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Design Optimization of Car Front Hood for Pedestrian Safety

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Abstract: ***Nowadays many people deaths in the world were reported from vehicle traffic accidents that involved with pedestrian impact in higher percentage. This percentage may increase if there is no strong attention to the pedestrian safety from automakers and authorities. This study will focus on the analysis of pedestrian head impact on a car hood with different types of materials; also the hood thickness will be analysed with different measurements during the head test impact using the numerical simulation analysis which is available in ANSYS finite element software. The pedestrian head and front hood will be modelled using CAD software. Therefore the simulation will demonstrate the effects on the impact performance for each type of materials with different thickness used in this research. The observation from the numerical analysis showed that aluminium had high deformation as compared to steel and magnesium materials of hood. The steel had lowest deformation but it had higher equivalent stress when compared to aluminium and magnesium. Furthermore the lowest type of thickness produced high deformation and high equivalent stress value for each material type. In general each material had its own characteristic; therefore manufacturers can evaluate the lower material cost or design a safe front hood using the same material but with different thickness that suitable for pedestrian safety.***

Keywords: ***Pedestrian safety; impact simulation; car hood deformation; Equivalent Stress; Energy Absorption.***

I. INTRODUCTION

Recently many traffic accidents involves with pedestrian. In big cities, usually the accident occurred during the pedestrian crossing the streets or roads. According to the report from World Health Organization (WHO), more than 270000 pedestrians lost their live on the world's road. This value was about 22% from the 1.24 millions road traffic deaths. WHO indicated that in developed countries, older pedestrians are more at risk to contribute this percentage. But in middle-income and low-income countries, children and young adults are often affected. The proportion of pedestrians killed in relation to other road users was highest in the African Region (38%) and lowest in the South-East Asia Region (12%). In some countries, the proportion of pedestrian fatalities could reach nearly two thirds of road traffic deaths, such as in El Salvador (62%) and Liberia (66%) [1]. Moreover, WHO reported in 2017 about 1.25 million people die each year as a result of road traffic crashes. They also said road traffic injuries were the leading cause of death among people aged between 15 and 29 years. In low and middle-income countries, the world's fatalities on the roads were 90% even though these countries have approximately 54% of the world's vehicles. They showed nearly half of those dying on the world's roads are "vulnerable road users" such as pedestrians, cyclists, and motorcyclists. Without sustained action, road traffic crashes were predicted to become the seventh leading cause of death by 2030 [1].

Most active area affected during pedestrian collision were, bumper, front hood, windscreen and A-pillars. The vast majority of automotive maker cannot change their car's design by adding another safety structure in short times, therefore they conduct researches to find other solutions for the safety of pedestrians. This research focuses on how to reduce the impact on the pedestrians which reduces the head injury criteria (HIC), and increase the scoring during pedestrian test in Euro NCAP or Asian NCAP testing. According to standard legal has been reported, for Europe Phase 1 as well as for Japan, the limit for HPC is separated into two different areas which were bonnet top zone A HPC or (HIC) <1000 and bonnet top zone B is HPC < 2000. This HIC value was calculated on the basis of the resultant acceleration of the head's center of gravity during head impacts [2]. Hall [3] had stated that bonnet or front hood was the outer structure at the vehicle. This front hood was the hinged cover over the engine of cars that allowed access to the engine compartment (or trunk on rear-engine and some mid-engine vehicles) for maintenance and repair. The vehicle front hood has outer panel between front end and wind shield of vehicle, and inner panel disposed and secured along the entire region of a reverse surface of the outer panel. As a result it raised not only the front of the hood but its trailing edge by at least 0.8 inch.

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Moreover, the impact of characteristics in Euro NCAP tests in terms of mass and impact velocity were the same as in European Directive 2003/102/EC which two head forms considered such as a child head with a mass of 2.5 kg and an adult head with a mass of 4.8 kg. The impact angles of the head forms are set to 50° measured from the ground reference line for the child head and to 65° for the adult head. Both head forms should impact the bonnet with a velocity of 40 km/h. Two head finite element models (FEM) have been used for the head impact simulations, a standard pedestrian head model and an anatomical head FEM model.

The pedestrian head model was the standard model which consisted of three parts, i.e. an aluminum sphere, an aluminum plate and a rubber skin [4].

In another research, Bhaska et. al. [5] studied comparison of steel, aluminum and composite bonnet in terms of pedestrian head impact. The new finite element model was capable to simulate head impact phenomenon between head form impactors and composite bonnet. This study also focused on the behavior of three identical bonnets made of steel, aluminum and composite. The results demonstrated that the energy absorption of aluminum bonnet was less than steel and composite ones and for keeping the aluminum bonnet at the same level of stiffness, therefore it was necessary to increase the thickness, See Fig. 1.

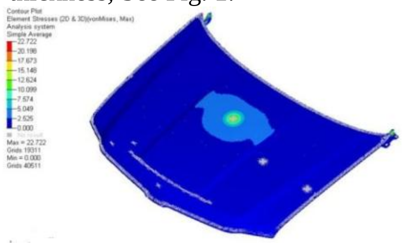


Fig. 1 Von-Mises stress distribution [5]

A similar study used the Hyper View post-processing software for a car hood analysis, in which the deformation could be seen at different time after 3D plot file importing. The front energy absorption (see Fig. 2) components of the car deformed sufficiently such as hood that was completely bent and tire contacted with fender, bumper and the front longitudinal beam were fully deformed. The above phenomenon could assure the energy absorption in the process of the collision. On both sides of the door and B-Pillars there were no obvious deformations which helped the crew to open the door to escape. The tank had no large deformation that could prevent the car from getting fire. The floor and the exhaust pipe were slightly bent down. The back of the car body has obviously risen [6].

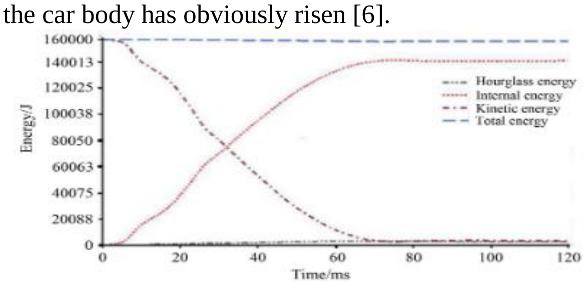


Fig.2 energy absorption during the crash [6]

Furthermore another research simulated the bonnet to head impact test by using LS-DYNA and Hyper-Mesh, see Fig. 3. The result was obtained which was approximately similar to the lab test results. This study showed that the interdependence of the HIC value, the bonnet reinforcement thickness, and the bonnet skin thickness were very complicated. The results focused on identifying the most useful values for the bonnet reinforcement thickness and the bonnet skin thicknesses to defend pedestrians while maximizing the bonnet stiffness. Beside that algorithm was used to identify numerous critical positions on the bonnet surface with respect to pedestrian safety. The algorithm used to optimize the thicknesses was solved by combining LS-DYNA to simulate and analyze the simulation results. The optimal bonnet was more pedestrian friendly but somewhat less stiff than the original bonnet [7].

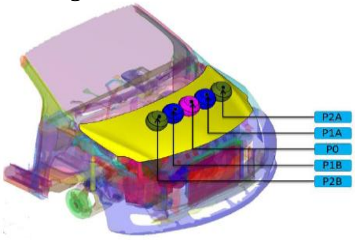


Fig. 3 head impact locations [7]

According to Arda et al. [8] who reported head impact test was experimented by using virtual analysis for an aluminum hood effects on pedestrian head damage during pedestrian impact test. Physical test had undergone when the pointed a few point at bonnet that had high HIC values in the simulation. Both HIC results of experiment and numerical analysis were compared that produced differences between at certain points about 9%, 18% and 1%. In this research, accepted data was obtained but needed development for optimum design. The methodology could be an effective method for the head impact evaluation and development for future studies. Furthermore using simulation could save cost and time of the analysis.

Other researchers such as Hatam et al. [9] conducted a study on modifying the inner plate using four different designs such as inner hood panel and outer plate by using elastic material and low carbon steel. The value was minimized to avoid the contact between the pedestrian head and top of the engine, which generated a sudden increase in the head acceleration that led to the increment in HIC value. The study observed that if the inner hood was completely covered the upper plate, that mad the hood stiffer and thus lack of deformation could occur in the hood and increased the head acceleration during the event of collision; see Fig. 4.

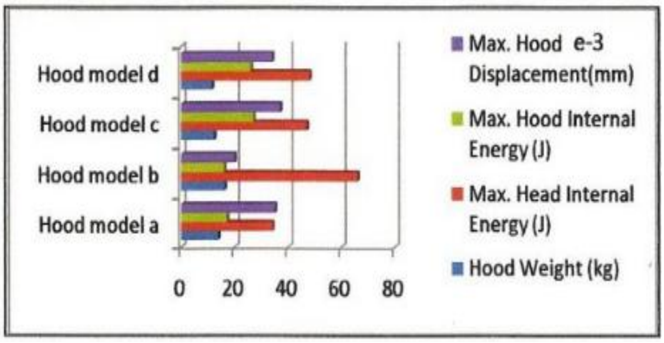


Fig. 4 results of head internal energy

On the other hand, pedestrian impact analysis was conducted with low speed impact. Different materials were used such as magnesium, aluminum. The study focused on comparing the differences between impact forces, the impactor inertia force in three states that were defined as common criterion. In impact force analysis, the magnesium bumper demonstrated the lowest value compared to other materials, this was due to lower rigidity of the magnesium. Hence, only the steel was nearer to fulfill the required condition example stress that was required to be less than the yield stress, however this condition was not satisfied by any material for ideal manufacturing process. The results concluded that with high strength material, maximum deformation was less and more energy was absorbed [10].

In recent study, the thickness of the outer panel in the upper front hood was found to be more important for the head protection due to the increasing of hood thickness that increased the value of HIC itself, see table 1. The thicker inner of hood and outer hood were less prone to deformation than thinner level, therefore they absorbed less impact energy and child pedestrian head absorbed more energy during collision experiments, which led to severe injury to child pedestrian head. Meanwhile, the materials of the inner and outer hood were not significant to head response but the thickness of the hood was significant to head response. As a result, the thinner of outer hood could helpfully decrease pedestrian head injuries during traffic accident [11].

Table 1 car front hood factors and levels for head collision

Factors	Levels	Parameters
Thickness of outer panel/ mm (A)	1	0.762
	2	1.524
Thickness of inner panel / mm (B)	1	0.674
	2	1.348
Material properties of outer panel (C)	1	Low-carbon steel
	2	Aluminum alloy
Material properties of outer panel (D)	1	Low-carbon steel
	2	Aluminum alloy

In this research, the amount of energy absorption of front hood vehicle will be studied using the difference of materials. Each material has its own limit of stiffness, strength and stress when impact applied. The thickness of the material also affects the value of the head injury criteria (HIC). The relation between the characteristic of materials is and thickness of materials applied on the front hood impact test will be defined. The research will be conducted by using the simulation software (Ansys) to establish the relation between materials and their thickness toward pedestrian protection.

II. METHIDOLOGY

The main purpose of the research is to investigate the amount of impact energy absorb by front hood with difference of materials and thickness. The model of sedan hood was chosen in the analysis. Ansys software of finite element analysis is used for the numerical analysis in this study. This simulation is a general purpose to simulate interactions of structural, vibration, physics, fluid dynamics, heat transfer and electromagnetic . It also attends to simulate tests or working conditions, test in virtual environment before manufacturing prototypes of products. Besides that, it can determine and improving weak points, computing life and foreseeing problems are possible by 3D simulations in virtual environment. The Ansys software is a one of the software that used for the numerical analysis and simulations involved structural, vibration, heat transfer and fluid dynamics. The methodology of this research as follow:

A. In this study explicit dynamics simulation is used due to non-linear response of solids, fluids and gases and their interactions. Also it can be used to determine the expected deformation and damage of the parts. The sedan front hood and the dummy head were modeled by using CAD Inventor software; see Fig. 1 and Fig. 2.

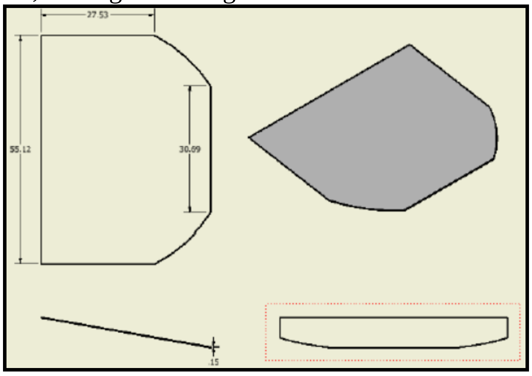


Fig. 1 the hood of sedan car

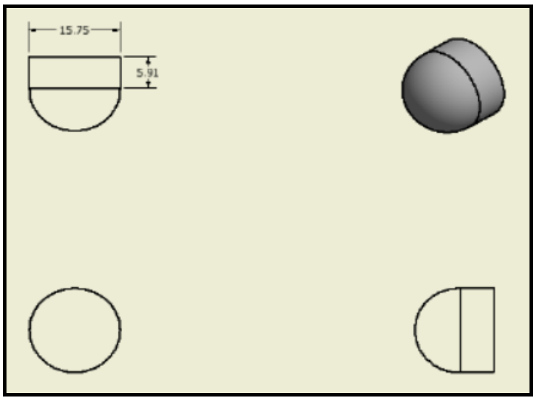


Fig.2 the head of pedestrian

B. This research will use simple dummies head models for measuring the pedestrian injuries, which categorized for adult with mass of 4.5kg.

C. Different materials will be used to conduct the analysis such as steel, aluminum and magnesium.

D. Two different thicknesses, 1mm and 3mm for each type of the materials, will be introduced for the front hood.

E. The speed of impact is 40km/h and the dummies head will crash into the hood at 65°.

F. The area of energy absorption at front hood will be evaluated; the data will be collected and compared between the different materials used for the front hood and their thickness.

In this research, only the front hood of a sedan car is considered for the analysis and that does not include any other parts of the car.

For the impact test, steel, aluminum and magnesium are the testing materials, which are used by automotive manufactures for the front hood. By varying the thickness of the hood material, energy absorption capability will differ which can influence the impact results.

III. RESULTS

The results include the graph and figure of the car hood numerical analysis for three different materials that are steel, aluminum and magnesium with two thicknesses of 1mm and 3mm. The adult dummy head impacts into the middle the hood. The final results will be represented by material deformation, stress and energy graph.

A. Material Deformation

The observation from Table 1 shows that the steel hood deforms at 0.32288mm for 1 mm of thickness. But for 3 mm thickness the deformation is 0.35267 mm. The front hood made from aluminum at the middle of the point of impact in red color it deform at 2.7559 mm but the area surrounding it in orange color which at 0.62766 mm, and this is for 1 mm thickness. However for 3 mm thickness the deformation is 0.30893 mm. For the type of magnesium at 1mm, the maximum value of deformation is 1.6953mm which overall the front hood is deform at maximum stage. On the other hand 0.57886mm of deformation produced from 3 mm, and the minimum value is -18.06 mm of deformation.

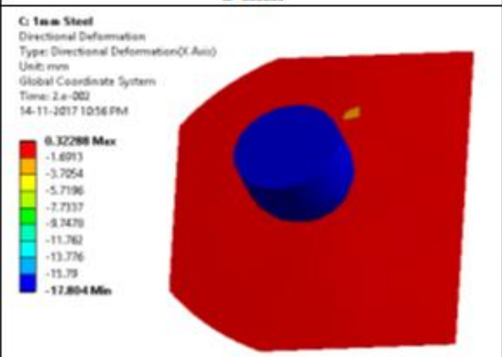
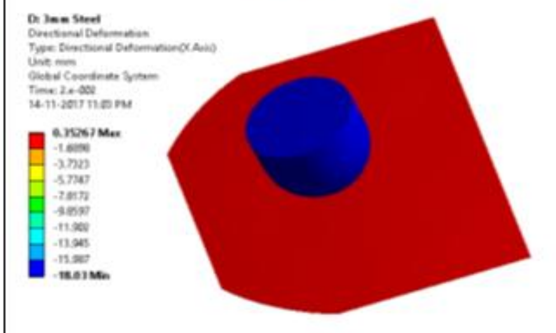
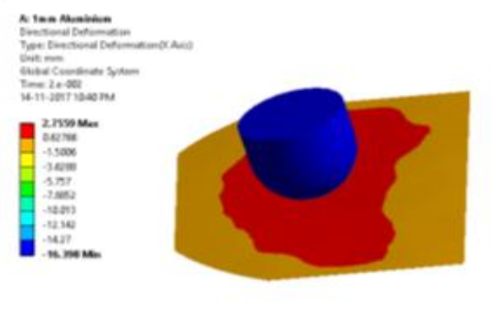
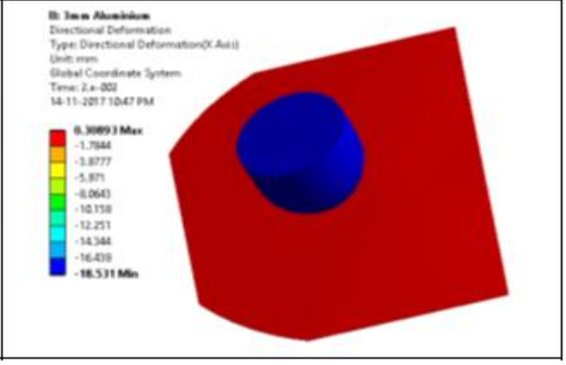
B. Equivalent Stress

In Table 2 the stress of steel material for 1 mm the maximum stress is 270.9MPa. But for 3 mm thickness of steel the indicator shows 220.73MPa of maximum stress. In aluminum front hood case at 1 mm thickness, there is stress in interval of 25.15MPa to 50.255MPa according to the colors dissipate in this stress test. For 3 mm thickness the stress is distributed entire the front hood during this test, and stress occurred at 37.433MPa to 49.892MPa. For magnesium material, the stress tends to occurred in range 23.882MPa to 41.786Mpa and few places plot at 47.754MPa when the hood thickness is 1 mm. 34.217MPa to 47.889MPa of stress range for magnesium hood of 3 mm thickness, and the maximum stress plots 61.562MPa.

C. Energy Summary

In this study, many types of energy are available and only internal energy is taken into consideration which produced inside the material itself that can hold the force exerted on it. According to the graph of energy summary in Table 3, the internal energy increases untill 1.6218x10^5 mJ and decreases back to 87654mJ for 1 mm thickness of steel hood. In case of 3 mm thickness, the internal energy fluctuates between 1.5345x10^5 mJ and 75608mJ. However for 1mm thickness of aluminum front hood during impact, the internal energy at peak point was 2.5010x10^5 mJ and it decrease until at 29128mJ, and it produces peak value of 2.0731x10^5 mJ and decreases until 46345mJ for 3 mm aluminum hood. In the last type of material it shows graph of internal energy in bell shape, the internal energy graph reaches 2.4521x10^5 mJ and minimum value of -223.87 mJ for magnesium 1 mm hood. Finally for 3 mm thickness of magnesium hood the internal energy inclines almost 2.3323x10^5 mJ and decreases back until 27326 mJ.

Table 1 the deformation of the hood for different materials and thicknesses

Material Type	Thickness	
	1 mm	3 mm
Steel		
Aluminum		

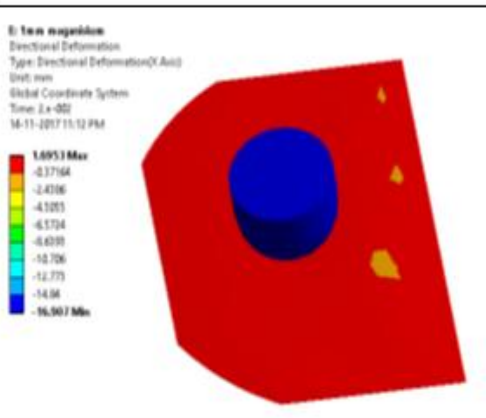
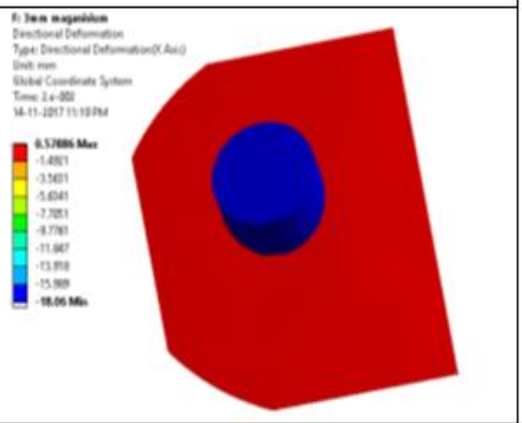
Magnesium		

Table 2 the equivalent stress of the hood for different materials and thicknesses

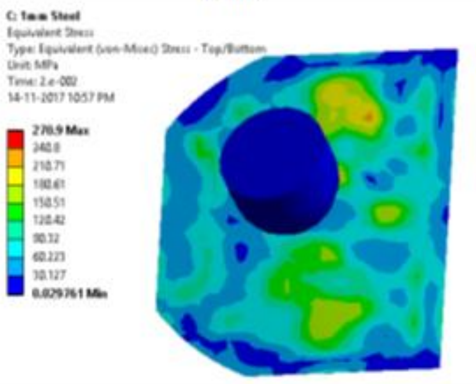
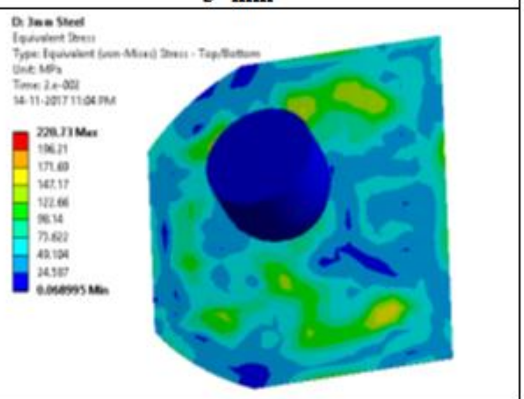
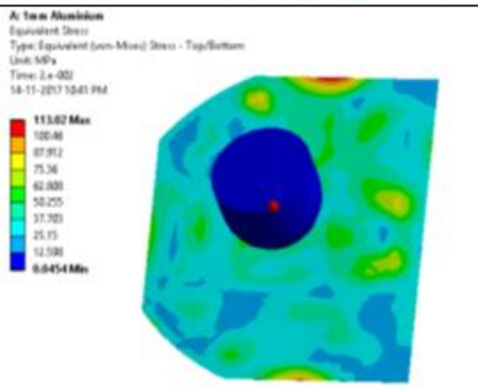
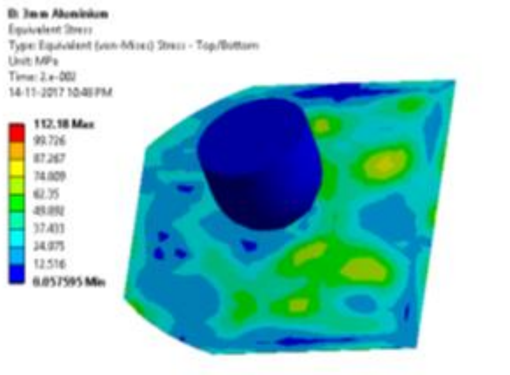
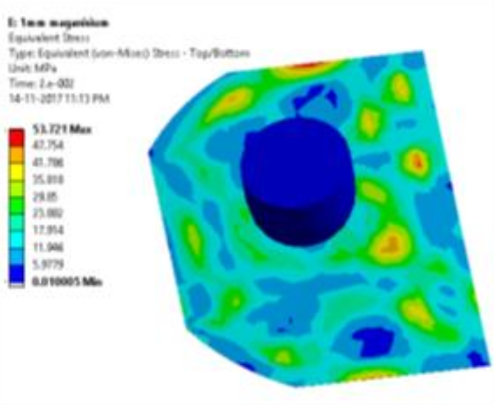
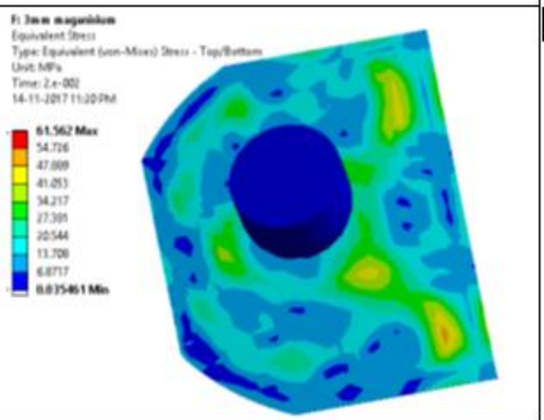
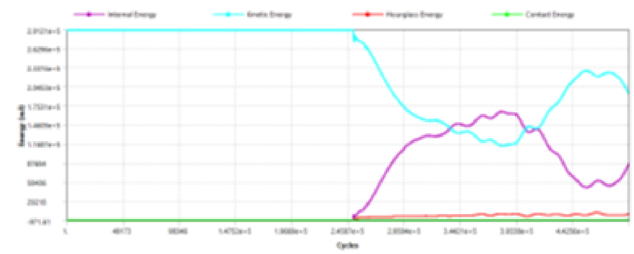
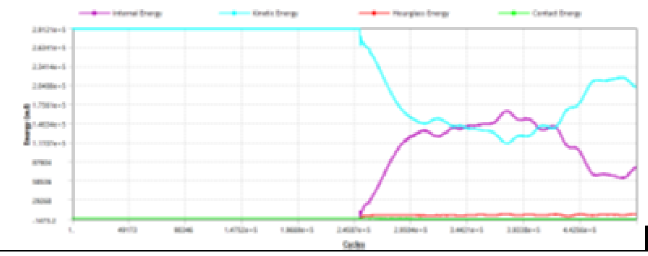
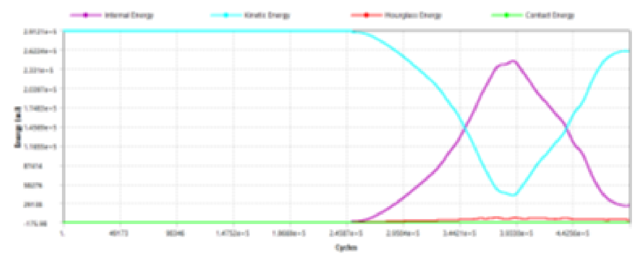
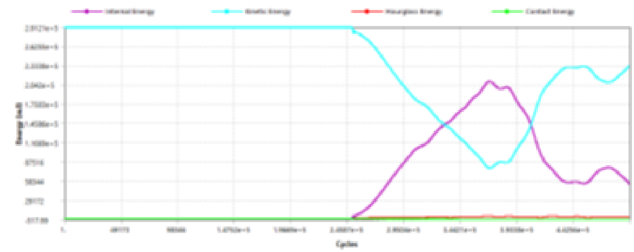
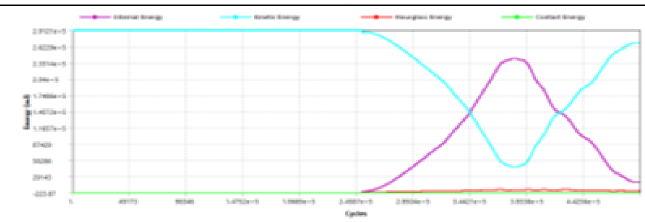
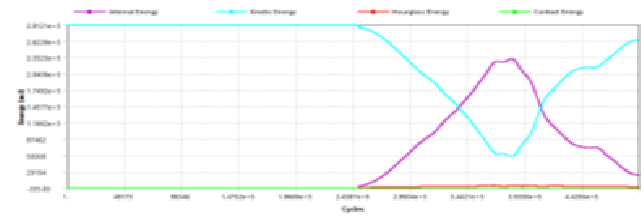
Material Type	Thickness	
	1 mm	3 mm
Steel		
Aluminum		
Magnesium		

Table 3 Impact Energy of the hood for different materials and thicknesses

Material Type	Thickness	Energy
Steel	1 mm	
	3mm	
Aluminum	1 mm	
	3 mm	
Magnesium	1 mm	
	3 mm	

VI. DISCUSSION

This study focuses on the analysis of sedan car hood during pedestrian impact, and the results will be presented by material deformation, equivalent stress and energy absorption capability produced from each type of materials used such as steel, aluminum and magnesium with two thicknesses of 1 mm and 3 mm. Therefore each result will be discussed in the following sections.

A- Total Deformation

The observation from Table 4 for 1 mm thickness of aluminum hood the maximum total deformation occurred at 156.23 mm on 1.6x10^-2 second. But for 3 mm thickness the maximum total deformation occurred at 140.61 mm on 1.5x10^-2 second. It shows when aluminum at 1 mm, the time taken for deformation occurred slower than 3 mm thickness; therefore the 1 mm also can deform more compare to 3 mm thickness of aluminum hood.

In the case of steel hood, it stresses out that the total deformation on 1 mm thickness front occurred at 1.4x10-^2 second compare to 3 mm thickness which occurred faster at 1.3x10^-2 seconds. 3 mm thickness of steel front hood shows maximum total deformation 129.64 mm less than 1 mm thickness that deforms up to 133.74 mm. Therefore decrease the thickness to achieve more total deformation for steel hood.

On the other hand the magnesium hood result for total deformation shows better total deformation at 1 mm which reached 152.39 mm as compared to 3 mm of magnesium that only deformed to 146.14 mm. However, at 1 mm thickness the time taken for it deform takes more was 1.6x10^-2 second compare to 3 mm thickness at 1.5x10^-2 second. Thus by decreasing the thickness of magnesium more total deformation can be achieved. Overall, this is influenced by the properties of material itself such as deformation plasticity properties for each one of them.

Based on Fig. 3 the results show 1mm of aluminum hood produces the highest value of total deformation of 0.15623 m at 1.60x10 -^02 seconds. The lowest value of total deformation at 2.00x10-^02 seconds was achieved by 3mm steel hood that deformed to 0.12112 m. Overall, the highest total deformation points was 1mm of aluminum and the minimum total deformation points by 3mm steel hood. 1 mm aluminum 1mm produced the maximum total deformation but when thickness increased, the deformation performance dropped. Moreover the magnesium hood is the second highest for total deformation, however the deformation was lessen by increasing the thickness. Furthermore the steel had the lowest value for total deformation.

B- Equivalent Stress

Table 5 presents the equivalent stress for 1mm of aluminum, 1mm of steel, 1mm of magnesium, 3mm of aluminum, 3mm of steel and 3mm of magnesium respectively. The equivalent stress is also convenient to define an Equivalent tensile stress or von Mises stress, which is used to predict yielding of materials under multiaxial loading conditions using results from simple uniaxial tensile tests. The von Mises yield criterion (also known as the Maximum Distortion Energy Theory of Failure) suggests that yielding of a ductile material begins when the second deviatoric stress invariant reaches a critical value. It is part of plasticity theory that applies best to ductile materials, such as some metals. Using this information an engineer can say his design will fail, if the maximum value of Von Mises stress induced in the material is more than strength of the material. It works well for most cases, especially when the material is ductile in nature. The high value of equivalent stress is 5.87x10^8 Pa for 1mm steel hood at 1.20x10^-2 second. However at 2.00x10^-2 second, the lowest value of stress is 5.37x10^7 Pa which was produced by 1mm magnesium hood. Therefore the steel at 1mm and 3mm had high ductility whereas 3mm magnesium had the lowest ductility among them. As a result for 1 mm aluminium is third highest for ductility, but it dropped when increased the thickness to 3mm, see Fig. 4.

C- Energy Summary

Referring to Table 3 this energy summary is the few of combination energy graphs in one graph and only internal energy is considered in this study. The internal energy is energy inside the material itself. For 1mm aluminum the highest point for internal energy is 2.5010x10^5 mJ while for 3mm thickness it occurs at 2.0731x10^5 mJ, so the lower thickness can increase the internal energy. Therefore at peak point, the graph for 3mm has little fluctuated value, but for 1mm thickness of aluminum is smooth graph.

The energy summary of steel hood increases up to 1.6218x10^5 mJ and decreases back to 87654 mJ for 1mm thickness. But for 3 mm the internal energy increases until 1.5345x105 mJ and decreases fluctuation to 75608 mJ. Thus, less thickness can increase the internal energy during the pedestrian impact.

On the other hand for 1 mm magnesium hood, the graph is bell shaped on maximum value of 2.4521x10^5 mJ and minimum value of -223.87 mJ. however the internal energy graph inclines 2.3323x10^5 mJ and decreases back until 27326 mJ for 3mm thickness of magnesium hood. Hence, less thickness of magnesium also can increase the internal energy of the impact.

Table 4 the total deformation

Time [s]	1mm Aluminium [m]	3mm Aluminium [m]	1mm Steel [m]	3mm Steel [m]	1mm Magnesium [m]	3mm Magnesium [m]
1.18E-38	0	0	0	0	0	0
1.00E-03	1.11E-02	1.11E-02	1.11E-02	1.11E-02	1.11E-02	1.11E-02
2.00E-03	2.22E-02	2.22E-02	2.22E-02	2.22E-02	2.22E-02	2.22E-02
3.00E-03	3.34E-02	3.34E-02	3.34E-02	3.34E-02	3.34E-02	3.34E-02
4.00E-03	4.45E-02	4.45E-02	4.45E-02	4.45E-02	4.45E-02	4.45E-02
5.00E-03	5.56E-02	5.56E-02	5.56E-02	5.56E-02	5.56E-02	5.56E-02
6.00E-03	6.67E-02	6.67E-02	6.67E-02	6.67E-02	6.67E-02	6.67E-02
7.00E-03	7.78E-02	7.78E-02	7.78E-02	7.78E-02	7.78E-02	7.78E-02
8.00E-03	8.90E-02	8.90E-02	8.90E-02	8.90E-02	8.90E-02	8.90E-02
9.00E-03	0.10008	0.10008	0.10008	0.10008	0.10008	0.10008

1.00E-02	0.1112	0.1112	0.1112	0.1112	0.1112	0.1112
1.10E-02	0.12218	0.12184	0.12154	0.12109	0.12213	0.122
1.20E-02	0.13244	0.1306	0.12895	0.1273	0.13215	0.13151
1.30E-02	0.14137	0.13648	0.13265	0.12957	0.14052	0.1388
1.40E-02	0.14858	0.13962	0.13374	0.12964	0.14688	0.14364
1.50E-02	0.15375	0.14061	0.1333	0.1287	0.15102	0.14614
1.60E-02	0.15623	0.13958	0.13205	0.12759	0.15239	0.14602
1.70E-02	0.15548	0.13678	0.13017	0.12616	0.15067	0.14332
1.80E-02	0.15158	0.13262	0.12769	0.12454	0.14617	0.1385
1.90E-02	0.1454	0.12753	0.125	0.12286	0.13981	0.13227
2.00E-02	0.13825	0.12171	0.12203	0.12112	0.13269	0.12543

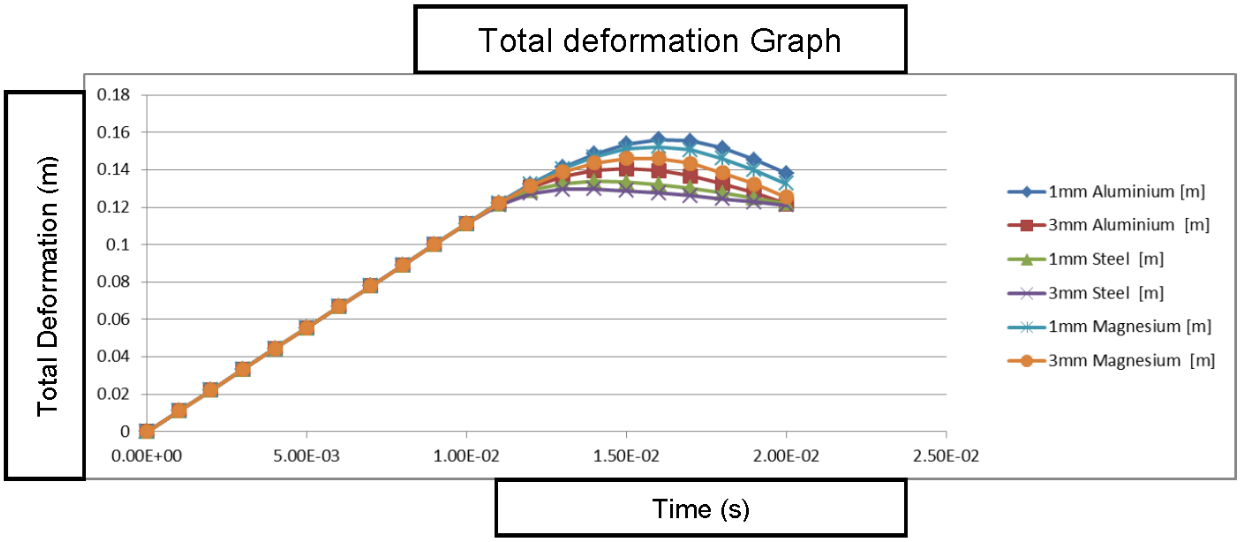


Fig. 3 total deformation of the materials with different thicknesses.

Table 5 the equivalent stress.

Time (s)	1mm Aluminium (Pa)	3mm Aluminium (Pa)	1mm Steel (Pa)	3mm steel (Pa)	1mm Magnesium (Pa)	3mm Magnesium (Pa)
1.18E-38	0	0	0	0	0	0
1.00E-03	0	0	0	0	0	0
2.00E-03	0	0	0	0	0	0
3.00E-03	0	0	0	0	0	0
4.00E-03	0	0	0	0	0	0
5.00E-03	0	0	0	0	0	0
6.00E-03	0	0	0	0	0	0
7.00E-03	0	0	0	0	0	0
8.00E-03	0	0	0	0	0	0
9.00E-03	0	0	0	0	0	0
1.00E-02	0	0	0	0	0	0
1.10E-02	1.82E+08	2.26E+08	5.18E+08	5.23E+08	1.39E+08	1.51E+08
1.20E-02	2.62E+08	2.95E+08	5.87E+08	5.42E+08	1.99E+08	2.12E+08
1.30E-02	3.12E+08	2.80E+08	4.68E+08	3.62E+08	2.25E+08	2.20E+08
1.40E-02	3.47E+08	2.44E+08	4.66E+08	4.16E+08	2.35E+08	2.13E+08
1.50E-02	4.14E+08	2.42E+08	4.32E+08	3.65E+08	2.72E+08	2.40E+08
1.60E-02	4.67E+08	2.12E+08	3.88E+08	3.29E+08	2.83E+08	2.31E+08
1.70E-02	4.58E+08	1.94E+08	3.46E+08	3.36E+08	2.71E+08	2.04E+08
1.80E-02	3.76E+08	1.61E+08	2.23E+08	2.38E+08	2.23E+08	1.70E+08
1.90E-02	2.27E+08	1.56E+08	2.12E+08	1.90E+08	1.32E+08	1.07E+08
2.00E-02	1.13E+08	1.12E+08	2.71E+08	2.21E+08	5.37E+07	6.16E+07

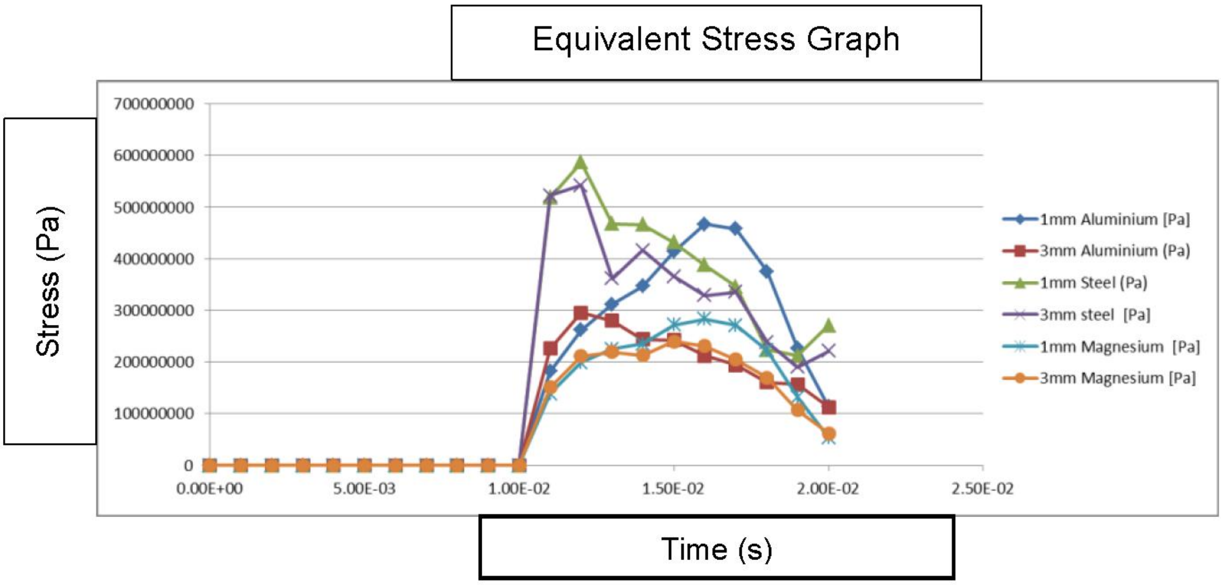


Fig. 4 equivalent stress for 3 materials with different thickness.

V. CONCLUSION

Based on the data result produced by the Ansys software, the observation shows that by using different thicknesses of same material can affect their deformation values, internal energy, and stress values. Aluminum had total deformation much similar with magnesium and steel had the lowest total deformation among the materials.

As conclusion, each material has its own characteristics. therefore for manufacturers in order to reduce the cost of production and they will evaluate the materials that are cheaper or they can build or design a safety front hood by using the same material but with different design which includes different thicknesses suitable for pedestrian safety. Furthermore future recommendations that can help the automotive industry for choosing a suitable material for front hood that comply with pedestrian safety. It is observed that each material has its own properties and ability that can cope with the demand of manufacturers especially in automotive field. Based on this study for pedestrian safety, the deformation of front hood must increases especially in crumple zone of the engine bay section, therefore it is suggested to use aluminum or magnesium because of their deformation performance during the event of crash.

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