FE MODELING OF THE COMPOSITE LAMINATE PANEL STRUCTURE OF THE VEHICLE HOOD TO MITIGATE THE IMPACT INJURY OF THE HEAD

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Abstract- The increased number of pedestrian injuries and fatal deaths are resulting from road accidents due to the increased urban population and number of private vehicles. In order to address this issue along with other safety measurements, design and materials of engine hood has been a key point for an automotive industry. In this study, the finite element models of the pedestrian adult head form and a composite laminate panel of the vehicle hood were created by ABAQUS/Explicit to predict the level safety of structures for pedestrian during a collision. The effects of different stacking sequences and the inclination angle of the hood laminate panel to HIC value, deformation and absorbed energy were investigated and discussed. Simulation results are validated by Euro-NCAP pedestrian head form impact to composite laminate panel. The results show that the FEM modeling of the composite laminate panel can effectively predict the pedestrian head injury and deformation pattern of the model. This method can be an appropriate tool for the vehicle, pedestrian safety evaluation and related development.

Key words- CFRP; pedestrian head impact; HIC; composite laminate panel; adult head form; FEM.

I. INTRODUCTION

The most common materials for the manufacturing of engine hood were steel, aluminum and recently, composite materials have been used due to its added advantage for pedestrian safety. The European regulations are a set of standards intended to reduce the risk of serious injury to pedestrians in terms of the impact of the speed up to 40 km/h. However, the mechanism of injury is complex. The Head Injury Criterion (HIC) indicates a measure of the likelihood of head injury arising from an impact, which is evaluated by the impactor in terms of the simulation of child and adult head. HIC includes the effects of head acceleration and the duration of the acceleration [1]. The design requirements for a car hood include numerous types of criteria. Among the others, the pedestrian protection is, in the last few years, taken full consideration in the design of a bonnet to reduce the head injury [2-5]. Teng et al [6] has used three kinds of sandwich hood structures and proposed for reducing pedestrian head injuries. The results showed that the hood structure with aluminum-reinforced polycarbonate material provides enough absorption capability to protect pedestrians from the impacts of accidents. Ryusuke at el [7] have used carbon fiber composite for the hood part of automobile as an alternative to steel, where the advantages of the composite were noticed. Currently, to attain satisfactory structural performance, the vehicle style is developed to accommodate road accident regulations; accordingly, this has led to the manufacture of high strength vehicles bodies which are able to absorb energy during an impact to protect and save the lives of many pedestrians [8-12]. Liu et al [13], studied friction effects in pedestrian headform impacts with vehicle hood and inclination angles from 3^o to 18^o and the simulation results showed the acceleration peak and HIC values increase with the increasing hood inclination angles. Takahashi *et al* [14], suggested adoption of CFRTP for the body parts of automobiles as an alternative to steel, especially focused on the hood in order to reducing the pedestrian injury at collision. The results showed that the hood using CFRTP has an advantage compared to that of steel in terms of pedestrian safety and lightweight. The aim of this study, is to optimize and analyze the vehicle hood laminate composite panel with numerical simulations. Finite element models of the pedestrian adult headform and composite laminate panel have been carried out by ABAQUS/Explicit to predict the risk injury level of the pedestrian head impact during a collision.

II. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

Carbon fiber/epoxy (Unidirectional prepreg, $179g/m^2$) was supplied by Weihai Guangwei Composites Co., Ltd. Tables 1 show the properties of the present carbon fiber prepreg.

Table 1. Properties of the present UD carbon fiber /epoxy prepreg

Property	Value
Fiber area weight(g/m^2)	125
Resin content (%)	30
Prepreg total weight (g/m^2)	179
Thickness (mm)	0.13

Fabrication of CFRP composite laminates

Laminates which consists of three different stacking sequences were made by a compression molding process. In the study the processing pressure was 2 MPa, curing for 30 min at 80℃, post-cure for 60 min at 135℃. The dimension of the sample was 320 mm X 320 mm (length*width). The lay-up of the composites were shown in Table 2.

Table 2. The specifications of the stacking sequences have been used.

Stacking sequence	Lay-up	Total plies number	Total laminate thickness (mm)
A/A	$[[0, 90, 45, -45]_2, 0, 90]_s$	20	2.6
B/B	$[0, 90]_8$	16	2.08
A/B	$[[0, 90, 45, -45]_2, [0, 90]_5]$	18	2.34

Head injury criteria (HIC)

HIC criteria are used to predict the risk of engine hood to pedestrian during the collision and the level of severity of engine hood design when the collision occurs [15]. The value of HIC depends on the engine hood design, materials, impactor type and structure. HIC is calculated according to the Equation (1):

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

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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 for the purpose of calculating the maximum value.In this study, HIC value is calculated using DIAdem [6] for the pedestrian head impact on automotive hoods.

Adult headform impactor Dimension

The adult headform made from aluminum, which is a homogenous construction in a spherical shape. The sphere covered with 14±0.5 mm thick synthetic skin (PE). The shape of the adult headform are presented in Figure 1. The whole headform volume was divided into three parts as shown in Figure 1, the outer skin indicated by V_1, the inner aluminum part V_2 and the cover plate V_3.

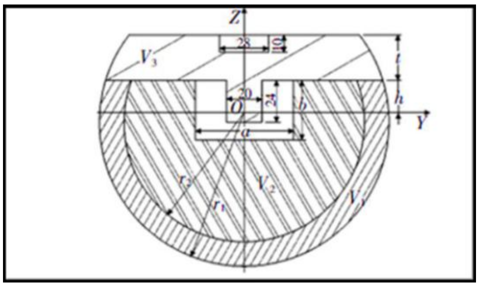


Fig.1. Adult headform impactor

From Figure 1, the diameter of the cylinder on which the accelerometers were positioned was 20 mm, and its height 24 mm; the diameter of the cylinder on cover plate was 28 mm, and its height was 10 mm; the thickness of the outer synthetic skin was 14 mm; the radius of the whole headform was 82.5 mm, and radius of the inner aluminum sphere was 68.5 mm.

Finite element modeling

Different finite element models have been created by ABAQUS/Explicit, adult headform model and composite laminate panel model. All these models were used to predict the HIC values for the pedestrian head impact on the center area of the composite laminate panel with different three inclination angle.

Modeling of the adult headform impactor

According to the geometry specification of the Euro-NCAP regulation, the finite element model of adult headform was created, which is the same model used in Ye et al [16]. The inner part and cover plate of adult headform were aluminum, which is extremely stiff compared to its polyethylene skin. It is considered as a rigid body element as shown in Figure 2. Reference points were considered in the two parts. For the cover plate of the headform reference point is considered at the center of the gravity to measure the acceleration history which is applied to adult headform. The impact angle of the adult headform was 65°according to Euro-NCAP regulations. The headform is launched against the hood at a speed of 11.1m/s.

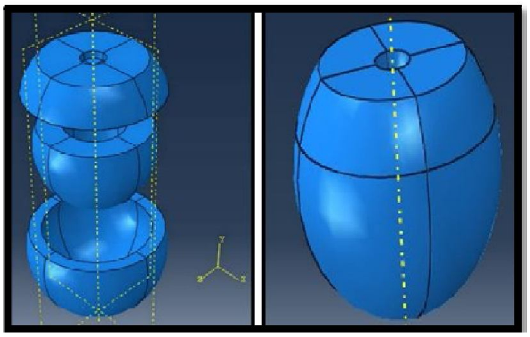


Fig.2. Numerical model of adult headform.

The inner part, cover plate of the aluminum is generated by C3D8R elements which are 8-node linear reduced integration with hourglass control. The polyethylene skin and inner part of the aluminum are connected to each other with constraint as "Tie" element. The cover plate of the aluminum is attached to inner and polyethylene with constraint as "Tie" element.

Composite laminate panel with the adult headform model

The model of the composite laminate panel was created by ABAQUS/Explicit consist of three types of the stacking sequence as shown in Table 2. The shell element was used where the number of the elements was 6400 with element type S4R (A 4-node doubly curved thin or thick shell, reduced integration, hourglass control, finite membrane strains). The area dimensions of the composite panel were 600x600 mm corresponds to ½ area of an average passenger car hood, due to simulation CPU time requirements. The inclination angles were 6°, 8° and 10° and the effect of the panel inclination angle on the HIC value was considered and discussed. Figures 3-4 shows the composite laminate panel with adult headform and whole simulation process. The impact angle of the adult headform was 65°.

The mechanical properties used in the finite element model were obtained from the tensile and bending test (under static conditions) according to ASTM 3039 and ASTM D7264, respectively. The impact test was carried out by Instron CEAST 9350 according to ASTM 7136 to get the performance index of the structure in terms of the absorbed energy and deformation. The mechanical properties of the lamina and the damage initiation parameters used for this model are presented in Table 3.

Table 3. Properties of lamina.

Property	Value	Property	Value
Longitudinal stiffness, E_1 (GPa)	139	Shear modulus, G_{23} (GPa)	3.2
Transverse stiffness, E_2 (GPa)	7.33	Longitudinal tensile strength	2070
Out-of-plane stiffness, E_3 (GPa)	7.33	Longitudinal compression strength	2070
Poisson's ratio, υ_{12}	0.0209	Transverse tensile strength	74
Poisson's ratio, υ_{13}	0.0209	Transverse compression strength	237
Poisson's ratio, υ_{23}	0.33	Longitudinal shear strength	120
Shear modulus, G_{12} (GPa)	4.3	Transverse shear strength	74
Shear modulus, G_{13} (GPa)	4.3	α	0

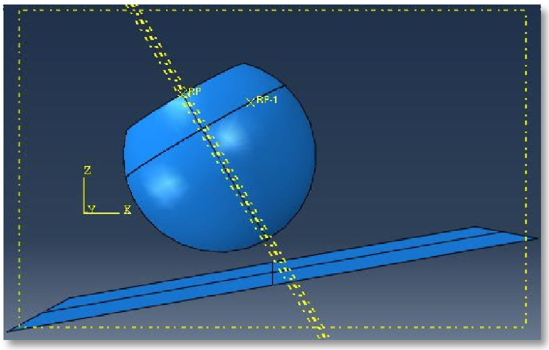


Fig.3. Numerical model of the composite laminate panel with adult headform

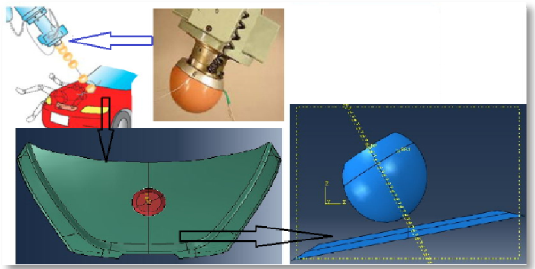


Fig.4. Pedestrian head impact simulation process.

Results and discussion

Collision Modeling of Headform to composite laminate

This section analyses the effect of stacking sequences of the laminate composite panel with different panel inclination angles on pedestrian head injury by performing headform impactor simulations according to the EURO-NAP protocol.Modeling of the composite laminate with different three stacking sequences as: A/A, B/B and A/B having lay-up of $[[0, 90, 45, -45]_2, 0, 90]_S$, $[0, 90]_8$ and $[[0, 90, 45, -45]_2, [0, 90]_5]$ respectively, has been carried out to investigate the effect of the three different panel inclination angles to the HIC, displacement and absorbed energy values of composite structures. From Figure 5 (a, b), the HIC values (a) and displacement (b) of the A/Astacking sequence with specified impact angle (65°) according to the EURO-NAP regulations, with various inclination angles of the composite panels (6°, 8° and 10°) were investigated. Lower HIC and higher displacement was observed at 6° inclination angle due to its occurrence time could be larger than other inclination angles. The acceleration peak and its occurrence time depend on the intensity of impact. Acceleration peak at 8° inclination angle of the panel was observed to be higher than the other and the HIC value, could be attributed to the increasing friction between the headform and composite panel at collision, and thus acceleration increases. At 10° inclination angle the panel showed lower displacement and acceleration value due to the variation of the head impact duration time and friction between headform and laminate panel as compared with other angles. Acceleration curves have peak values, which are common in crack analysis and demonstrate the intensity of the impact and any increase in the peak values leads to higher HIC values.

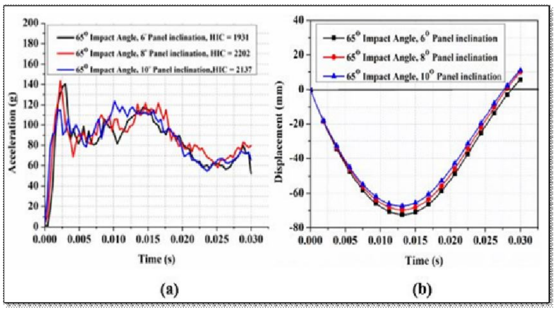


Fig.5. HIC value with different inclination angle of composite panel (a) and maximum displacement (b) for A/A.

Figure 5 (b) show the Z displacement of the panel at different inclination angle. The plots explain the bending and flexibility of the composite panel at collision with different three inclination angles. The increase in the inclination angle showed a decreased in the displacement due to the friction coefficient of head impact between the headform and panel changed. This led the panel structures not absorbing impact energy and reduce the deformation of the panel**.** Highest displacement which, means more deformation occurred in the structure and a higher ductility index would mean that most of the total energy was absorbed in crack propagation. The first peak on the graph are formed as the result of the collision of the headform in to the panel. In this impact, the second peak does not influence the HIC because the HIC window does not involve the second peak.

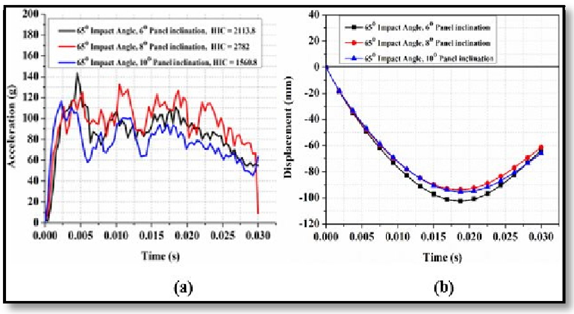


Fig.6. HIC value with different inclination angle of composite panel (a) and maximum displacement (b) for B/B.

In Figure 6 (a), lowest HIC value was observed at 10^o inclination angle of the panel with lowest acceleration peak due to the clear effect of the orientation of the lay-up and inclination angle when compared with other structures. Higher displacement and acceleration peak at 6^o was recorded. The displacement in Figure 6 (b) at 8^o and 10^o was observed to be almost the same. Higher HIC value was observed at 8^o though there are several peaks throughout the graph, after the first peak representing the spring nature of the structure. This led to the increase in the acceleration peak and not accounted in HIC value, but, involve in the total amount of the impact energy absorbed.

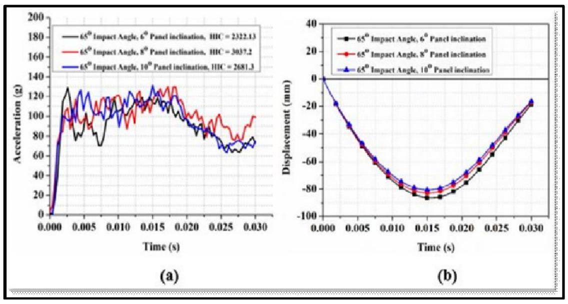


Fig.7. HIC value with different inclination angle of composite panel (a) and maximum displacement (b) for A/B.

The acceleration peaks of the panel at different inclination angles did not have similar behavior with different HIC values. In this case the inclination angles showed to have an influence in HIC values and the acceleration peaks of the composite panels. In Figure 7 (a), higher HIC value was recorded in case of 8^o inclination angle same as shown in Figure 6 (a) and Figure 5 (a). This is due to this angle greatly affects the headform impact sensitivity to friction coefficient was shown for all the stacking sequences. As shown in Figure 7 (b), the displacement showed decreased with the increasing inclination angle. Lower HIC value was recorded at 6^o with higher displacement same as shown in Figure 5 (a), due to the fact that the outer lay-up of those structures in Figure 5 and Figure 7 was the same. The value of displacement varied according to the design procedure and that indicated to the occurrence of the deformation which occurs in the composite panel after the impact.

Comparison of 3 different panel structures.

HIC value

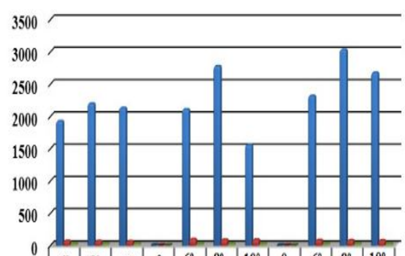
In Figure 8, HIC values for three different stacking sequences A/A, B/B and A/B with different three inclination angle of the composite panel are shown which were performed by DIAdem program software. Figure 8 shows the HIC values for all the composite structure panels. According to the EURO-NCAP the HIC value of the structure should be 650 to 2000. A/A stacking sequences at 6° shown satisfied the requirement of the test standard. Also the B/B stacking sequence at 10^o was found to have lower HIC value than other structures due to its highest displacement at 10^o among all the structures in same inclination angle. This was in agreement in terms of the displacement with the flexural test also, showing a high displacement compared with other structure due to its ductility property (indicating to high displacement due to the high elongation property of this structure). It can be reported that the structure achieves the basic requirements of the pedestrian safety in which the HIC value should be less than 2000.

Displacement

From Figure 8, the effect composite laminate panel thickness is observed clearly to have an influence on the maximum displacement of the structures. A/A, B/B and A/B have thickness 2.6, 2.08 and 2.34 respectively. It was observed that the B/B stacking sequence showed the highest deformation among all the other structures, however, it achieved the lowest HIC value. In this case, the design of the engine hood according to this finite element model proposes to use soft material, especially in the engine hood structure to avoid or mitigate the impact injury of the head. Among all the models, the deformation should not be significant to maintain the style of the engine hood after the collision. The recommended distance between the rigid bodies and inner structure must be between 76-88 mm. A/A and A/B structures were investigated on this issue due to lay-up orientation and bending stiffness of the composites. If the HIC results of the composite laminate panels are less than 2000 which is desired to design the engine hood and should be energy absorbing (softer) without compromising the structural integrity of the vehicle.

Absorbed energy

In Figure 8 the HIC, displacement and absorbed energy of the laminate panels with different three stacking sequences and inclination angles were obtained and compared. The higher HIC values were observed in all the stacking sequences at 8^o inclination angle of the laminate panel. Due to higher bending stiffness property of the A/A and A/B stacking sequences which, was also shown in the load-displacement curve of the flexural test have higher bending stiffness than B/B stacking sequence, for that the values of the displacement showed lower than the B/B stacking sequence. Lower HIC value was observed in B/B stacking sequence because of more damage and deformation could occur when the headform collides with the laminate panel, leading to the impact energy being used in crack propagation and decreased the headform acceleration. All the absorbed energy increased with the increase in inclination angle for the same structure.



	6°	8°	10°	0	6°	8°	10°	0	6°	8°	10°
HIC	1931	2202	2137	0	2114	2782	1561	0	2322	3037	2681
Displacement (mm)	72.4	69.7	67.4	0	102	93.8	95.5	0	86.4	82.8	80.5
Absorbed energy (J)	18.9	21.9	22	0	18.4	20.3	20.8	0	19.8	21.2	21.4
	A/A				B/B				A/B		

Fig.8. HIC, displacement and absorbed energy values for the A/A, B/B and A/B stacking sequences.

CONCLUSION

A new approach of FE modeling of the composite laminate panel of the vehicle hood with different stacking sequence structures was investigated. In this study, ABAQUS/Explicit software, certain structures (adult headform and composite laminate panels) have been designed to predict the risk level of the composite laminate panel structures of the vehicle hood to pedestrian during a collision. Modeling of the composite laminate with different three stacking sequences as: A/A, B/B and A/B have lay-up $[[0, 90, 45, -45]_2, 0, 90]_S$, $[0, 90]_8$ and $[[0, 90, 45, -45]_2, [0, 90]_5]$ respectively, has been carried out to investigate the effect of the three different panel inclination angles to the HIC, displacement and absorbed energy values of composite structures. The higher HIC values were observed in all the stacking sequences at 8^o inclination angle of the laminate panel. Due to higher bending stiffness property of the A/A and A/B stacking sequences, the values of the displacement showed lower than the B/B stacking sequence. A/A and A/B stacking sequences were achieved the recommended displacement of less than 88 mm but, its HIC values were unacceptable. Lower HIC value was shown in the B/B stacking sequence at 10^o laminate panel inclination angle. The simulation results showed that the models with $[0, 90]_8$ stacking sequence of 6^o and 10^o inclination angles of the composite panel causes reduction in composite panels HIC, and the deformation was increased due to the better crashworthiness regarding to its light weight. The lowest head displacement was observed in the case of the composite panel with $[[0, 90, 45, -45]_2, 0, 90]_S$ stacking sequence due to their ability to absorb energy.

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