Simulation and Test Validation of Windscreen Subject to Pedestrian Head Impact

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Abstract

Pedestrian head impact with windscreen is one of the major causes for pedestrian severe injury or fatality. A FE model is established with shell and solid elements representing different layers of a laminated windscreen. Major strain criterion is used to deal with the failure of windscreen. Simulation results are validated by Euro NCAP pedestrian head-to-windscreen impact tests. The results show that the FE modeling of windscreen can effectively predict the pedestrian head injury and the failure pattern of the windscreen. This method can be an effective tool for vehicle pedestrian safety evaluation and development.

1. Introduction

Head injuries accounted for the highest proportion of pedestrian fatalities among the body areas injured in fatal accidents[1]. Head impacts with the windscreen are often seen among the car-to-pedestrian accidents. The most widely-used automotive windscreen today consists of two soda lime glass components adhered by a Polyvinyl butyryl (PVB) interlayer. When the glass components break under impact loading, fragments of broken glass stay adhered to the PVB interlayer, thereby reducing the possibility of occupant injury caused by flying glass fragments[2, 3].

Because of the increasing requirements on the pedestrian protection performance in the Euro NCAP new rating, the performance of pedestrian head in the windscreen tests becomes more and more important. There is an urgent need to increase pedestrian CAE predictive capability for windscreen impacts and hence develop countermeasures early in the vehicle development cycle.

Sun et al.[4] built a windscreen FE model which consisting a layer of solid element representing PVB interlayer and two glass layers of shell elements with nodes coincident to the PVB solid elements. The fracture criterion for brittle fracture based on the maximum major stress was applied to model the fracture behavior of glass and no damage was assumed for the PVB interlayer. The results show good correlation with tests under the load a quasi-static rigid sphere. Unfortunately, no quantitative analysis was done regarding to the pedestrian head injury in their study. Timmel et al.[5] used a smeared model with two shell elements of equal thickness to model the windscreen. A validation test was carried out where a spherical impactor was shot against the center of a windscreen and the acceleration of the impactor of the test was comparable to the numerical results. However, instead of the center area, the lower base area of the windscreen is more critical and harder to get good performance when pedestrian head impact occurs. There are always strong structures beneath the windscreen (i.e. screenrail and dash upper panel), which tends to cause more serious head injury and will be tested according to Euro NCAP procedure.

The main objective of this work is to establish and validate a windscreen FE model which is capable to predict the head injury. LS-DYNA® is used as the solver.

2. Euro NCAP Pedestrian head-to-windscreen Test Protocol

According to the Euro NCAP Protocol (version 5.2), to assess the pedestrian head protection performance, Wrap Around Lines (WAL) and Side Reference Lines (SRL) divide the bonnet and windscreen into 12 zones, 6 for adult head (A1~A6) and 6 for child head (C1~C6). Each zone will be impacted to assess the pedestrian head protection performance. Each zone is further divided into 4 quarters named A, B, C and D (shown in Fig 1). In each zone, one position in one quarter is selected by Euro NCAP. In the same zone, the manufacture can choose to nominate 1 to 3 quarters and Euro NCAP will select another impact position to represent the nominated quarter(s). For each quarter, the full score is 0.5 points[6]. For adult head impact on the windscreen, a headform of 4.5kg is shot to the windscreen with 40km/h and 65° to the Ground Reference Level (shown in Fig 2). The lower base of the windscreen is often chosen since it is deemed as most potentially injurious.

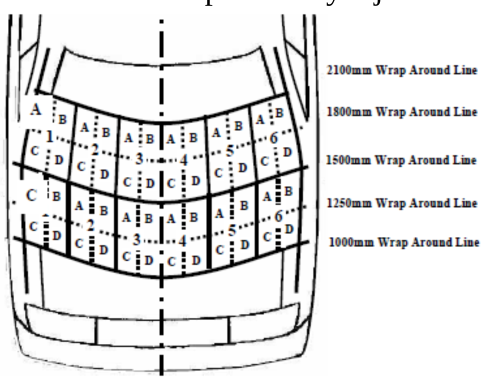


Fig 1 Euro NCAP pedestrian head test area

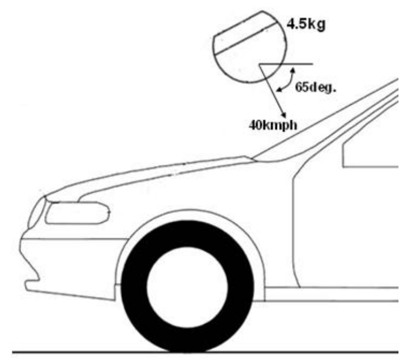


Fig 2 Adult headform impacting the windscreen

Head Injury Criterion (HIC) is used to evaluation the severity of injury, which is calculated based on head acceleration as follows.

$$\mathrm{HIC} = \max_{t_1 < t_2,\ t_2 - t_1 \le 15\mathrm{ms}} \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}$$

According to Euro NCAP protocol, 0.5 points will be awarded when HIC is below 1000 while no points when HIC is above 1350. When HIC falls between the two limits, the score is calculated by linear interpolation.

3. FE Model Description

One passenger car is marked up according to Euro NCAP protocol and two impact positions (A3B and A5B) at the windscreen lower base are selected shown in Fig. 3.

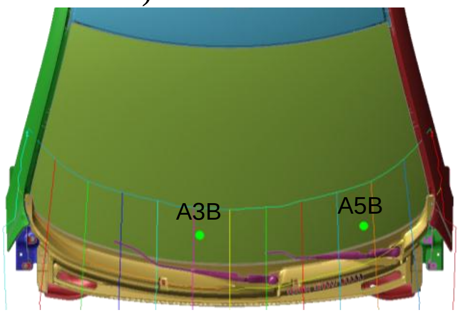


Fig 3 Adult head impact position

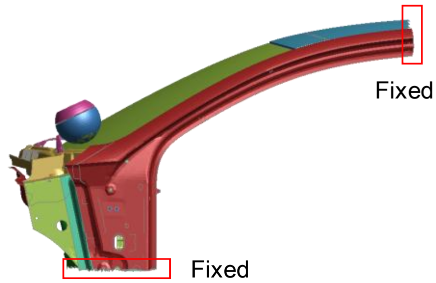


Fig 4 FE model of headform-to-windscreen impact

3.1. Headform and car FE model

The FE model showing adult headform impacting the windscreen with the required speed and angle is shown in Fig. 4.

The car model is simplified from the whole vehicle model and includes those components such as windscreen, A pillar, screenrail, roof, windscreen adhesive and wiper beam, etc. The lower end of the A pillar and the rear end of the roof are fixed as the boundary condition, shown in Fig 4. It is noted that the plastic dash board panel may have some effect to the impact performance at position A3B and A5B. However, in this study, in order to isolate the plastic dash board panel effect and focus on the windscreen, the mesh of plastic dash board panel is removed. When the validation physical test is carried out, the plastic dash board panel is also removed to make the test and simulation comparable.

*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE is used to deal with the contact between the headform skin and the windscreen and the friction coefficient is set to 0.5. For the other components, *CONTACT_AUTOMATIC_SINGLE_SURFACE is used and the friction coefficient is set to 0.2.

3.2. Windscreen FE Model

A total 5-layered mesh is used to simulate the laminated windscreen, shown in Fig. 5. The top layer and bottom layer of shell elements with 2.1mm thickness are used to represent the glass components. The middle layer is modeled with solid elements representing the PVB interlayer. To better deal with contact between the shell and solid elements, 2 layers of null shell elements with *MAT_NULL are modeled with the coinciding nodes on the upper and lower surface of the PVB interlayer solid elements. The windscreen FE model consists of 258880 shell elements and 64720 solid elements. The average size of the shell elements is 4mm*4mm. The nodes on the upper surface and the lower surface of the PVB interlayer are tied to the upper glass and lower glass layer, respectively.

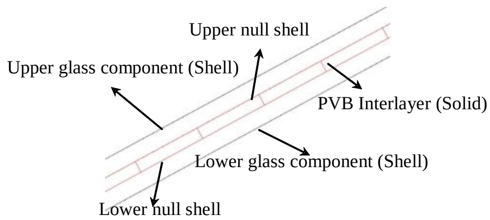


Fig 5 Windscreen FE model - 5 layered mesh (Y sectional view)

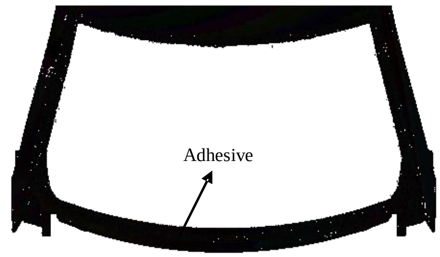


Fig 6 Windscreen adhesive (solid elements)

The lower glass component is tied to the frame with the adhesive, shown in Fig. 6. The adhesive is modeled with solid elements. *MAT_ELASTIC with density of 1250kg/m^3, Young's Modulus of 9MPa and Poisson Ratio of 0.49 is used for the adhesive.

In the short deformation case, the windscreen shows linear elastic characteristics, which is determined by the glass. For large deformation, the PVB interlayer plays the dominant role since the glass components cannot withstand large strains. When the windscreen is subjected in the pedestrian head impact, the glass components fail and still stick to the PVB interlayer. However, the PVB interlayer usually doesn't fail and still has a load-carrying capability. So in the FE model, the material property should be defined respectively.

Glass Components

The glass components show linear elastic behavior and then brittle failure when a certain criterion is reached. Sun el at. used a simplified User-Routine material model for the simulation available in ABAQUS/Explicit. Once the critical major stress is exceeded, the element of glass is deleted[4]. In LS-DYNA, *MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY can be equivalently used. Once the critical major strain is exceeded, an element is deleted. The failure stress is dominated by the intrinsic inside the glass, normally from 10MPa to 60MPa[7]. In this paper, the failure stress is defined as 50MPa and the critical major strain is set to 0.1%. 2500kg/m^3, 70GPa and 0.24 are used for density, Young's modulus and Poisson's Ratio, respectively.

PVB Interlayer

PVB interlayer can be seen as nearly incompressible with Poisson's Ratio of 0.49 and density of 1100 kg/m^3. It can be modeled as hyperelastic material such as Blatz-Ko material, Mooney-Rivlin material and Ogden material[5]. In this paper, *MAT_MOONEY-RIVLIN_RUBBER is used. A standard function to describe rubber-like behaviour is the material law given by Mooney and Rivlin[8]. The strain energy density function is determined by constants A, B and Poisson's Ratio and defined as:

$$W = A(I_1 - 3) + B(I_2 - 3) + C\left[\frac{1}{I_3^2} - 1\right] + D(I_3 - 1)^2$$

$$C = 0.5A + B,\ D = \frac{A(5\nu - 2) + B(11\nu - 5)}{2(1 - 2\nu)}$$

Where

$I_1,\ I_2,\ I_3$ are invariants of right Cauchy-Green Tensor,

Shear modulus $G = 2(A + B)$,

Young's modulus $E = 2G(1 + 2\nu)$,

Previous studies[4,5] have shown that for PVB interlayer, when constant A and B are set to 1.45MPa and 0.06MPa, the simulations show a good correlation with tests. In this paper, the same value is used.

Null Shell Layers

The aim to model 2 layers of null shell elements with the coinciding nodes on the upper and lower surface of the PVB interlayer solid elements is to better deal with contact between the shell and solid elements. *MAT_NULL is used with the same Young's modulus and Poisson's ratio as the PVB interlayer. The thickness of the null shell is 0.5mm.

4. Results and Analysis

4.1. Acceleration pulse and HIC

The simulation results of the normalized acceleration pulse of the adult headform at A3B and A5B are shown in Fig. 7 and Fig. 8, respectively, and compared with physical test results. For both positions, the correlation of the acceleration pulse as well as HIC between the simulation and the test are good. Take A3B as example shown in Fig. 7, The acceleration pulse has two peaks. The first peak is relatively small and the duration is about 2ms due to the brittle failure characteristic of glass component. After the first peak, the PVB interlayer takes over and carries the load and the acceleration of the headform increases. Starting from time 9ms, the headform contacts with the flange of cross beam for plastic dash board fixation and the acceleration increases more rapidly, see Fig. 9. At time 12ms, the acceleration goes to the peak because the max deformation of cross beam is reached. HIC is only decided by the second peak of the acceleration pulse, both in the simulation and test case. In the simulation, the duration of the second peak is longer than that in the test, which results in a higher HIC.

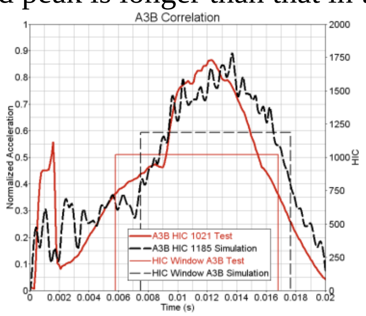


Fig 7 Acceleration and HIC Correlation between simulation and test results at A3B

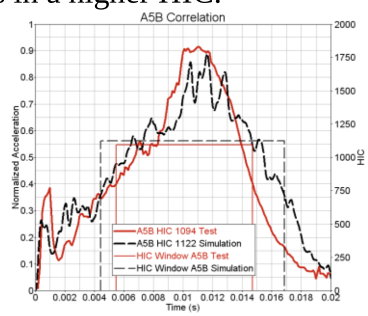


Fig 8 Acceleration and HIC Correlation between simulation and test results at A5B

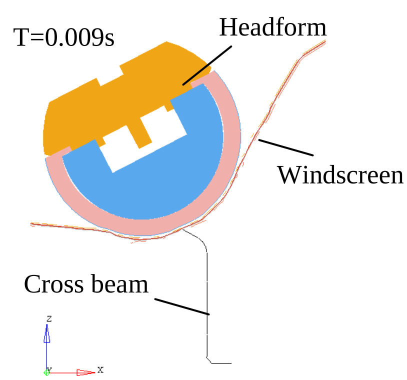
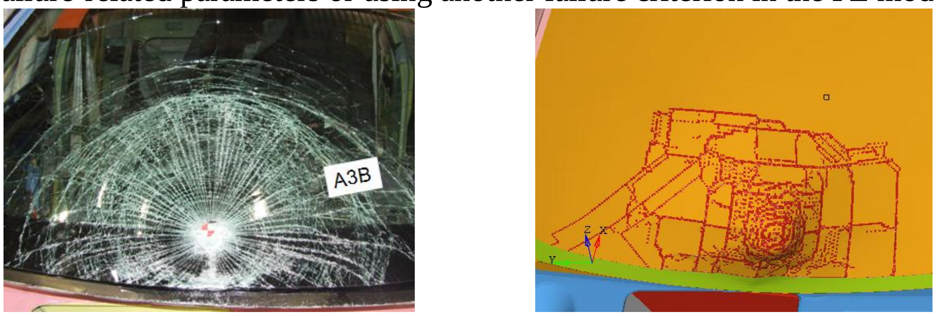


Fig 9 Headform impact with the dashboard cross beam (steel)

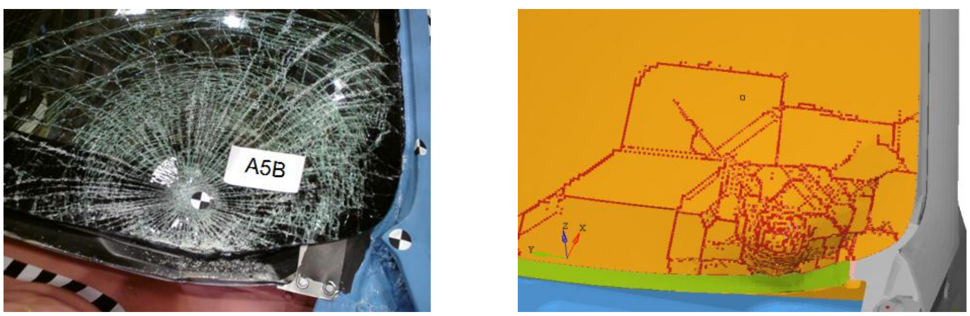
4.2. Failure pattern of windscreen

The comparison of windscreen failure pattern between test and simulation for two impact positions are shown in Fig. 10 and Fig. 11, respectively. The scopes of failure for the test and the simulation are comparable. Fig. 12 shows the failure propagation of the windscreen subject to headform impact at position A3B. A circumferential crack and a spider-web crack are observed in the test. While in the simulation, these two kinds of cracks can also been observed but a circumferential crack is more obvious. This can be further improved in future study by tuning the failure-related parameters or using another failure criterion in the FE model.



(a) Test result at A3B (b) Simulation result at A3B

Fig 10 Comparison of windscreen failure pattern between test and simulation at A3B



(a) Test result at A5B (b) Simulation result at A5B

Fig 11 Comparison of windscreen failure pattern between test and simulation at A5B

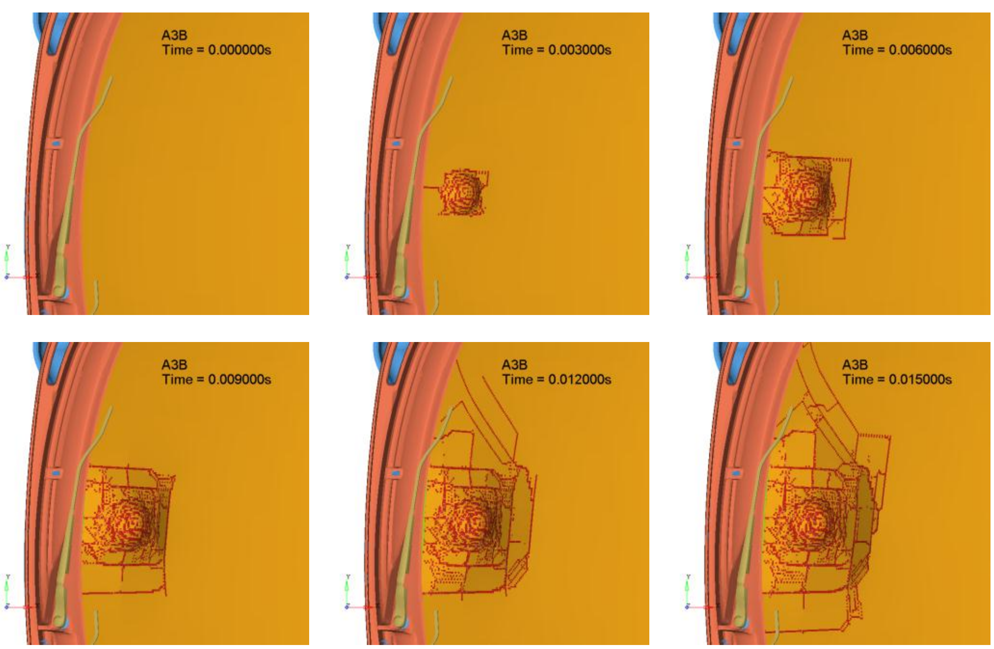


Fig 12 Failure propagation of the windscreen at A3B

5. Summary

The laminated windscreen is modeled as a 5-layered mesh, which consists of 2 layers of shell elements for glass components, 1 layer of solid elements for the PVB interlayer and 2 layers of null shell elements to better deal with the contact. The glass components are characterized with brittle failure using major strain criterion while no failure is assumed for the PVB interlayer. The simulation results show a good correlation with Euro NCAP head-to-windscreen test results in terms of the acceleration pulse and HIC. This modeling method can be an effective tool for vehicle pedestrian safety evaluation and development.

Future study can be extended to investigate the failure pattern of the windscreen and its relationship with injury severity. The plastic dash board should be also taken into account when designing detailed countermeasure for pedestrian head protection.

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