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Pedestrian safety investigation of the new inner structure of the hood to mitigate the impact injury of the head

Mohammad Hassan Shojaeefard, Amir Najibi*, Meisam Rahmati Ahmadabadi

School of Automotive Engineering, Iran University of Science & Technology, P.O.Box: 16846-13114, Tehran, Iran

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A B S T R A C T

Increasing the safety of the road transportation leads to reducing the costs of road accidents, especially improving the safety of the pedestrians who are the most vulnerable road users. Regarding the new regulations on the pedestrian safety, automakers have recently paid certain attention to the front-end design of the vehicles. The collision of the pedestrian's head to the automotive hood is the main reason for fatal injuries in pedestrian to vehicle impacts. Head Impact Criteria (HIC) measures the possibility of inducing serious injury to the pedestrian's head in collision with the hood.

In this paper, a new finite element model has been developed to simulate the collision between headform impactors and five different hoods according to the EEVC WG17 regulation requirements. This model was utilized to compare pedestrian friendliness of four hoods with four new different inner layers including hemispherical, conical, wavy, and the combination of wavy–conical structures to the original hood and the engine parts are modeled as rigid.

It is shown that the pedestrian safety has rigorously improved in the new structures with respect to the original one. In the new designs, the entire structure is involved in energy absorption so it leads to the mitigation of head acceleration to a certain level.

Finally, the masses of different structures are compared and it is illustrated that the new structures are not much heavier than the original structure. Moreover, the torsional and latch stiffness of the new structures are much better than the original one.

1. Introduction

Transportation is an important criterion in assessing the development of different countries, but it can be harmful, too. Pedestrians and cyclists are among the most vulnerable road users.

Yearly more than 6100 pedestrians (15% of fatalities) and 3900 cyclists (10% of fatalities) are killed and some thousands are injured in road accidents in Europe [1]. In 2005, 9804 pedestrians were killed in road accidents in Iran [2]. Pedestrian fatalities account for 13%, 28%, 28% and 16% of all traffic fatalities in U.S, England, Japan and European nations, respectively [3].

Pedestrian head trauma is the cause of the most serious injuries and fatalities in vehicle to pedestrian accidents representing 80% of severe injuries and the cause of 62% of fatalities. The vehicle hood is the area, which is the most likely to collide with the head of pedestrians in these accidents. It can be concluded that increasing the safety of the hood is the best way to increase the safety of the pedestrians [4].

Steel hoods are usually made of an upper body and an inner body. The inner body is used for structural strength and the upper body is used for aerodynamic and style purposes [5].

The most important cases which influence the design of the hood inner body are: hood durability, hood closing endurance, hood slam test (misuse), lateral stiffness for mounted hood, hood stiffness for bending and torsion, denting and buckling, hood fluttering, manufacturing requirements for drawing, hood performance for high speed and low speed crashes, and hood surface quality. Furthermore, the most important case is that the hood has to fulfill the HIC target at every point within the impact area in the hood top zone [1].

Based on the Lawrence assessment, the little changes considered at the primary levels of the design of the car fronts are low cost and have been effective [7].

Different organizations have developed legislations and test procedures to assess the level of pedestrian protection for vehicle front ends. Studies included full scale dummy tests, cadaver tests, accident reconstructions, analysis of accident data and computer simulations [6].

Test procedures developed by the EEVC WG17[1] consist of three subsystem tests including the impact of headforms into the vehicle hood, the impact of a legform into the front bumper, and the

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* Corresponding author. Tel.: +98 939 508 0493; fax: +98 21 88013029.
E-mail addresses: mhshf@iust.ac.ir (M.H. Shojaeefard), najibi@iust.ac.ir, a.najibi@yahoo.com (A. Najibi), rahmatimeitham@gmail.com (M. Rahmati Ahmadabadi).

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impact of an upper legform into the leading edge of the hood. Vehicles should be able to pass pedestrian tests, at the speed of 40 km/h in all proposed test points [4].

EEVC test procedures for evaluating pedestrian's head safety in collision with the hood, comprised two phases. The first phase of legal introduction started in 2005 and a more stringent second phase followed in 2010 [8]. A schematic of the second phase of the EEVC child and adult headform subsystem tests is shown in Fig. 1. Euroncap performs its headform tests based on these regulations [14].

In the second phase, two types of child and adult headforms are considered. [1]. The mass of the child and adult headforms are 2.5 kg and 4.8 kg respectively and both headforms contact the hood top at the impact speed of 40 km/h, based on the EEVC/WG17 regulations.

Time history of the head's acceleration is measured using a sensor, installed at the center of gravity of the headform impactors and biomechanical criteria of HIC is used to assess the severity of the impact to the pedestrian's head.

Acceleration–time graph of the headform impact into the hood has two stages. The first milliseconds acceleration is defined by the initial active mass; Therefore, the material and the thicknesses have the major influence in this stage. The later acceleration is defined by the stiffness of the structure such as the component sizes, their mountings and their design which have an increasing influence at this stage [1] and in this phase, the HIC should not exceed 1000.

The use of physical tests to optimize the safety level of a new hood design is costly and time consuming so a potentially faster and cheaper way is using finite element (FE) simulations using a model of headform impactor, which is validated [4].

Serre et al. has focused on child anthropometry and identifying the possible impact points during accidents. In particular, it is shown that for children above 12 years the thigh is directly hit by the bumper whereas head impacts principally into the hood. Furthermore, it is discussed that children aged less than 9 years tend to be thrown forward or knocked down instead of having a wrap trajectory [10].

Hilfritch et al. has studied the effects of hoods made out of modern steel on pedestrian protection [12].

Buckmaster and Hwang have studied the use of a thermoplastic composite material (HPPC) for horizontal automotive body panel applications (such as hoods, roofs and trunk lids). Pedestrian test results indicated that the energy absorption characteristic of HPPC allows such a hood to meet the pedestrian safety requirements without the need for extra intrusion into the engine compartment [9]. There is also a study on a kind of foam composite material engine hood that can reduce the injury value of pedestrian head [13].

Masoumi et al. have developed some new finite element models to simulate head impact phenomenon between headform impactors and steel, aluminum and composite hoods. It is shown that the amount of HICs, which are measured at the collision points for composite hood are much less than those measured at the same points for steel and aluminum hoods. There is also a comparison between the cost, weight and structural performance of three hoods made of different materials [5].

Interdependence of the HIC value, the hood reinforcement thickness, and the hood skin thickness is very complicated [14]. Teng and Ngo have analyzed and proposed a method of identifying the most effective values for the hood reinforcement thickness and the hood skin thicknesses to protect pedestrians while maximizing the hood stiffness.

Zhang et al. have analyzed the mechanism of shock absorbing glue between inner and outer panels of engine hood for mitigating head injury of pedestrian. Finally, the effects of shock absorbing glue distribution are compared through the calculation on the FE model of real vehicle [15].

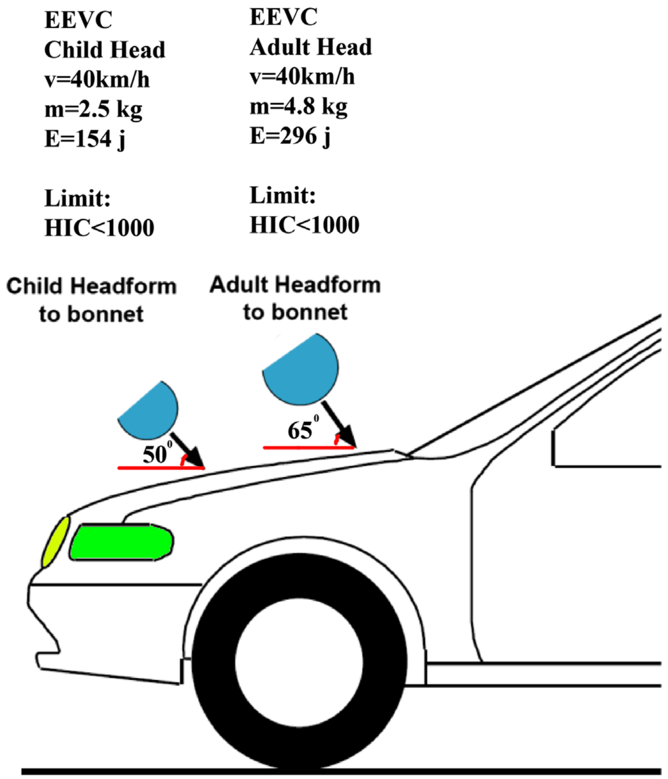

Fig. 1. A schematic of the second phase of the EEVC child and adult headform subsystem tests.

A sandwich hood design which has a potential to improve the hood's ability to absorb the impact energy of a pedestrian's head with a relatively small underhood clearance, has been represented. However, no attempt was made to assess manufacturability of the sandwich structure in this study [16].

Costin D. Untaroiu et al. have utilized recent developments in FE software using a validated headform model to investigate an FE optimization approach for hood design. At first the development and validation of an adult headform impactor finite element (FE) model have been presented in this study. A generic hood design including buckling aluminum spools connected to two cover plates is proposed for the study. The geometric characteristics of a cylindrical spool shape, together with the thickness of upper and lower hood plates, are considered as the design variables [4].

All of the designs that have used a modified inner layer, have changed hood material (mostly to the aluminum or composite) to reduce stiffness. Using steel in automotive industry has many advantages including low cost, easy shaping, good corrosion resistance with zinc cover, weldability, recyclability and good energy absorption in accidents. Considering these advantages, there is a need to propose a hood design, which is made of steel and can satisfy pedestrian safety requirements.

In this paper, some new designs have been proposed for hood inner structure, which are made of steel. They will be able to meet hood structural strength requirements (i.e. torsional and latch beam loads requirements) and at the same time can fulfill the requirements of the second phase of the EEVC regulations for pedestrian head safety. For this purpose, four new inner structures have been developed by replacing the inner parts of the original inner structure with four uniquely shaped panels with numerous hemispheres, cones, waves and combination of waves and cones.

The impacts of standard child and adult headforms to these five different designs have been simulated in this study. ABAQUS, an explicit finite element code was used to simulate the impacts. At first, the development and validation of numerical adult and child