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Computation modeling of laminated crack glass windshields subjected to headform impact

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ABSTRACT

Polyvinyl butyral-laminated glass has been extensively applied to automotive windshields to reduce the severity of head injuries resulting from pedestrian–vehicle crashes. Thus, designing an optimized pedestrian protection design for laminated windshields (LWs) has become a priority. In this study, finite element models that describe LWs, headform, and sub-frontend vehicles are established to numerically investigate the dynamic mechanical behavior of LWs subjected to headform impact. First, headform impact tests are conducted on five different locations on an LW. Second, a single-layered model for LW is proposed using a formatted material constitutive description. A reasonable consistency is observed between the numerical simulation and test results for the acceleration–time behavior of LWs. Third, a triple-layered LW model is devised to provide a highly realistic cracking morphology with an enhanced impact response for LWs. Fourth, the characterized material constitutive properties are applied to LWs with different thicknesses on another vehicle. The simulation and test results show a satisfactory correlation, thereby providing a solid foundation for formulating pedestrian protection design guidelines for LWs to reduce the severity of head injuries resulting from pedestrian–vehicle crashes.

1. Introduction

Automotive accidents have sharply increased in number in recent years [1,2] and have become one of the major causes of deaths worldwide [2], particularly among vulnerable road users (VRUs) [3,4]. In VRU–vehicle crashes, the contact between the head of a VRU and the windshield is statistically confirmed as the leading cause of fatal head injuries or death [5–9]. Therefore, improving the pedestrian protection performance of windshields is crucial. To evaluate the pedestrian protection performance of windshields in pedestrian–vehicle crashes, a head–windshield impact test must be performed according to the pedestrian testing protocol of the European New Car Assessment Program (Euro NCAP). An accurate head–windshield impact simulation must also be performed instead of expensive, time-consuming physical tests to help automotive manufacturers predict the pedestrian protection performance of windshields. Therefore, an accurate and robust laminated windshield (LW) model must be proposed. Peng et al. [10], Kang et al. [11], and Liu et al. [12] performed a series of impact experiments and correlated the results of these experiments with those of numerical simulations. Using an accurate LW model can easily indicate the severity of headform injuries and detect the pedestrian protection performance of windshields via simulations without the need to perform preliminary tests.

Polyvinyl butyral (PVB)-laminated glass is manufactured by compressing two sheets of annealed glass and a PVB interlayer under high temperature and pressure. Meanwhile, annealed glass or annealed float glass is manufactured through a float process [13]. Accordingly, numerous researchers have attempted to study the mechanical behavior of PVB- and composite-laminated glass

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from the component material aspect. For PVB, Iwasaki et al. [14] proposed a nonlinear constitutive model based on stress–strain curves obtained from quasi-static tensile tests. Xu et al. [15] reported the mechanical behavior of PVB under dynamic compressive loading with strain rates ranging from 700/s to 4500/s. Zhang et al. [16] and Hooper et al. [17] experimentally studied the dynamic tensile mechanical behavior of PVB by conducting a series of dynamic tensile tests. Based on experimental data, Zang et al. [18] proposed the modified Johnson–Cook model that comprehensively described the rate-dependent characteristics of PVB under dynamic tensile loading by using the stress–strain curves under different strain rates. This model also covered those loading

Table 1
Individual initial impact velocities for the five tests.

	Impact point 1	Impact point 2	Impact point 3	Impact point 4	Impact point 5
Velocity (m/s)	9.770	9.640	9.640	9.690	9.660

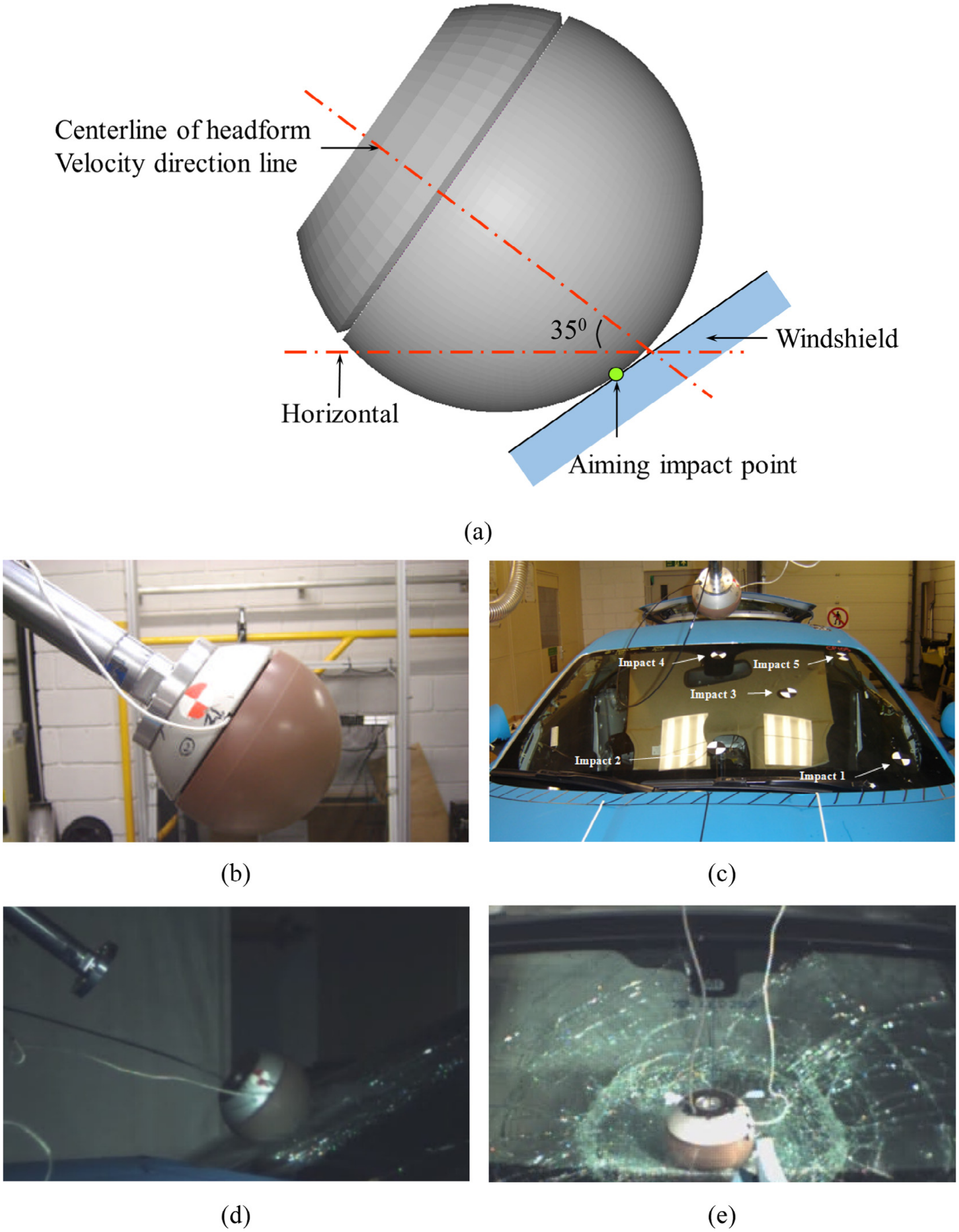

Fig. 1. (a) Abbreviated illustration of the contact condition when the headform initially impacts the windshield. Main equipment, process, and results for this test: (b) Headform impactor. (c) Test vehicle. (d) Impact process. (e) Impact result at impact point 2.