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Head Impact Analysis Validation of Composites Bonnet Using Finite Element Modeling

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ABSTRACT

The significant number of pedestrian injuries in the world and fatal deaths are resulting from road accidents and an event of a collision between the people and car, that due to the increased urban population and number of private vehicles. This paper deals with the development of a new finite element model to simulate the collision between the adult headform impactor and vehicle hood composite structure according to the EURO-NCAP requirements. The pedestrian head impacted by three points over the outer structure of the hood with three different inclination angles. The effects of the inclination angles (6°, 8° and 10°) and impact points (A, B and C) over the surface of the composite hood structure to HIC value, displacement and absorbed energy have been investigated, and the results have been compared with each other.

Introduction

In vehicle to pedestrian collisions, the main reason for fatal injuries is the pedestrian to vehicle impacts, which, significant accidents are caused by the direct impact of the pedestrian head to the front part of automotive hood during an event of a collision. [1-4]. To avoid and to reduce this number of the pedestrian injuries and fatal deaths with other safety measurements, we must care about the design and material of vehicle hood because that will be a critical point for an automotive industry [5-8]. Principally the test concerning the level of protection for the head consists of firing a child headform into the front part and an adult head into the rear part of the bonnet top (including the wing tops). According to EURO-NCAP, for both the child and the adult, the head protection criteria are for the Head Injury Criterion (HIC) should be between 650- 2000, this value is depending on test procedures [9]. The impact of a pedestrian with the front of the car (bumper, bonnet leading edge) affects the head trajectory so that the impact is angled and the velocity is likely to be different to the car's forward impact velocity [10]. The relationship between the vehicle speed and the impact angle and speed of the head depends on the height and position of the pedestrian plus the shape of the car. Numerous studies have established the effectiveness of remodelling the hood structure to realize a more uniform stiffness profile and improved energy-absorbing efficiency [11]. Presently, to accomplish satisfactory structural performance, the vehicle design is developed to accommodate road accident regulations and extract the safety certificate that means the vehicle hood should be subject to a real test of the pedestrian impact test. To keep and save the lives of numerous people on the road the design of car casings ought to have a high quality which can assimilate energy during an impact [12-16]. The effect of steel, Aluminum and composite material (E-Glass/epoxy composite and carbon fiber/epoxy composite) on the pedestrian head injury criteria of the hood system were analyzed and compared by Nursherida et al. [17]. Liu et al. [18], studied friction effects in pedestrian headform impacts with vehicle hood and inclination angles from 3° to 18° and the simulation results showed the acceleration peak, and HIC values increase with the increasing hood inclination angles. Takahashi et al. [19], recommended the adoption of CFRTP for the body parts of automobiles as an alternative to steel, mainly focused on the composite hood structure to reduce the pedestrian injury at the event of the collision. The differences aspects of my previous work [20] to current paper the methods that carried out were same, and only the differences including types of the composite structure, type of the carbon fiber structure and mechanical properties of the composites were different, so the results of the whole model were different.

This study aims to predict the pedestrian head impact into an engine hood structure with numerical simulations. Adult headform impactor and vehicle hood structures have been created using ABAQUS/Explicit software to predict the pedestrian risk level during a vehicle collision. The effects of the inclination angles and head impact points on HIC values, displacement and absorbed energy were investigated.

Head injury criteria (HIC)

The equation that used for the measurements of the head injury of the whole model for the pedestrian head impact was head injury criteria (HIC). It has been used to predict the risk of engine hood to a pedestrian during the collision [21]. DIAdem program software was used in this study for the HIC value measurement [21, 22]. HIC is calculated according to the below Equation:

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$$HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2 - t_1)$$

Where (a): the resultant acceleration (as a multiple of 10 ms^{-2} or about 1 g).

t_1, t_2: two-time instants (in seconds), which define the start and end of the recording when HIC is at maximum. Values of HIC at the time interval t_1-t_2 is greater than 15 ms are ignored to calculate the maximum value.

Adult headform impactor

The dimensions, shape and mass of the adult headform impactor were used as same with my previous paper in [20].

Finite element modeling

Adult headform model and automotive hood model have been created by ABAQUS/Explicit. As simulation for a real test of the pedestrian safety these models were used to predict the HIC values, displacement and absorbed energy for the pedestrian head impact on the three points (A, B and C) on the engine hood composite structure with different three inclination angles.

Modelling of the adult headform impactor and automotive hood

According to the Euro-NCAP protocol, the finite element model of adult headform was created, which is the same model used in [20, 23]. The test requirements of the EURO-NCAP for adult headform are presented in Figure 1.

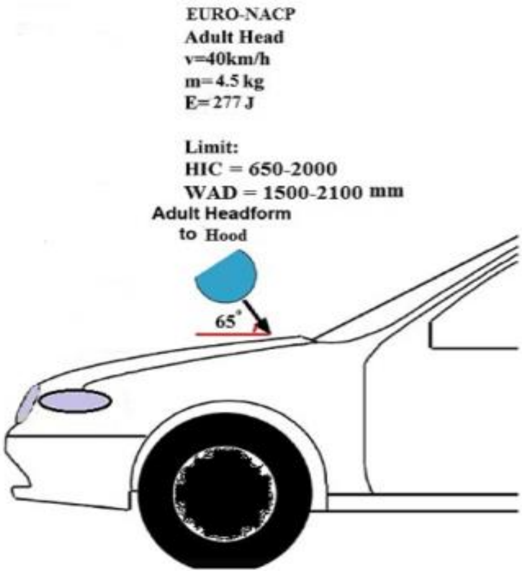

Figure1. A schematic of the EURO-NCAP adult headform subsystem test

Table 1. The specifications of the stacking sequences have been used.

Stacking sequence	Lay-up	Total plies number	Total laminate thickness (mm)
1	$[[0, 90, 45, -45]_2, [0, 90]_5]$	18	2.00

Table 2. Properties of the lamina.

Property	Value	Property	Value
Longitudinal stiffness, E_1 (GPa)	109	Shear modulus, G_{23} (GPa)	4.2
Transverse stiffness, E_2 (GPa)	8.33	Longitudinal tensile strength (MPa)	1070
Out-of-plane stiffness, E_3 (GPa)	8.33	Longitudinal compression strength (MPa)	1070
Poisson's ratio, υ_{12}	0.03	Transverse Tensile strength (MPa)	64
Poisson's ratio, υ_{13}	0.03	Transverse compression strength (MPa)	220
Poisson's ratio, υ_{23}	0.35	Longitudinal shear strength (MPa)	110
Shear modulus, G_{12} (GPa)	3.3	Transverseshear strength (MPa)	64
Shear modulus, G_{13} (GPa)	3.3	A	0
Density, ρ (kg/m^3)	1600		

For the automotive hood modelling used in the current study was the same as in [20]. The stacking sequence was used for the automotive hood model as shown in Table 1. The mechanical properties used in the numerical simulation of the composite automotive hood model are presented in Table 2.

Pedestrian headform impact test points

Three points of the pedestrian adult headform impact were selected irregularly over the surface of the hood structure as shown in Figure 2. 9 tests in total were done on headform impact tests which were performed on the engine hood simulation processes. The position of the head impact points was between the warp around distance (WAD) on the center line (1500-2200 mm).

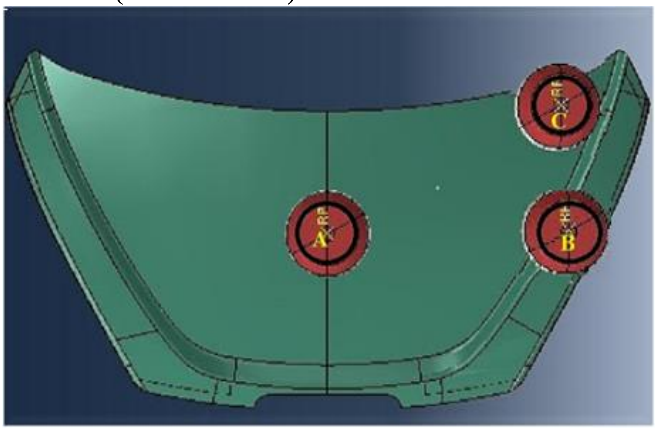

Figure 2. Pedestrian headform impact points.

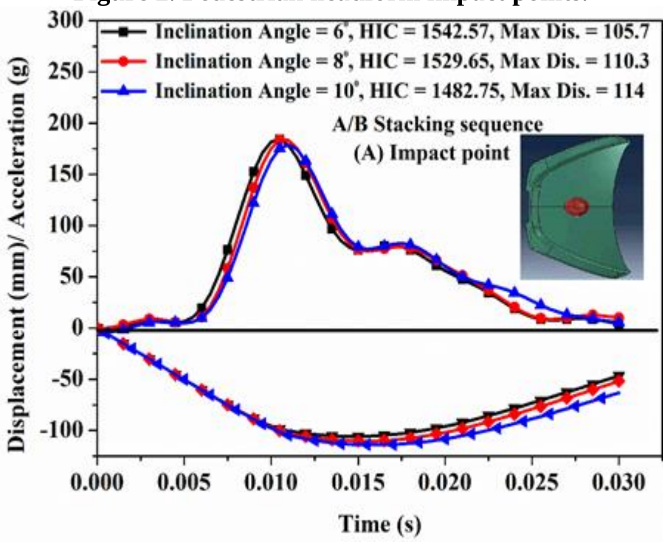

Figure 3. HIC and displacement values on (A) impact point for the hood structure.

Results and Discussions

Hood composite structure

Impact point (A)

From Figure 3, the behaviour of acceleration-time and displacement-time shows similarity in curve mode. The hood structure at 6° inclination angle shows higher acceleration peak and HIC, which demonstrate the intensity of the impact and an increase in peak values leads to higher HIC values. At 10°, lower HIC value and higher displacement were observed due to greater head impact duration when it strikes the engine hood. Figure 4 illustrates to the distributions of the stress on (A) at t_1 and t_2 and maximum stress and displacement at 6°, 8°

and 10. The head impact duration affected the HIC values in that when the time duration was small or large. Lower impact duration was observed at 8° equal 0.0075 s than other angles at 6°, 10° just 0.0115s.

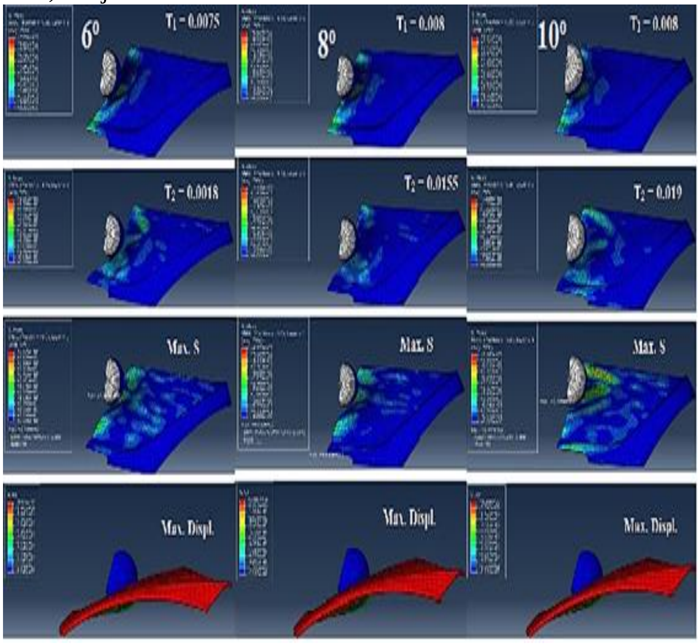

Figure 4. Stress distributions on (A) impact point at t_1 and t_2 and maximum stress and displacement at 6°, 8° and 10°.

Impact point (B)

From Figure 5, all the HIC values were observed to be over 2000 because this point was located on the engine hood hedge. Accordingly, it's a hard point and stiffer area which leads to higher values of HIC values than the suggested values belonging to EURO-NCAP regulation.

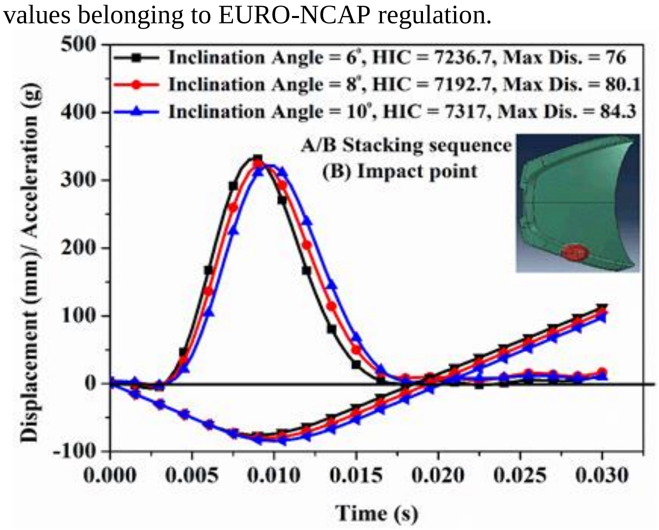

Figure 5. HIC and displacement values on (B) impact point for the hood structure.

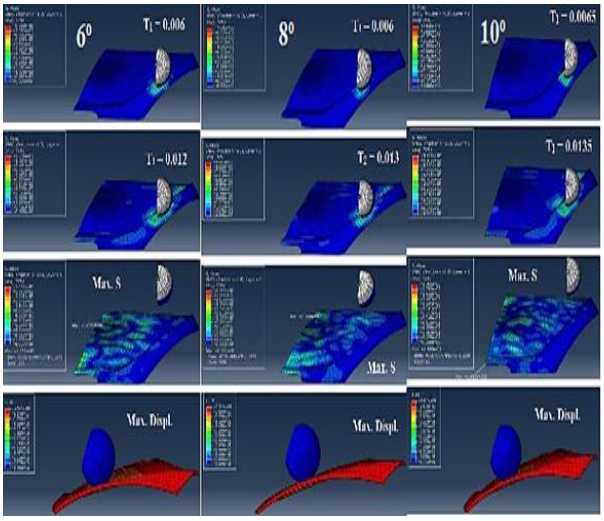

Figure 6. Stress distributions on (B) impact point at t_1 and t_2 and maximum stress and displacement at 6°, 8° and 10°.

The acceleration peak and values were observed to be decreasing with the inclination angle increases, but, the displacement values were shown to increase with the increasing inclination angles. Stress distributions with different engine hood inclination angles are shown in Figure 6. Energy absorbing at this point was observed to be smaller than the impact point at (A), which explains the bending stiffness of the engine structure which does not depend on the engine hood design. The energy absorbing was lower at this point, leading to higher HIC and lower displacement values.

Impact point (C)

From Figure 7, the head impact at (C) point was found to be stiffer than other impact points (A and B), which indicates a highest HIC values and lowest displacement as compared to other points in the same structure. Acceleration peak and HIC values were observed to increase with the increasing inclination angles, but the displacement decreased with the increasing inclination angles. The acceleration-time and displacement-time curves look to have the same trajectory. However, the difference between first-time contact and end time (t_1 and t_2) as shown in Figure 8. The score points of HIC values at this impact point (C) according to the EURO-NCAP proposal test was (0) point, which means the HIC > 2000. The head impact duration at this point was observed to be smaller than (A and B), which indicates a high HIC value and lowest displacement. Ahad *et al.* [24] the influence of engine hood material type (aluminium, steel, carbon fiber epoxy CF/EP and glass fiber epoxy GF/EP composites) have been studied, and the results showed that using composite materials for the hood covering decreases the HIC value compared to metal materials.

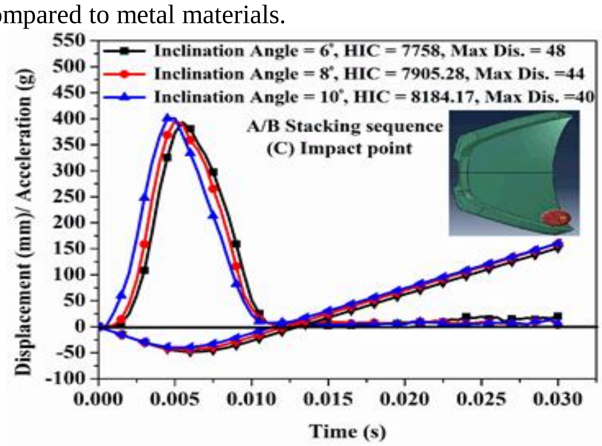

Figure 7. HIC and displacement values on (C) impact point for the hood structure.

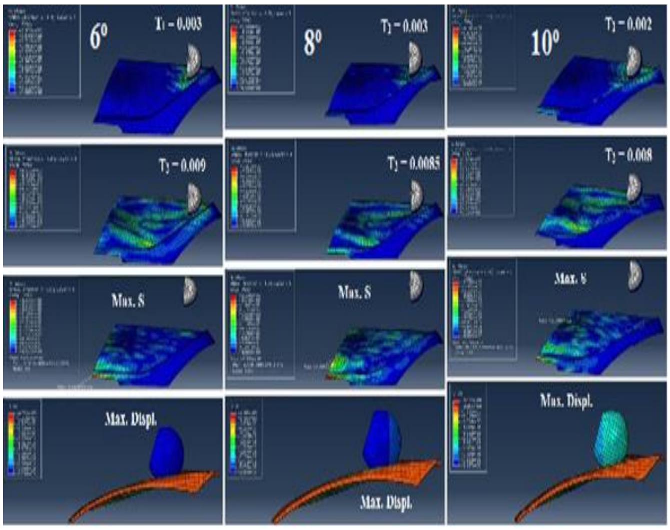

Figure 8. Stress distributions on (C) impact point at t_1 and t_2 and maximum stress and displacement at 6°, 8° and 10°.

Effects of the head impact duration on HIC values

The effects of the head impact duration on HIC values Figure 9 were seen, as indicated when the duration was larger, it leads to lower HIC values, which means deformation and under hood clearance will be larger than the short time duration. This issue was observed in hood composite_structure when the headform impacted at (A) impact point on the surface of the engine hood. Figures 9 shows the effects of the head impact duration on the selected impact points with different inclination angles.

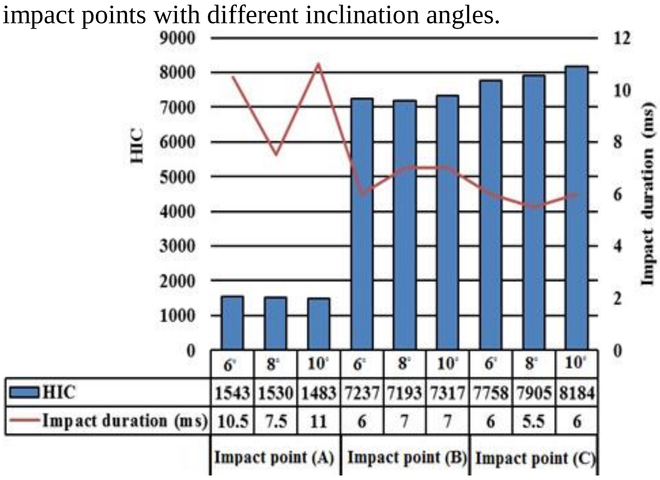

Figure 9. Effects of the head impact duration of the hood structure.

Effects of head impact points and inclination angles to HIC, displacement and absorbed energy as follows:

HIC value

For the hood structure, head impact at (A) was attained the requirement of the pedestrian safety with a lowest HIC value of less than 2000 (Figure 10). For other points, it could be said that the points were located in an active area on the hood structure, and since the two sides of the engine hood was fixed, and there is no vertical displacement. These points (B and C) are hard points, and this can increase HIC. Three head impact points were chosen for the test process. The HIC values of head impact at (B and C) points are described as hard points with the lowest energy absorbing and higher toughness than a head impact at (A). Head impact at (B and C) was located in the stiffer area than other points, sudden increases in HIC values of these points are unavoidable because these points are simulated with zero vertical displacement boundary condition.

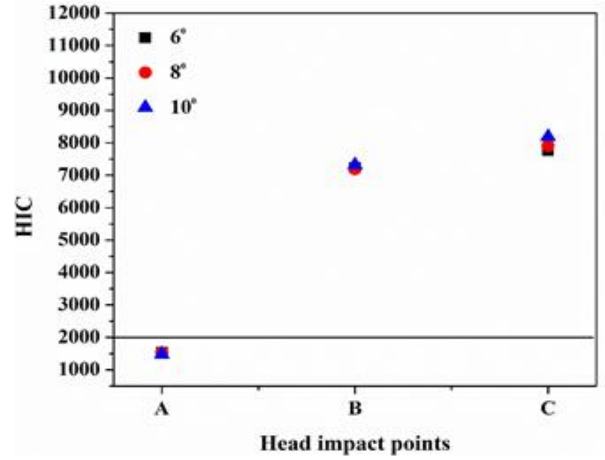

Figure 10. HIC distribution of the selected impact points of the hood structure.

Displacement

The displacement of the engine hood after headform hits the engine hood with different inclination angles and head impact points are summarized and presented in Figure 11. In general a good and acceptable under hood clearance, the better HIC values. This issue has been conducted in numerous research, and the HIC values decrease with the increase in the displacement. The vertical distance between the hood outer surface and engine hood compartment should be set-up at acceptable levels without deforming the car style.

At (A) point as shown in Figure 11 reveals that with better HIC values the displacement increases. The hood structure at 10° inclination angle in this study recorded the highest displacement with a lowest HIC value among all the head impact point. Increasing the displacement can lead to less HIC. However, more displacement may result in the head collision to the hard parts of the engine compartment (rebound), and the HIC value will increase. It means that the manufacturing structures for engine hood should not only absorb the impact energy but should also be able to avoid further deformation of the hood.

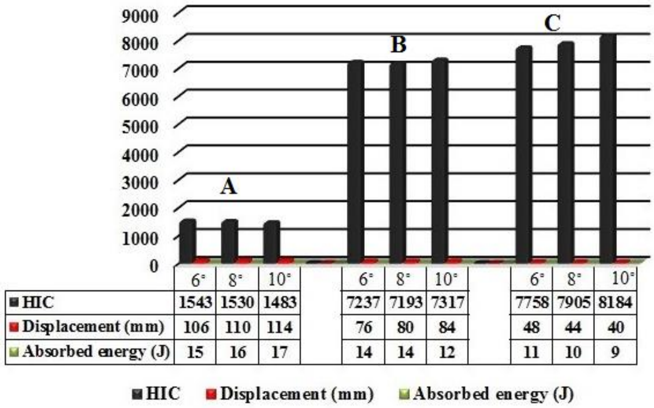

Figure 11. HIC, Displacement & absorbed energy values for the hood structure of three different head impact points (A, B and C) & inclination angles (6°, 8° and 10°).

Absorbed energy

The absorbed energy of the engine hood modelling is a vital factor for designing the hood to avoid and mitigate the head impact injury. As seen from Figure 11, the energy absorbed was shown to be higher in (A) head impact point for the hood structure due to the engine hood stiffness variation at this point was different compared with other points (B and C). B and C impact points were observed to have resistance to the head impact force in the direction of the impact and shown hardpoints due to their location in the hard area of the hood.

Conclusions

In this study, ABAQUS/Explicit software, certain structures (adult headform impactor and engine hood) have been designed to predict the pedestrian risk level during a vehicle collision. As a summary of HIC values for engine hood structure: $[[0, 90, 45, -45]_2, [0, 90]_5]$ at 6◦, 8◦ and 10◦ inclination angles were investigated and discussed. For the hood structure at (A) head impact points, HIC values were shown to be less than 2000, which means the structure at this point with different engine inclination angles satisfied the requirements of pedestrian safety. However, the HIC values of head impact at (B and C) points are described as hard points with the lowest energy absorbing and higher toughness than a head impact at (A). The structure at 10◦ inclination angle of (A) head impact point in this study recorded the highest displacement with a lowest HIC value among all. Increasing the displacement can lead to less HIC. However, more displacement may result in the head collision to the hard parts of the engine compartment (rebound) and HIC increase.

The effects of the head impact duration on HIC values were apparently indicated when the duration was large; it led to lower HIC values, which means deformation and under hood clearance will be larger than the short time duration. The energy absorbing found to be higher in(A) head impact point for inclination angle 10° due to the engine hood stiffness variation at this point is different compared to other points (B and C).

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