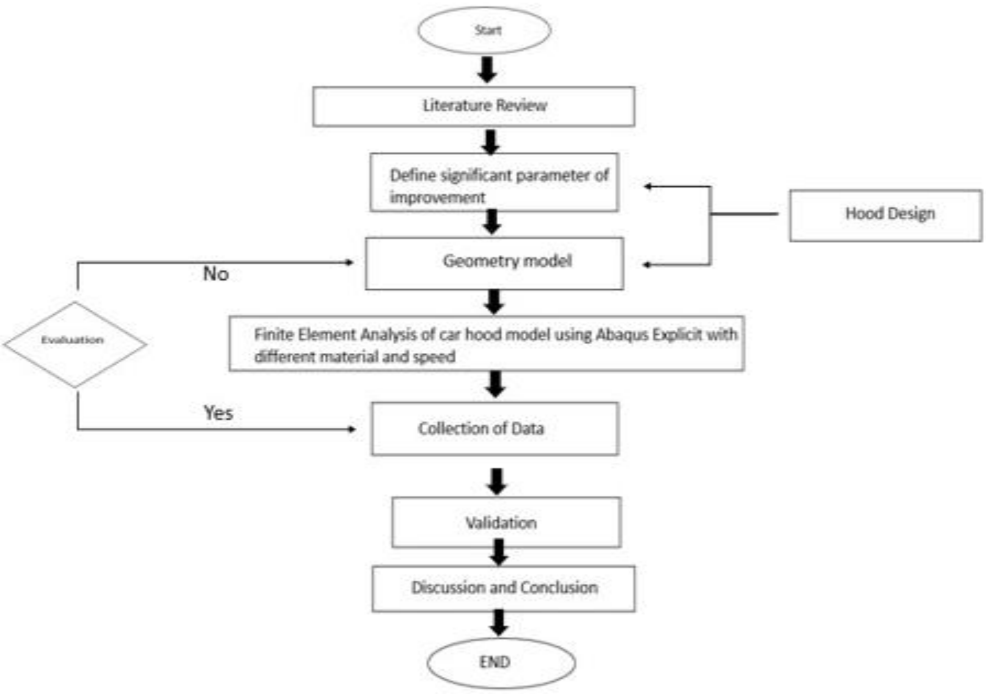


Figure 1: Flowchart of research methodology

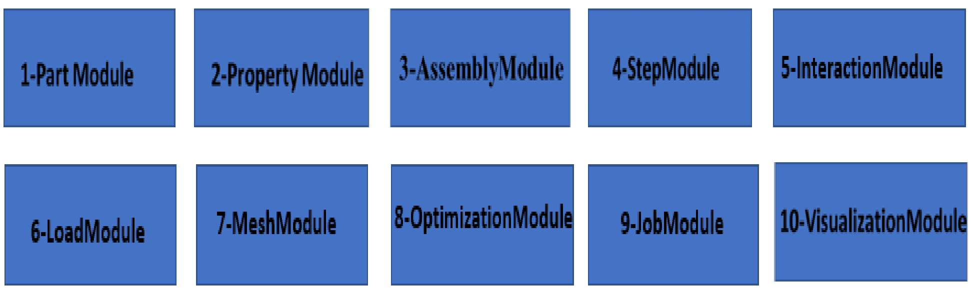


Figure 2: Step by step towards structural simulation using Abaqus Explicit

Figure 3 shows the relationship between input and output parameter. There are three variables used as an input in simulation. The first input is the properties of steel and aluminium. The modification on the material was applied to the car hood model. In the beginning of simulation was to determine the hood deformation with different thickness on car speed of 50 km/h. The thickness of the car hood selected was 1.00 cm, 1.25 cm and 1.50 cm.

The various speed was applied in this simulation except for the car hood thickness deformation with speed 75 km/h and 100 km/h. Result or output consists of maximum hood deformation, Equivalent Von mises stress, energy absorption, kinetic energy, internal energy and strain energy. Output generated by a simulation to predict system performance.

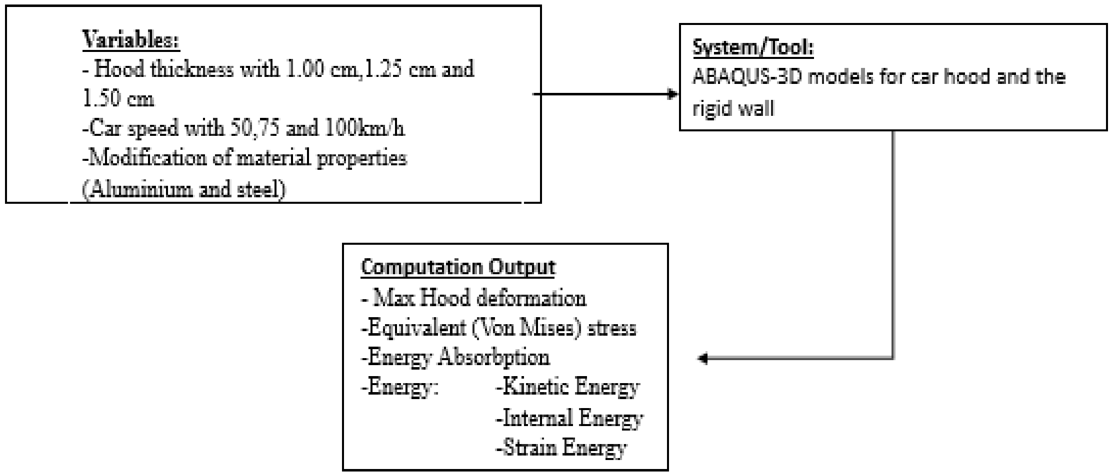


Figure 3: Relationship between input and output parameters

Table 2 and Table 3 shows the materials used and simulated as hood materials. Material modification applied to the car hood model brings about certain changes in their properties. The material mechanical properties that have been introduced in Abaqus were taken from [15] for Aluminum and [16] for steel material. So, the mechanical properties used was (density, young modulus, Poisson's ratio, yield stress and plastic strain). The young's modulus for the Steel is 71700 MPa, and the Poisson's ratio was 0.29, with density 7.85e-09 kg/m^3. For aluminium is 94000 Mpa, and the Poisson's ratio was 0.33, with density 2.85e-09 kg/m^3.

Table 2: Input Steel Properties in Abaqus

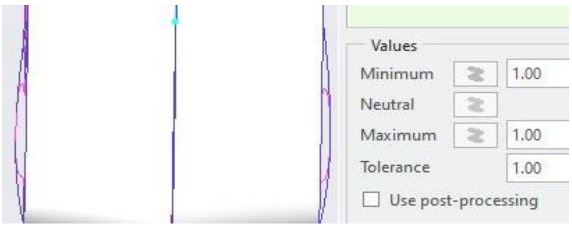
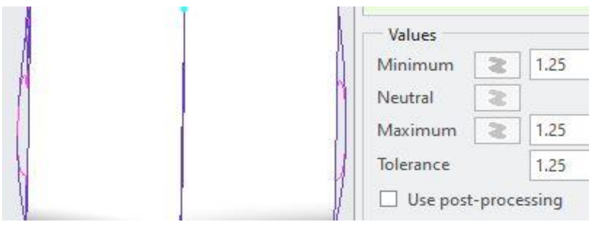
Mass Density (kg/m^3)	Young Modulus [Mpa]	Poisson's ratio	Yield stress [Mpa]	Plastic strain
7.85e-09	71700	0.29	207 N/mm^2	0 ε
			210 N/mm^2	0.0010279 ε
			230 N/mm^2	0.001763 ε
			250 N/mm^2	0.0027177 ε
			270 N/mm^2	0.0039248 ε

Table 3: Input Aluminium Properties in Abaqus

Mass Density	Young Modulus [Mpa]	Poisson's Ratio	Yield stress [Mpa]	Plastic strain
2.85e-09	94000	0.33	350 N/mm^2	0 ε
			368.71 N/mm^2	0.001 ε
			376.5 N/mm^2	0.002 ε
			391.98N/mm^2	0.005 ε
			403.13 N/mm^2	0.008 ε

Table 4 shows the modification of car hood thickness. The modification of a hood aims to provide a compatible of hood deformation for frontal impact position at speed 50 km/h with different thicknesses (1.00 cm, 1.25 cm and 1.50 cm)

Table 4: Car Hood thickness

Part	Hood Design	No. of nodes	No. of elements
Hood thickness (1 cm)		307	201
Hood thickness (1.25 cm)		329	240

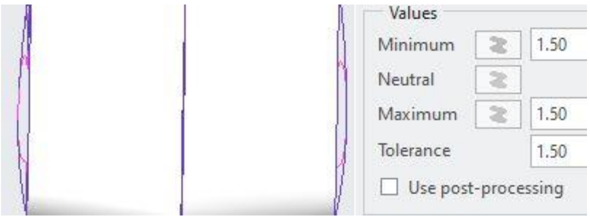
Hood thickness (1.50 cm)		349	279

Figure 4 shows the geometry of the car hood. The length of the car hood is 1.652 m and 1.074 m for the width.

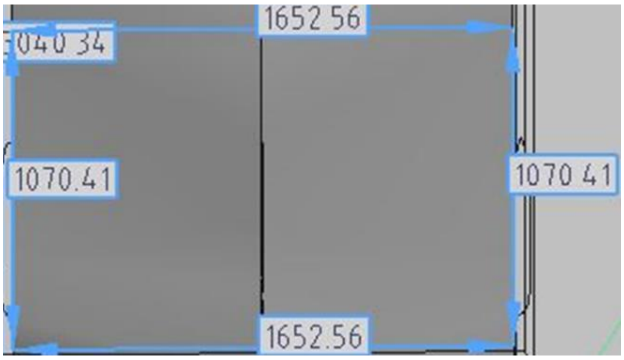


Figure 4: Geometry of the car hood

Figure 5 and Figure 6 shows the car design in side view. The side view of an object shows the length, width and height dimensions. The design was created by using Creo 5.0 software, and the file was converted to .igs file. Dimensions are added to the sketch to define the size and location of the geometry. The .igs file was input in Abaqus software and started to use in the simulation.

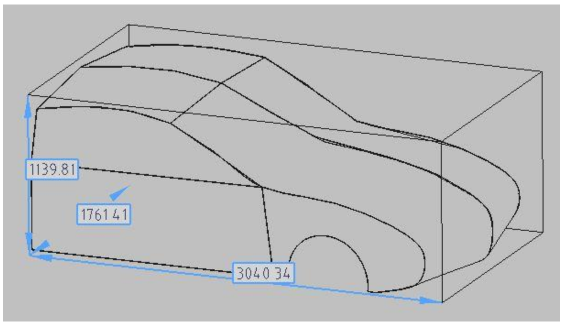


Figure 5: Car design in wireframe view

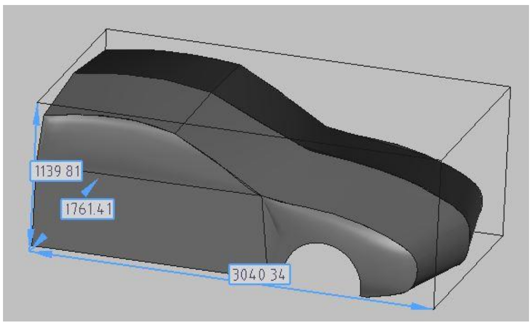


Figure 6: Car design in solid 3D

The 3D model rigid wall was created by using the modelling feature such as extrude by Abaqus software. The distance between the rigid wall and car hood is created in assembly module. The horizontal distance between the rigid wall and the car hood was 10 m and is represented by the z-axis in Abaqus as shown in Figure 7.

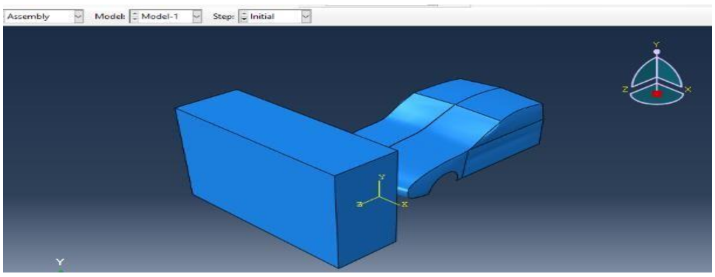


Figure 7: Assembly part

Figure 8 shows the step analysis in the simulation. The analysis step was created in the step module, the procedure of the step was chosen to Dynamic Explicit with a step time of 0.02. Automatic time incrementation was used, the stable increment estimator was selected to global with a time scaling factor of 1. Maximum time increment was unlimited. The default time incrementation scheme in Abaqus/Explicit is fully automatic and requires no user intervention [9]. Mass scaling was not applied for any region of the model. Linear and quadratic bulk viscosity parameters were set to default values of 0.06 and 1.2 respectively.

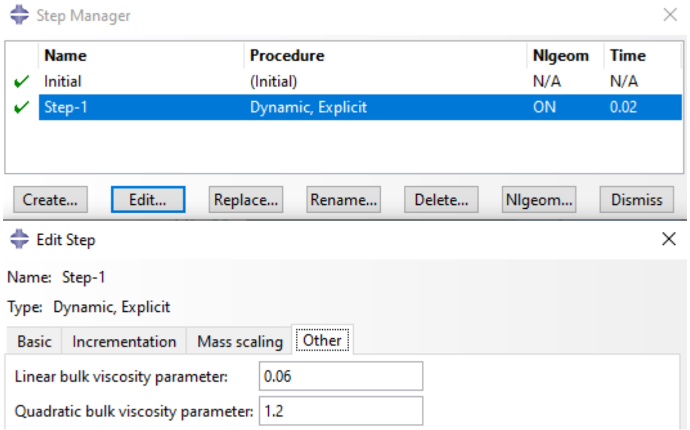


Figure 8: Analysis step applied to the mode

Figure 9 shows the contact definition used is explained following by the constraints and connections applied. The contact definition was made in the contact property tool, a mechanical tangential behavior was defined. The penalty friction formulation was used with a friction coefficient of 0.3. A low value of friction coefficient was chosen since the tires were not included in vehicle part.

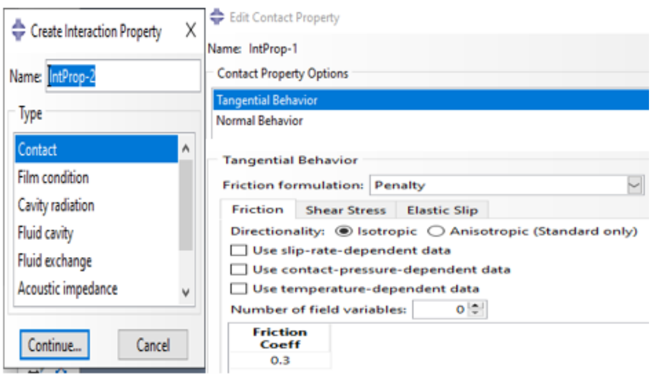


Figure 9: Contact definition applied to the surface

Figure 10 shows the speed of the car. The load was created to defined and managed the following prescribed boundary conditions. Gravity load with a value of 9810 mm/s^2 was applied for the entire vehicle. Different Impact velocity of the vehicle was, 13889 mm/s (50 km/h), 20833 mm/s (75 km/h), 27778 mm/s (100 km/h).

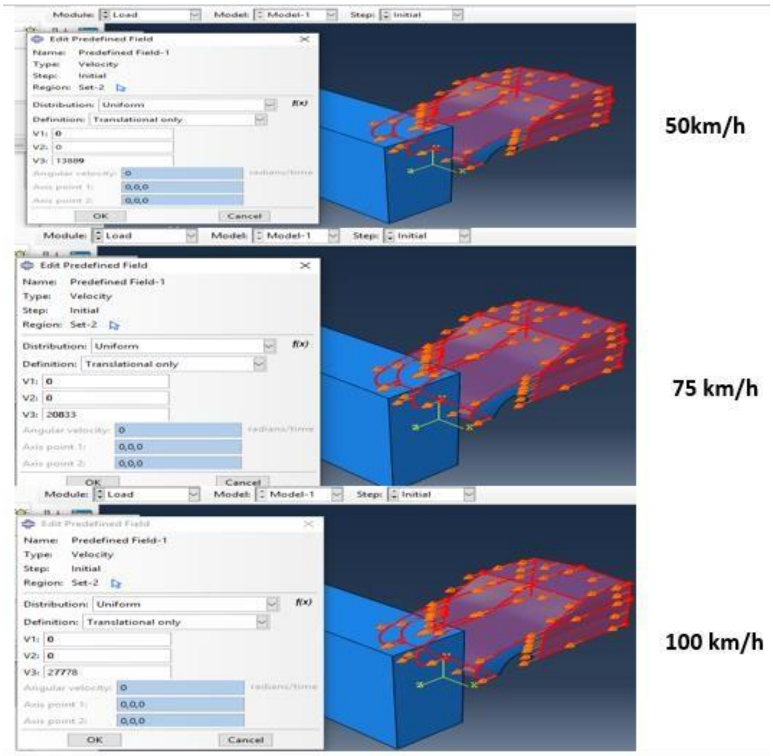


Figure 10: Different Impact speed of the vehicle

Figure 11 show the type of boundary condition used in Abaqus. A reference point is assigned at the middle of the rigid wall where fixed, with common of ENCASTRE, boundary condition was applied. Fixed boundary conditions, ENCASTRE, was applied.

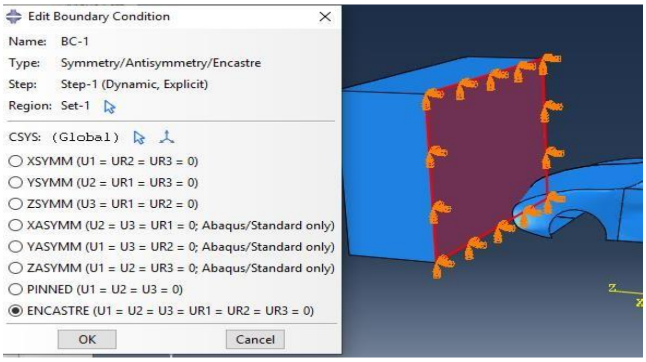


Figure 11: The fixed boundary condition applied to the end post

Figure 12 shows an example of the mesh generated. Mesh of the design was created using a global mesh setup in Abaqus/CEA simulation. Mesh global seeds were setting provided for car and the rigid wall which scaled from 50 to 100. The element typeset with chosen explicit and linear, which is applied for 3D stress in rigid wall and for the car front, was set with chosen explicit and linear shell as shown in Figure 13.

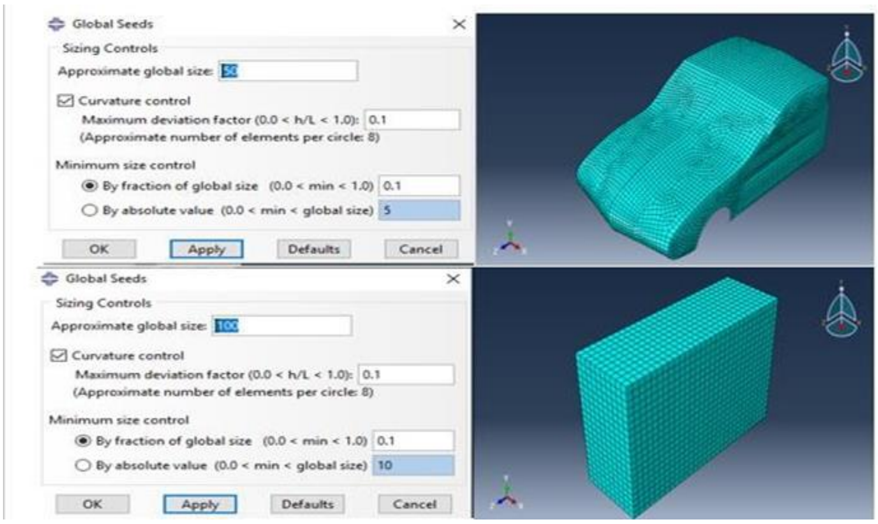


Figure 12: Mesh generated

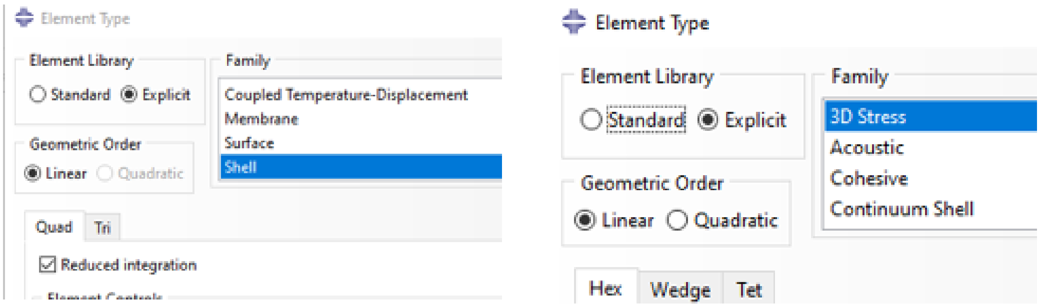


Figure 13: Element type

3. Result and Discussion

The observation from Table 5 and Table 6 shows that the steel hood deforms at 124.08 mm for 1.00 cm of thickness. For 1.25 cm, the deformation is 110.08 mm. But for 1.50 cm thickness, the deformation is 93.68 mm. For the aluminium hood at 1.00 cm, the maximum value of deformation is 118.20 mm, and for 1.25 cm the deformation is 100.20 mm. On the other hand, 84.90 mm of deformation produced from 1.50 cm of thickness. Value of displacement varies according to the mechanical properties and thickness that indicate deformation on the car hood after the impact. From the data, it observed that steel with 1.00 cm thickness obtains the highest deformation.

Otherwise, the lowest deformation at 84.90 mm was obtained by aluminium (1.50 cm). The observation on the deformation of car hood deformation shows that the maximum deformation is not recommended because more modification is needed for the hood's thickness and material properties. Indicates that steel has less elasticity compared to the aluminium. Moreover, this research in line with Masoumi [4] reported that steel has more displacement than aluminium. It means that aluminium has better crashworthiness regarding its lightweight. The effective thickness of the car hood is recommended to optimize the protection. Besides, the strength of hood is necessary to minimize the contact of engine components of the vehicle during the collision. Moreover, hood thickness and material type become the main factors that influence equivalent stress and deformation value. It means that structure must be strengthened in front of static and dynamic forces, and at the same time, it should be able to reduce the intensity of impact and avoid extra deformation of the hood [17].

Table 5: the deformation of the hood for different materials and thicknesses

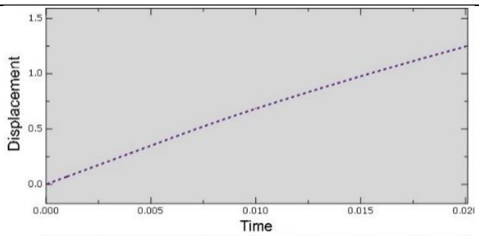
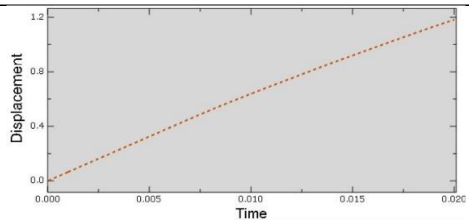
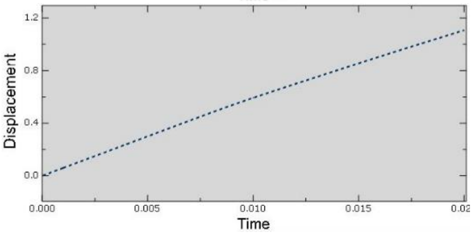
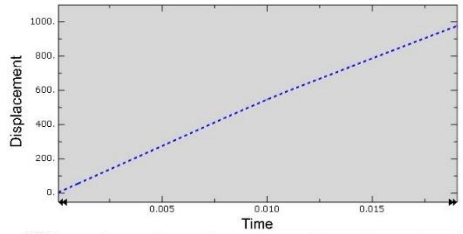
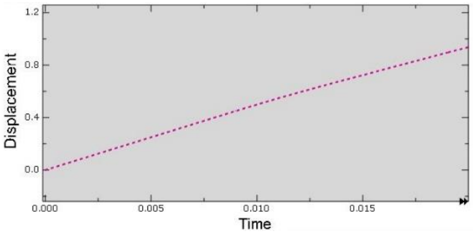
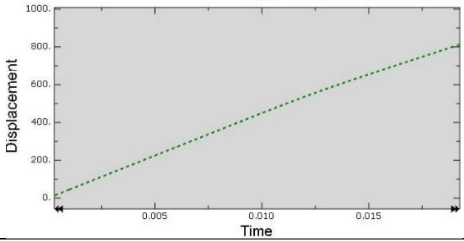
Thickness	Material	
	Steel	Aluminium
1.00 cm		
1.25 cm		
1.50 cm		

Table 6: The maximum deformation of car hood

Hood material and thickness		Max deformation (mm)
Steel	(1.00 cm)	124.08
Aluminium	(1.00 cm)	118.20
Steel	(1.25 cm)	110.08
Aluminium	(1.25 cm)	100.20
Steel	(1.50 cm)	93.68
Aluminium	(1.50 cm)	84.90

The variable car hood thickness was not included in this section. This section focuses on modifying the car hood material properties and speed in terms of hood deformation, von mises stresses, energy absorption, kinetic energy, internal energy and strain energy. Figure 15 shows the result of car hood deformation. It can be observed the crash module moving with different speeds and material absorbing energy even at high speeds 100 km/h. The analysis shows that the hood has a large deformation because of the frontal impact. The collision process continues, and the car hood's condition becomes worse leads to the possibility of severe injuries to passengers. To meet the crashworthiness of the car hood, the module should absorb max energy which is dissipated during the collision. The values of young's modulus, Poisson ratio, mass density, and yield strength will affect the car hood deformation during impact.

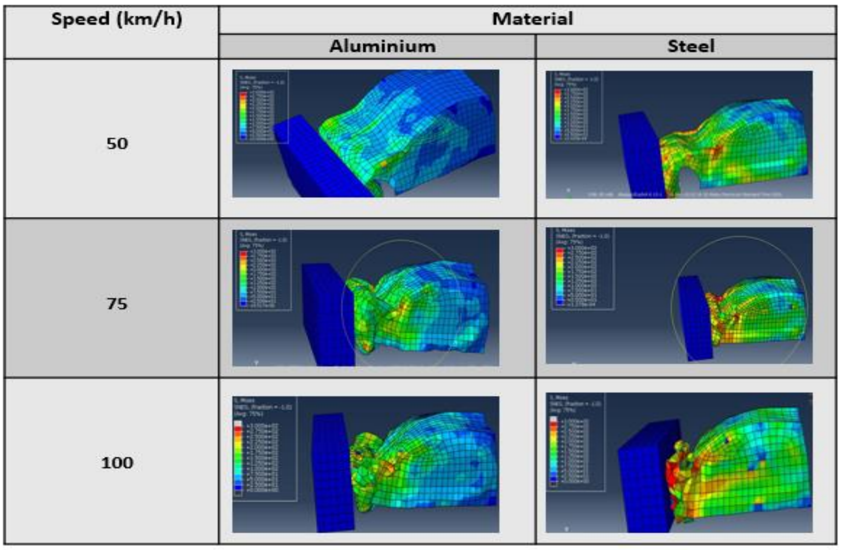


Figure 15: Deformation of the car hood

Table 7 shows the value of von mises stresses. The maximum von-mises stresses at the car hood were found to be (346,341), (338,328) and (337,324) MPa for 50, 75, and 100 km/h respectively. The maximum stress in steel hood was about 346 Mpa against the vehicle's speed at 100 km/h. The stresses in both the material increases with the increase in speed and structural steel have a high value of stress compared to that of aluminium. It is evident from theses analysis that the equivalent stresses in aluminium material are only 5-13 % of that of structural steel body and deformation is almost same. The hood material aluminium has good ability compared to steel material at various speed from the static analysis. According to a paper made by Wilhelm M [18], the choice of materials for a vehicle is the first and most important factor for automotive design related to both the quality and cost. Various materials can be used in the automotive body and chassis, but the design is the main challenge. The most important criteria that material should meet are lightweight, economic effectiveness, safety, recyclability and life cycle considerations. Lightweight materials can improve fuel efficiency more than other factors. Weight reduction can be obtained by replacing high-specific weight materials with lower density materials without reducing rigidity and durability. Some of material that is lighter than steel is aluminium, magnesium, composites and foams. Aluminium and magnesium alloys are more costly than the currently used steel and cast irons [19].

Table 7: Comparison of stresses for different material at various speed

Speed (km/h)	Aluminium	Steel
50	323.5 Mpa	337.0 Mpa
75	328.1 Mpa	338.8 Mpa
100	340.7 Mpa	346.4 Mpa

Table 8 and Figure 16 shows the data of energy absorption. The maximum value of the hood energy absorption is 5.31E+06 for aluminium material. The minimum energy absorption is 4.61E+06 for steel at high speed of 100km/h, which is aluminium is better in energy absorption for material used due to it has high young's modulus when compared to steel material and also impact force distribution is uniform in aluminium material. Based on the results obtained, the car hood aluminium contributor can absorb more energy in high and slow speed impact. From the analysis, the hood material aluminium is having good ability compared to steel material at various speed.

Table 8: Total energy absorption of the material

Speed (km/h)	Aluminium	Steel
50	3.24E+06	1.27E+06
75	4.29E+06	3.02E+06
100	5.31E+06	4.61E+06

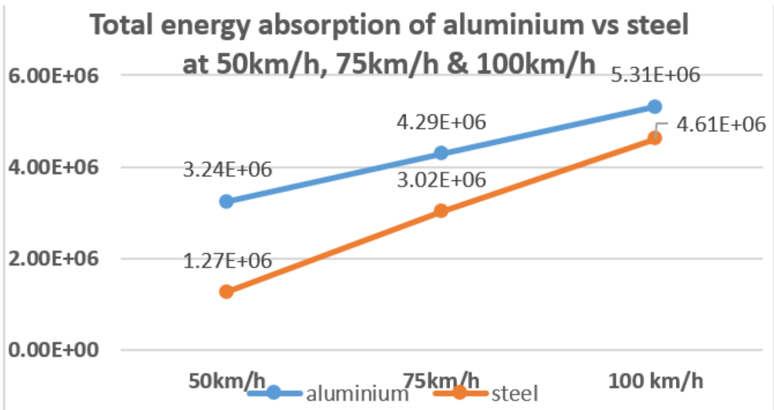


Figure 16: Total energy absorption of aluminium vs. steel at speed 50, 70 & 100 km/h

Figure 17 represent the strain energy of aluminium and steel at speed 100 km/h. Aluminium exhibits the minor deflection because the energy nearest turns to zero and the atom completely absorbs the kinetic and internal energy. The aluminium hood becomes early into zero value of internal energy than steel when the material point is unloaded completely. According to T. Kebir [20], the area under the stress-strain curve is the strain energy per unit volume absorbed by the material. Conversely, the area under the unloading curve is the energy released by the material. During unloading, the recoverable part of the strain energy is released until it becomes zero.

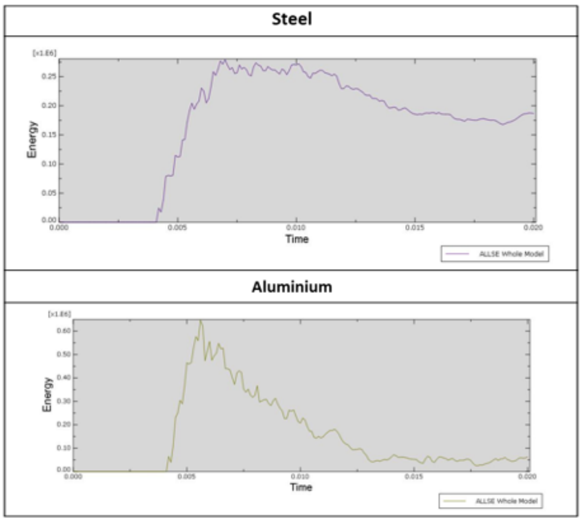


Figure 17: Graph of strain energy for steel vs aluminium at speed 100km/h (J sec^{-1})

Table 8 shows the amount of internal energy absorbed by aluminium and steel material. The amount of internal energy absorbed by aluminium is 6275, 9735 J and 30271 J and for steel is 2220 J, 4817 J, 15007 J at the speed of 50, 75, and 100 km/h respectively. According to H. Chi and B. Gong [21], most of the kinetic energy in the collision process is converted into the internal energy of the car, because the metal plastic deformation after the collision increases the internal energy a lot. It was found that internal energy increased with time. Among the two materials, steel material absorbs maximum internal energy of 30271 J followed by with steel 15007 J, as shown in Figure 18.

Table 8: Amount of internal energy absorbed by aluminium and steel

Speed (km/h)	Aluminium	Steel
50	6275 J	2220 J
75	9735 J	4817 J
100	30271 J	15007 J

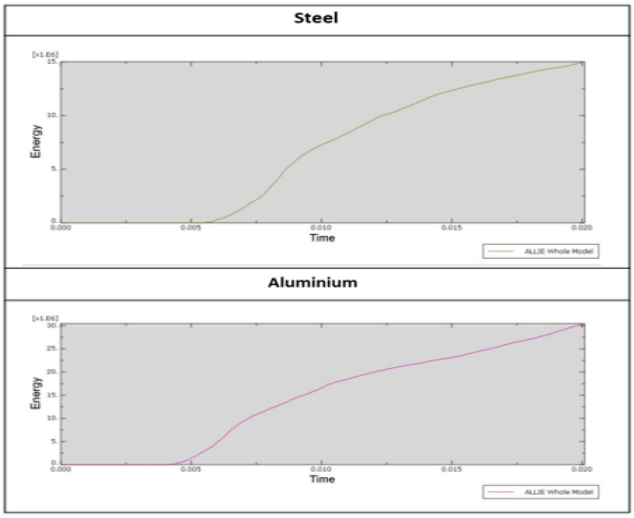


Figure 18: Internal energy aluminium vs steel at speed 100 km/h (J sec^{-1})

4. Conclusion

In conclusion, we can say that the hood material aluminium has good ability than steel material at various speeds because aluminium material absorbs a large amount of kinetic energy and internal energy. Its low density and high specific energy absorption performance and good specific strength are its most essential properties. Therefore, those material need to be re-engineered to achieve mechanical strength, but still aluminium offers weight reduction. The effective thickness of car hood is essential to optimize the protection. Besides, the strength of hood is necessary to minimize the contact of engine components of the vehicle during a collision.

Moreover, hood thickness and material become the main factors that influence equivalent stress and deformation value. Another reason for the larger deformation obtained in the simulation could be the less kinetic and internal energy during impact, as mentioned above. Since the simulation has less kinetic energy during the crash, it will also provide larger plastic deformations. Steel material deforms more and absorbs less energy when compared to aluminium. Steel is not an appropriate material in absorbing energy to reduce the impact of the collision. The densities of steel have the highest density compared to aluminium. The higher the mass density of a material will decrease the strength of the material.

The amount of energy absorption in different speeds and materials can affect a car hood's condition and the car's whole body. Hence, the material and the speed limit are essential to reducing the crash. Many research that have already been made to make the automotive world a better place in terms of methods uses and material selection just as to make sure that safety is the priority matter in designing vehicles for the people. This study concludes that Abaqus/Explicit has all the potentials to simulate the impact behaviours on a vehicle. The global stiffness of the test installation was not fully captured by the model used here. However, a full-scale crash can be simulated using Abaqus/Explicit provided a proper vehicle model and a detailed model of the test installation.

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References

[1] Rimy, M.M. & Abdul Aziz, Faieza. (2010). Simulation of Car Bumper Material using Finite Element Analysis. Journal of Software Engineering. 4. 257-264.

[2] Fuchs, E.R.H., F.R. Field, R. Roth and R.E. Kirchain, 2008. Strategic material selection in the automobile body: Economic opportunities for polymer composite design. Composites Sci. Technol., 68: 1989-2002.

[3] T. Teng, C. Liang, C. Hsu, C. Shih, and W. Hsu, "Assessment of a Car Hood of Aluminum Foams," vol. 127, pp. 142–144, 2018.

[4] Masoumi A, Shojaeefard MH, Najibi A. Comparison of steel, aluminum and composite bonnet in terms of pedestrian head impact. Saf Sci 2011;49: 1371–80.

[5] J. Marzbanrad, M. Alijanpour, and M. S. Kiasat, "Design and analysis of an automotive bumper beam in low-speed frontal crashes," Thin-Walled Struct., vol. 47, no. 8– 9, pp. 902–911, 2009.

[6] Untaroiu JS, Crandall JR. A design optimization approach of vehicle hood for pedestrian protection. Int J Crashworthiness 2007;12(6):581–9

[7] Fechová, Erika & Kmec, Jozef & Vagaská, Alena & Kozak, Dražan. (2016). Material Properties and Safety of Cars at Crash Tests. Procedia Engineering.

[8] Bisagni, C. et al. (2004). “Progressive Crushing of Fiber-reinforced Composite Structural Components of A Formula One Racing Car”, Composite Structures

[9] Dassault Syst`emes. Abaqus 6.14 Online Documentation: 1.1 The Abaqus prod- ucts. Dassault Syst`emes.

[10] Hanssen, A.G., Langseth, M. & Hopperstad, O.S. (2001). Optimum Design forEnergy Absorption of Square Aluminum Columns with Aluminum FoamFiller. International Journal of Mechanical Sciences 43, pp. 153-76

[11] Marzbanrad, J. Alijanpour, M., and Kiasat, M.S., 2009, "Design and Analysis of an Automotive Bumper Beam in Low-Speed Frontal Crashes" Thin-Walled Structures. 47(8–9):902–911.

[12] "Materials – Microstructure and properties 4 Microstructure and properties," Alum. Automot. Man., pp. 1–29.

[13] E. A. Association, "Applications car body crash management systems," Eur. Alum. Assoc., pp. 1–26, 2013.

[14] V. Dayal, A. Sharma, and M. A. Murtaza, "Crash Simulation of a Car Body," vol. 19, pp. 8521–8527, 2018.

[15] ABAQUS (2010) Analysis User's Manual. Version 6.10, Dassault Systemes Simulia, Inc.

[16] Abaqus/Explicit Adbanced techniques, "Numerical Modeling of Materials," *iMechanica*, 2005.

[17] Shojaeefard, M. H., A. Najibi and M. R. Ahmadabadi (2014). Pedestrian safety investigation of the new inner structure of the hood to mitigare the impact injury of the head" Thin- walled Structures77: 77-85.

[18] Wilhelm M. Materials used in automobile manufacture-Current state and perspectives. Le Journal de Physique IV, 1993, 3(C7):31-40

[19] Sun H, Hu P, Ma N, Shen G, Liu B, Zhou D. Application of hot forming high strength steel parts on car body in side impact. Chinese Journal of Mechanical Engineering, 2010(2):1-6

[20] T. Kebir, Z. El Abidine Harchouche, A. Elmeiche, and M. Benguediab, "Dissipated strain energy of aluminum alloy 6061-T6 induced by low cycle fatigue," *Ann. Chim. Sci. des Mater.*, vol. 43, no. 5, pp. 329–334, 2019.

[21] H. Chi and B. Gong, "Analysis of energy conversion law in vehicle collision accident," *J. Phys. Conf. Ser.*, vol. 1486, no. 7, 2020.