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Finite Element Modelling of Car Hood Panel for Pedestrian Protection during Impact

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Abstract: Pedestrian protection during accidents is one of the important criteria in the design of new “pedestrian friendly cars” that is in compliance to the new regulations requirements for pedestrian and road users’ safety. In this study, the collision between headform impactors and vehicle hoods is simulated using FE models developed according to the European Enhanced Vehicle-Safety Committee (EEVC/WG17) regulations. The impact was simulated in LS-Dyna to study the hood performance in terms of pedestrian safety by evaluating the Head Injury Criteria (HIC). The performance of the hood was investigated by varying the section dimensions of the panel pillar with comparisons to the original dimensions. Results indicate that the section dimensions of the panel pillar is one of the keys to control the performance of hood during collision by reducing the HIC and the head injury risk level of pedestrian during accidents.

Keywords: Pedestrian protection, Headform impactor, HIC, Friendly car design, Hood inner plate pillar

1. Introduction

According to the World Health Organization (WHO) 2013 statistics report, over 1.24 million people died on the road annually, and 50 million were injured. A total of 75% of accident deaths are pedestrian related. As a result, a large number of deaths and injuries are now due to road traffic accidents, which is one of the major problems worldwide. Globally, pedestrian fatalities count for 50% of the total accidents [1]. Because of the increasing pedestrian fatalities and the high cost of medical treatments, researchers and designers has started to improve the vehicle designs to invent “pedestrian friendly cars”.

Pedestrian friendly car design must achieve the European Enhanced Vehicle-Safety Committee (EEVC/WG) regulation tests results required for hood and bumper parts [2]. The performance of the hood with respect to pedestrian safety is determined via the Head Injury Criteria (HIC). HIC has been established to identify the severity of the head injury through the risk curve. The value of HIC is related to the probability of 50% for adult pedestrian face bone and skull fracture or deform at impact with rigid body and the acceptable amount is ≤ 1000 [2].

In the past, automotive industry companies took into account the toughness as a major factor in manufacturing the car’s body and parts. Most of the cars are commercially designed to meet global market demands. Due to this reason, the current hood design is too stiff for the human head, causing severe pedestrian injury. Cars designers have tried to increase the hood’s ability to absorb impact energy by decreasing its stiffness using accessories. Kerkeling et al. [3] studied the effect of the hood – hinge design, Liu et al. [4] used a sandwich panel between the outer hood plate and panel, and Belingardi et al. [5] used a thermoplastic and wire structure panel to increase the impact energy absorption and improve the HIC value. However, these designs are very costly.

In this study, the collision between headform impactors and vehicle hoods is simulated using FE models developed according to the EEVC/WG17 regulations. The impact was simulated in LS-Dyna to study the hood performance in terms of pedestrian safety by evaluating the HIC. The performance of the hood was investigated by varying the section dimensions of the panel pillar with comparisons to the original dimensions.

2. Numerical Model

2.1 Headform Model

Based on the EEVC/WG17 requirements, the adult impactor consists of a spherical shape wrapped by vinyl skin. The global diameter is 165 ± 1; total mass is 4.8 ± 0.1 kg and the accelerometer is in the center of gravity of the head shown in Figure 1. The impactor undergoes dynamic validation tests at velocity of 40 km/h [2, 6].

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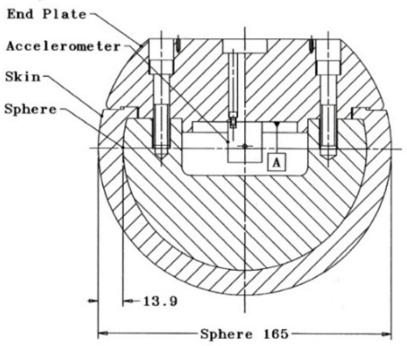

Fig. 1 FE Adult pedestrian headform model parts and dimensions [2].

The headform model is built using Solidworks and meshed using Hypermesh. Figure 2 shows the four parts of FE headform impactors. The accelerometer position shown represents the brains inside the skull. The specifications of the head parts are shown in Table 1. The material specification is shown in Table 2 [7].

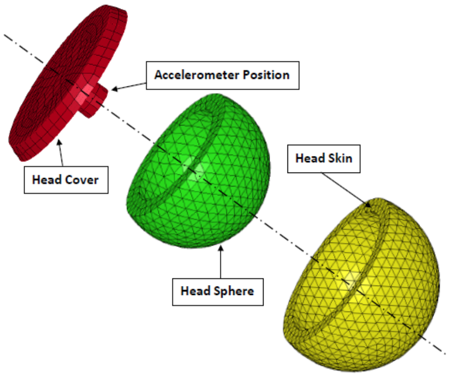

Fig. 2 FE headform impactor parts

Table 1 Headform part specifications.

Part name	Mass (kg)	Material in EEVC/WG	Material in LS-DYNA
Skin	0.3	Vinyl skin	007- Blatz-Ko-Rubber
Sphere	4.0	Aluminum 6061-T6	001 - Elastic
Cover	0.5	Aluminum 6061-T6	001 - Elastic

2.2 Hood Panel Assembly Model

Figure 3 shows the car hood panel assembly of the Proton Waja M 1.6 – Line 2012. The reason this model was selected had been due to the fact that the model suffered from a "low Star –Rate" of 3.5/5 after new pedestrian safety regulations were employed. The height X1 is 25 mm and the width X2 is 40 mm. The material is carbon steel, the thickness of the outer hood plate is 1.2 mm, and the panel is 0.8 mm. The material specification is shown in Table 2 [7]. The total hood assembly weighs 11 kg. The impact simulation process is carried out using the LS-DYNA for 10 s with impact occurring at 6 s.

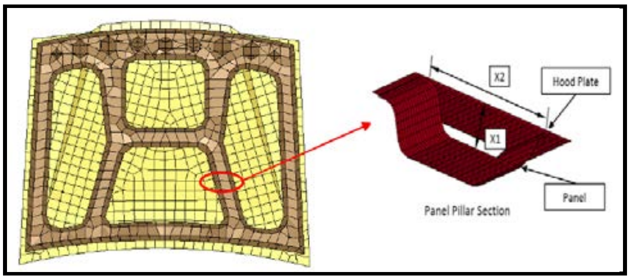

Fig. 3 FE model of hood assembly

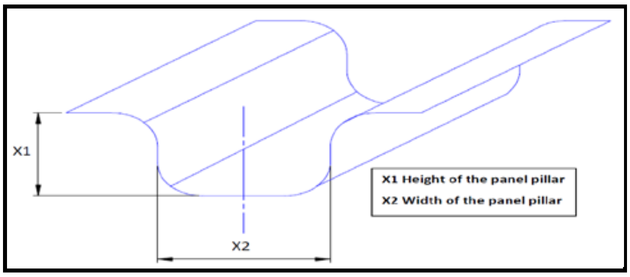

Fig. 4 Height and width of the panel pillar

Table 2 Mechanical properties of headform and car hood materials

Material	Density (kg/mm^3)	Yield stress, (N/mm^2)	Young's Modulus (GPa)	Poisson's ratio
Al 6061-T6	2.7×10^{-6}	276	68.9	0.33
Vinyl	1.17×10^{-6}	34	2.01	0.4
Carbon steel	7.8×10^{-6}	215	210	0.3

The section dimensions, X1 and X2 of the panel pillars shown in Fig 4 were altered to evaluate its effect on the car hood performance for pedestrian safety and on the level of the HIC criteria. The height and width of the panel pillars are varied into nine different X1 and X2 combinations for the current model with other parameters fixed; panel map, thicknesses and materials.

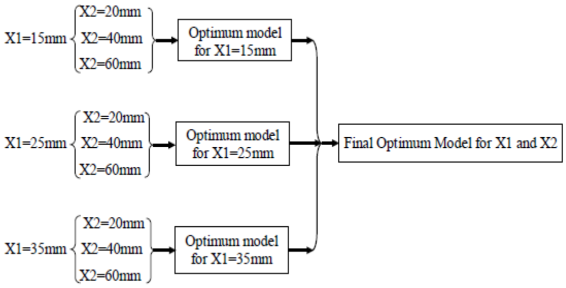

Fig 5 Height and width dimensions of the panel pillar section for the nine concept models.

These nine models are divided into three groups according to height X1=15mm, X1=25mm, and

X1=35mm and width X2=20mm, X2=40mm and X2=60mm as shown in Fig. 5.

3. Results and Discussion

Three major parameters were analyzed; the hood deformation, internal energy absorption by the hood and panel, and HIC [8]. The maximum deformation of the current hood design and the current panel design is 37.68 mm and 39.69 mm respectively as shown in Fig.6 and Fig. 7. An ideal hood and panel design should be soft and has high capability to absorb the impact energy during pedestrian accidents. Thus a large deformation is desirable. Furthermore the gap between the hood and the engine for the current car model is 60 mm, therefore there will be no collision between the head and the engine.

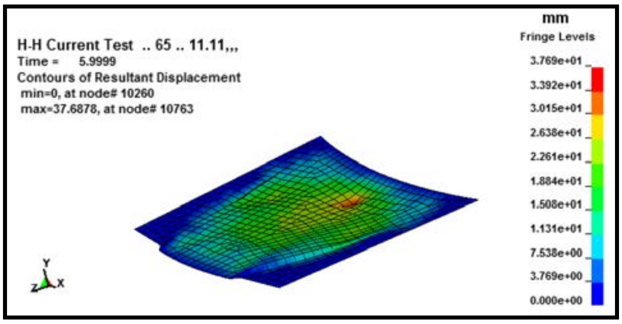

Fig. 6 Maximum hood deformation

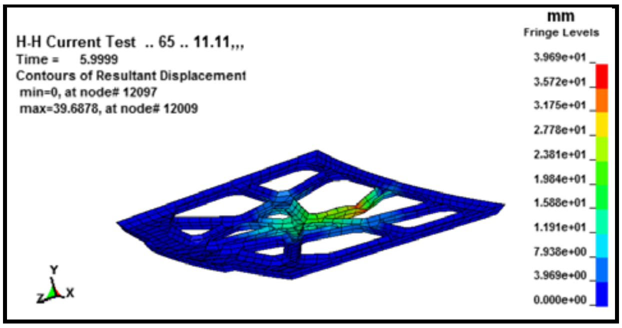

Fig. 7 Maximum panel deformation

Figure 8 shows the energy behavior during impact for the current hood panel design. The total impact energy remains at a constant during collision (curve C – 296.23 J). Some of this kinetic energy is converted into internal energy (curve B – 180 J) in the hood and panel, while the rest remains as kinetic energy in the head (curve A – 116.23 J). Approximately 40% of the total energy remains in the head as kinetic energy. This remaining energy affects the brain and connective tissue and increases Contrecoup Brain injuries [9]. This, in turn, increases the HIC and level of injury.

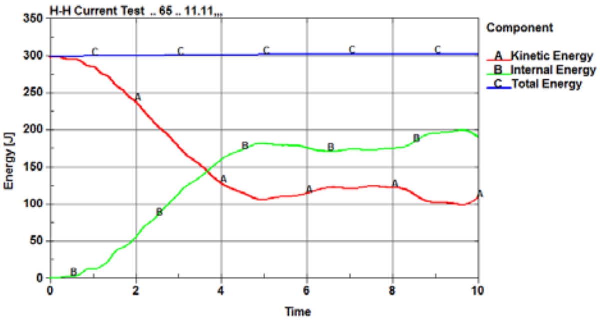

Fig. 8 Energy Behavior during Impact

The magnitude of the HIC criteria determines the head injury level. To calculate the magnitude of HIC, the following formula is used,

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

Where *a* is the head resultant acceleration in gravity unit (G), t_1 and t_2 are the initial and final impact instants in seconds, and $(t_2 - t_1) \leq 15$ms [10]. The HIC calculated via LS Dyna is 1700 for the current hood panel design as shown in Fig. 9.

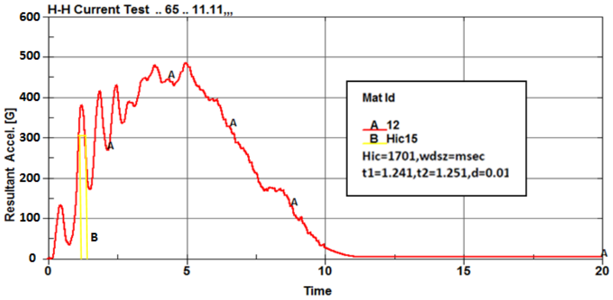

Fig. 9 Head acceleration and HIC

The corresponding level of brain injury risk obtained from the head injury risk of skull fracture percentage Mertz Curve [8] is 70% as shown in Fig. 10. The maximum acceptable head - brain risk and skull fracture value for head injury risk to be considered safe is 16%, which corresponds to HIC=1000 [11]. The high level of brain injury risk makes the current hood panel design unsafe for pedestrians and road users during accidents.

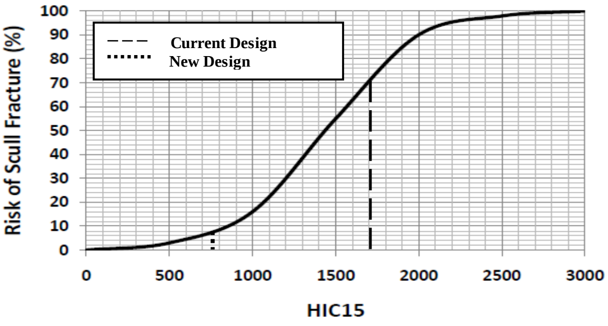

Fig. 10 Mertz Curve for Head Injury Risk

Table 3. HIC for different panel pillar dimensions (X1-X2)

X1 (mm)	X2 (mm) 20	40	60
15	1843	1572	743
25	2034	1700	1321
35	2059	2175	1733

Table 3 shows the HIC for the nine different hood panel models including the current model. The HIC decreased with decreasing X1 however increased with decreasing X2. In general, reducing the dimensions of the panel pillar lead to lower stiffness. Rapid successive vibrations that occur in the hood as a result of very low stiffness leads to the occurrence of oscillatory acceleration which in turns increases the HIC. Thus, dimensions required to improve the performance of the hood panel vary according to specifications of the hood and panel map. For the car model chosen in this study, the optimum panel dimensions are X1 = 15 mm and X2 = 60 mm, where the HIC is 743. The corresponding internal hood panel energy is 263 J and the hood deformation is 40 mm. The head injury risk can be reduced to less than 10%, which is a huge improvement from 70% injury risk (see Fig. 10).

4. Summary

The headform impactor is used to determine HIC and the injury risk level. The HIC depends on the magnitude of the head acceleration and the time it takes to reach this acceleration. Head acceleration depends on the hood stiffness and its ability to spread the energy generated from the collision. The hood stiffness can be controlled by varying the panel pillar dimensions. Therefore the panel pillar section dimensions are one of the most important parameters that influence the hood performance for pedestrian safety to mitigate head injury risk.

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