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Effect of material type, stacking sequence and impact location on the pedestrian head injury in collisions

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ABSTRACT

In this study, the effect of engine hood material type (aluminum, steel, carbon fiber epoxy CF/EP and glass fiber epoxy GF/EP composites) has been investigated on the pedestrian head injury in a collision (HIC). Child and adult Finite Element head models have been implemented for the simulations. In the models made of composite materials, effect of different stacking sequences has been investigated and four different 8-layered non-crimped fiber (NCF) composites with the stacking sequences of $[0]_8$, $[90]_8$, $[0/90/0/90]_s$ and $[-45/0/45/90]_s$ have considered. It was seen that using CF/EP composite instead of steel decreases the HIC value and hood weight by 42.6% and 46.8%, respectively. Moreover, $[0]_8$ and $[90]_8$ stacking sequences have the minimum and maximum HIC values among all the stacking sequences, respectively. Moreover, using composites made of glass fibers leads to higher HIC values with respect to those made of carbon fibers. In this study, the effect of location of head impact and hood thickness on HIC value for different hood material has also been investigated. For most of the locations, using composite materials led to lower HIC values. Increasing the skin thickness increases the HIC value for all the materials and its effect is more on steel, carbon-epoxy, glass-epoxy, and aluminum materials respectively. Increase in the hood thickness has higher effects on medial locations compared to lateral locations.

1. Introduction

In fast developing cities, demand for personal and public use of cars increases year by year, especially in developing countries. Due to the nature of daily urban life, people have to cross the streets and conjunctions, which in case of carelessness of the driver or the pedestrian, can lead to their injury or death. In average, 10% of urban pedestrian accidents are fatal [1]. Statistics of accident-related deaths are still very shocking. For example in 2012, nearly 30,800 people lost their lives in traffic accidents of the United States, including 4783 pedestrians [2]. Large annual number of accident-related deaths makes automobile manufacturers considers more and more restrictions each year. In this context, standards have been adopted by organizations such as European Union-The European New Car Assessment Program (Euro-NCAP) and the European Enhanced Vehicle Safety Committee [3] (EEVC), and car manufacturers are required to follow them.

In urban traffic, passenger cars are the main cause of accidents. For example, in 2012, from the total number of 45,637 vehicles that were involved in fatal crashes in the USA, 39.6% were passenger cars [2]. Statistics show that the front sides of cars have caused deaths more than any other sides (30.7%) [2]. Furthermore, studies show that heads and legs of the pedestrian are the most injured body parts [4] (see Fig. 1).

The automobile hoods and bumpers, which pedestrians frequently collide into during accidents, should be designed for the safety of the pedestrians. Pedestrian impact tests are performed according to regulations provided by European Enhanced Vehicle Committee (EEVC) which has recently become the European Union directive 2003/102/EC [6]. The criterion used to assess the severity of a possible injury is Head Injury Criterion (HIC) [7].

In order to optimize the design of a hood to reduce the consequences of a head-hood impact for a passenger, the effects of the stiffness of the hood skin and its underneath support part at the location of collision, the shape of the hood inner support, and the rigid engine components located under the hood surface have to be investigated. Studies show that adding a hollow space between the support and skin parts of the hood decreases the head injuries significantly; one way to achieve that is to make the cross section of the reinforcing beams hollow [8]. Moreover, the reinforcing structure under the hood must be flexible and ductile. During a pedestrian's head-car hood collision, the rigid engine components (under the hood) have a significant role in the extent of head injuries. When designing a hood, it must be kept in mind that the hood maximum deflection must be limited in order to inhibit its impact to internal parts. That is why the inner support has to be

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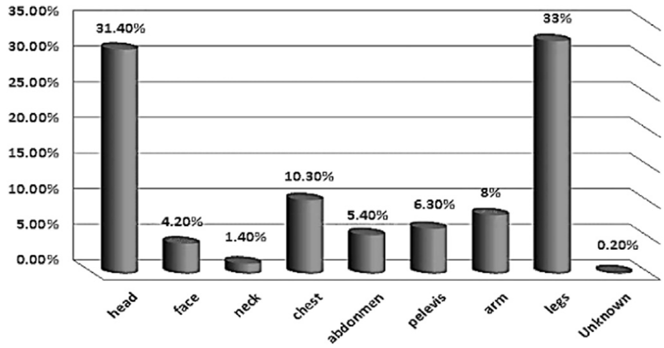

Fig. 1. Injury distribution in human body [2].

relatively strong and stiff [5].

Since the majority of accident deaths are caused by head injury, many studies have been conducted in the field of structural design of hoods to reduce the casualties. Huang et al. [9] evaluated and optimized the performance of a reversible hood (RH) for prevention of head injuries to an adult pedestrian from car collisions, and showed that with this method HIC value can be reduced to less than allowable value. Liu et al. [10] showed that in the pedestrian head form impact test, the contact friction between the head form and the engine hood affects the head form kinematics and head injury criterion to some extent. They also showed that the angle between the head form impact direction and the hood surface greatly affects the head form impact sensitivity to the friction coefficient. Yao et al. [11] proposed the idea of an A-Pillar Mounted Airbag System (AMAS) with the aim to prevent head from directly impacting against stiff structures such as A-pillars, windshield frames and edges. Kerkeling et al. [12] proposed a new design for reinforcing the plate under the hood and showed how the hood design could become compatible with the pedestrian protection requirements.

In urban accidents, pedestrian head impact location is different depending on the vehicle type. Maki et al. [13] focused on the injuries sustained by bicyclists and pedestrians in collisions with vehicles and analyzed them in a comparative way. They showed that the head were the main injured body region in fatal accidents. They showed that the risk of fatal injury is higher for sedans, SUVs and minivans, respectively.

Composites have shown to be stronger materials with respect to their metal counterparts while having lower weights. Anyway, high quality composites are more expensive than metals which is why today the usage of composite materials can typically be found in racing and luxury cars. However, usage of composites for conventional cars is increasing day by day. Carbon Fiber Reinforced Plastic (CFRP) and Glass Fiber Reinforced Plastic (GFRP) are the most popular composites in automobile's industry [14]. Since composites made of carbon fibers are relatively expensive, they are rarely used in conventional vehicles although they are a common material in racing cars. Glass fibers are much cheaper than carbon fibers, which makes using GFPR composites for conventional cars more beneficial. However, due to the lower mechanical properties, using GFPR composites for parts that are important to car safety, such as chassis, is not recommended, while they are still satisfactory materials for car hood.

Several studies have been dedicated to investigation of using composite materials in the construction of the car chassis and body parts. Kewak et al. [15] suggested a hood completely made of fiberglass composite with reinforcing ribs that was 30–40% lighter than a similar structure made of steel. Stammen et al. [16] demonstrated the importance of the zones chosen for the impact test evaluation due to the presence of the inner part of hood and its influence on the local stiffness of hood surface. Peng et al. [17] presented a method to assess the protective performance of a passenger car hood to decrease pedestrian head injuries in car-to-pedestrian collisions. They proposed three types of hoods, sandwich structure hood, multi-cone, and wavilness inner-panel hoods, made of aluminum to protect the pedestrian's head. The results indicated that all the proposed hood designs showed a significant improvement in injury mitigation. Shojaeefard et al. [18] developed a new finite element model to compare pedestrian friendliness of four hoods with four different inner parts including hemispherical, conical, wavy and the combination of wavy-conical structures to the original hood and the engine parts were modeled as rigid according to the EEVC WG17 regulation requirements. They showed that their designs had rigorously improved the pedestrian safety with respect to the original one because of involvement of the entire structure in energy absorption.

Many factors have to be taken into account simultaneously in designing a car's hood: elegant appearance, aerodynamic properties and safety aspects. This study investigates the effect of material selection (i.e. aluminum, steel, CF/EP and GF/EP composites) of engine hood on the pedestrian head injury (HIC) in a collision. Due to the high cost of experimental testing, finite element models are created and analyzed in LS-DYNA® FE code. As an example for this type of hood, the finite element model of Chevrolet Silverado's hood has been used. In models made of composite materials based on laminate theory, effect of different stacking sequences are also investigated and four different 8-layered non-crimped fiber (NCF) composites with stacking sequences of $[0]_8$, $[90]_8$, $[0/90/0/90]_s$, and $[-45/0/45/90]_s$ were considered. The effect of location of head model impact, as well as the effect of variation in hood skin thickness will be studied on the resulting HIC values for hoods made of different materials and stacking sequences.

2. Validation of material models

Collision between human head and car's engine hood, during an accident, can be considered as a low-velocity impact. Due to high costs and/or unavailability of headmodel-car hood collision experimental test facilities, Finite Element modeling has been implemented in this study for investigating head-hood impact. Four different materials (aluminum, steel, carbon fiber epoxy CF/EP and glass fiber epoxy GF/EP composites) have been considered for the hood skin, while only stiff steel supports have been used in order to limit the deflection of the hood. For appropriate introduction of these materials into LS-DYNA®, it is first necessary to choose suitable material models for their mechanical behavior in low-velocity impact. In order to do that, drop hammer impact tests with rigid impactors were carried out on aluminum and steel plates. The material properties of the composite plates were taken from [22].

2.1. Aluminum and steel

In this study, aluminum 7075-O alloy with mechanical properties listed in Table 1 has been used. This material is strong, with strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys, so it is often used in automotive and

Table 1
Elastic material properties of Aluminum 7075-O and Steel 1008.

	ρ (kg/m^3)	E (GPa)	G (GPa)	υ
Aluminum 7075-O	2810	71.7	26.9	0.33
AISI 1008	7850	200	80	0.29