# Impact Behaviors of Laminated Glass Plate System Due to Foreign Object

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***Abstract*— Foreign object impact on laminated glass plate that is used automotive window glass can be caused internal damage that reduces the strength of the material of window glass significantly. Impact behaviours on automotive glass window like laminated glass is studied by the use of the coded plate finite element approach. To predict the Impact behaviors of laminated glass plates, an effective finite element simulation based on the Whitney and Pagano's First-order Shear Deformation Theory (FSDT), Hertz's contact law and Dharani's PVB interlayer model is carried out. Consequently, Impact behaviors of MG plate system is more sensitive than those of LG plate and prone to more fracture risk. And we can see that the magnitude of PVB thickness in LG plate system does not affect so much on dynamic behaviors like contact force, contact duration, deformation, kinetic energy and wave propagation etc. except in-plane stress.**

***Index Term*— Impact behaviors, Foreign object, Laminated glass plate, Glass thickness, Polyvinyl butyral (PVB).**

## 1. INTRODUCTION

Laminated glass (LG) plate system consists of multilayer of glass plies adhered by a polyvinyl butyral (PVB). Glass plies are separated by a PVB interlayer that prevents the glass plies from damage by foreign object impact and then, reducing the possibility of body injury. But unlike the monolithic glass (MG) plate composed of a brittle material, LG plate can reduce the number of dangerous flying fragments as many fragments are adhered by a PVB interlayer. The main purposes of the PVB interlayer are to provide absorption of dynamic energy and adhesion to the two glass plies. Therefore, the PVB interlayer can be acted as a barrier avoiding failure, penetration and fracture. But in spite of their advantages, the efficient application of LG plate is limited because of the difficulties in their optimization at the preliminary stage of their design.

For optimal design for LG plate is required a thorough study of the impact behaviors of automotive LG due to impact.

The impact responses of isotropic materials and composite laminates subjected to static and dynamic loading have been studied in terms of analytical and numerical works by Whitney and Pagano's First-order Shear Deformation Theory (FSDT) [1, 2]. Many papers about contact law and PVB effect on impact of two materials and LG plate for architectural applications have been studied by Hertz and Dharani [3, 4].

In this study, Whitney and Pagano's First-order Shear Deformation Theory (FSDT) based on Hertz contact law and Dharani's PVB model law is used to predict the overall dynamic responses on the MG and LG plates. The dynamic responses such as the histories of contact force, deflection, wave propagation and in-plane stress during impact are obtained to study PVB interlayer effect for the LG plates. From these results, the impact behaviors of LG plate are compared with those of the LG plates with different thickness of the same total glass thickness, and PVB interlayer effect on the impact behaviors of LG plate due to foreign object is also studied.

## 2. IMPACT FINITE ELEMENT MODEL

Assume a quarter model of LG plate consisting of three layers of total thickness $h$ subjected to low velocity impact by an impactor of radius $R$ with initial impact velocity $V_0$. And then, the model is assumed to be impacted at the center by an impactor with radius 6.35mm as shown in Fig. 1.

To study the impact response between glass plate and impactor, the element displacement function by Whitney and Pagano [1] is taken. FSDT in consideration of Hertz's contact law [3] that both loading and unloading process is conducted for the study of the impact response of the MG and LG plates with the same total glass thickness subjected to small mass impact. The thicknesses of the MG and LG plates considered are 12mm and 12.76, 13.52, 14.28mm, respectively. In other words, PVB interlayer of LG plates have 2, 4 and 6 interlayers (thickness of 1 interlayer=0.38mm).

Similar processes for impact finite element simulation were presented in Ref. [5, 6] in detail.

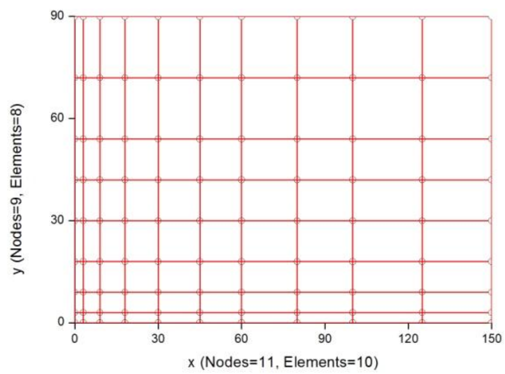


Fig. 1. A quarter model of LG plate system

## 3. RESULTS AND DISCUSSION

Fig. 2 shows contact force histories for various PVB interlayer thicknesses at 30μs at same total glass thickness under impact loading. From Fig. 2, the maximum contact forces for both the MG and LG plates occur at around 15μs after the initial impact. We can see that the maximum contact force in the MG plate is a little (3-5%) larger than those of LG plate, but PVB thickness in LG has no significant effect on contact force for small mass impact. And also, we can see that the deflections of plate in LG plate are larger than that of the MG plate, and the higher the thickness of PVB interlayer in LG plate, the higher the magnitude of deflection becomes.

Fig. 3 shows the relationship of contact force and plate deflection of the MG and LG plates with same total glass thickness due to impact loading. Fig. 3 depicts the identical results as the same as Fig. 2 because of low flexure stiffness of PVB interlayer at given velocity. We can see that the maximum contact force does not occur at the maximum deflection. It shows a typical wave-controlled impact that the plate deflection is localized to the region around the impact point, and the contact force and deflection are never in phase [7].

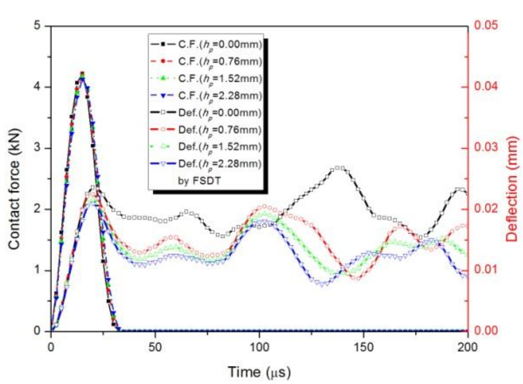


Fig. 2. Contact force histories for various PVB interlayer thicknesses at 30μs

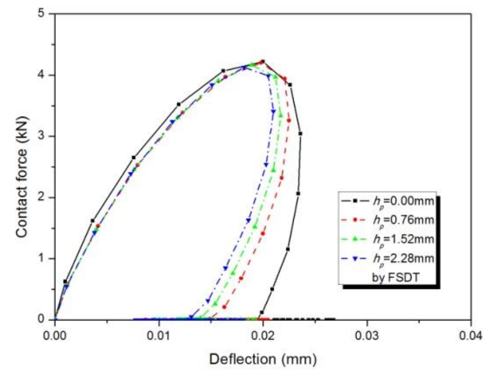


Fig. 3. Comparison of contact force and deflection for various PVB interlayer thicknesses

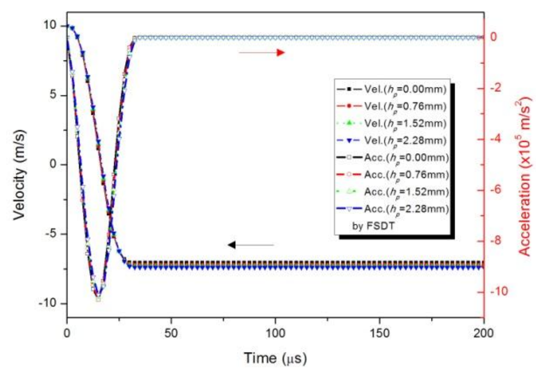


Fig. 4. Velocity histories for various PVB interlayer thicknesses

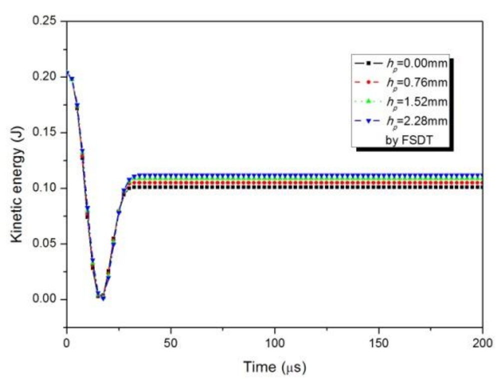


Fig. 5. Kinetic energy histories for various PVB interlayer thicknesses

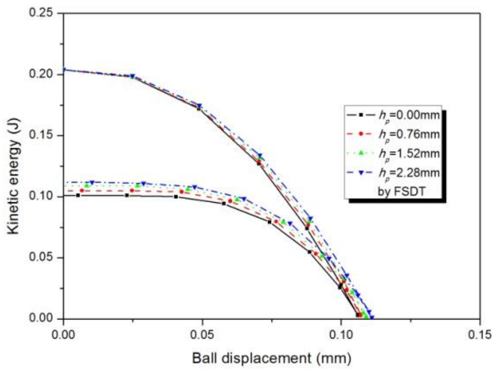


Fig. 6. Comparison of kinetic energy and ball displacement for various PVB interlayer thicknesses

Velocity and kinetic energy histories for various PVB interlayer thicknesses are given in Figs. 4 and 5. The velocity and energy at the time zero are the initial velocity and energy of impactor at which the impactor hits the target. Velocity curves of Fig. 4 decrease and take negative values and remain constant by time. These negative values represent rebound velocity of the impactor. Minimum kinetic energy in Fig. 5 occurs when velocity is zero. At Fig. 5, the lowest tip of the curve shows minimum kinetic energy and the end of curve that remains constant shows the rebound energy. And also, the energy difference between initial energy and rebound energy becomes absorbed energy by target.

From Fig. 4, we can see that velocity histories for LG plates except the MG plate are independent of the thickness of PVB interlayer. It can be seen that from Fig. 5 the existence of PVB interlayer between the MG and LG has significant effect on rebound energy but PVB thickness in LG plate does not affect so much. From Fig. 6, three closed loops of kinetic energy-displacement curve for LG except the MG have approximately same area. And also, it can be seen that from Fig. 6, PVB interlayer number is no significant effect on kinetic energy.

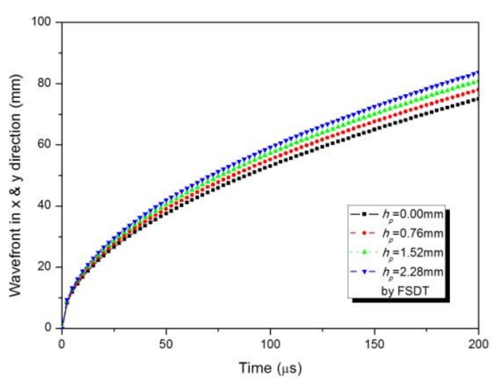


Fig. 7. Wavefront histories in *x*-direction at impact point for various PVB interlayer thicknesses

Fig. 7 shows wavefront histories in *x*-direction at impact point for various PVB interlayer thicknesses obtained from this analysis in consideration of wave propagation model. From Fig. 13, we can see that the higher the thickness of PVB interlayer in LG plate is, the larger the wavefront becomes because of the bending rigidity of plate even though the difference is a little. But because the difference of wavefront due to various thickness of PVB interlayer of LG plate except the MG plate is very small, it can be concluded that the thickness of PVB interlayer is no significant on the magnitude of wavefront.

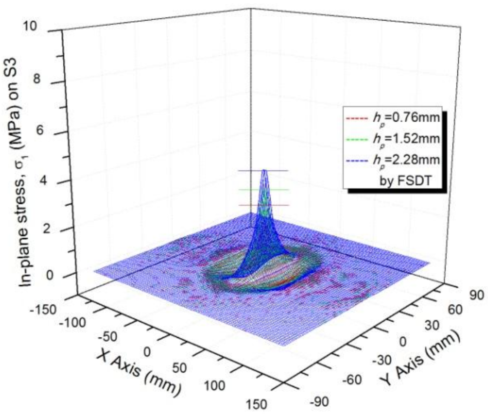


Fig. 8. The in-plane stress histories for MG and LG plate with various thickness on S3 at 15μs

Fig. 8 depicts the in-plane stress histories for MG and LG plates with various thicknesses on S3 (under side of PVB interlayer) at 15μs. We can see that in-plane stress of LG plate is larger than that of MG plate unlike result shown on S4.

## 4. Conclusion

In this study, a simple and effective finite element simulation based on Whitney and Pagano's First-order Shear Deformation Theory (FSDT) and Hertzian contact law for the impact responses of MG and LG plates under impact by foreign object. is suggested. Impact behaviours such as contact force, energy, wave propagation and stress in MG plate system is more sensitive than those of LG plate system in the same glass thickness and prone to more damage risk. This means that PVB interlayer of LG plate system may eventually be protected from impact failure and LG plate system is more impact resistant than MG plate system. But we can see that the variation of PVB thickness of LG plate system does not affect so much on impact behaviours. And also, PVB interlayer number is no significant effect on kinetic energy of LG plate. In addition, the maximum stress by this impact analysis is observed at top (S1) and bottom (S4) surface of glass plate and the minimum stress at PVB surfaces (S2 and S3) of LG plate. That is, it means that the PVB interlayer between two glasses by small mass impact is essential for protection the inner glass from damage of foreign object. These results of this study may be suggested a guideline in making some preliminary design considering dynamic behaviours for multilayer (glass/film/glass etc.) with different material properties in the future.

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