International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 19 (2018) pp. 14469-14472
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The Film Effect on the Impact Behavior of the Coating Glass Plate by Higher-Order Finite Element

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Abstract

To study the film effect on the impact behavior of the coating glass plate, a refined Higher-order Shear Deformation Theory (HSDT) connected with a generalized power law instead of Hertz's contact law are suggested, and its analysis result is compared with wave propagation model and energy balance model to verify the reliability of the analysis result. Through the impact analysis by the higher-order finite element, the behaviors like contact force, deflection and in-plane stress in monolithic glass plate are more sensitive than those of coating glass plate and prone to more fracture risk. But we can also see that variation in thickness of coating film does not affect impact behaviors very much.

Keywords: Film Effect, Coating Glass, Higher-Order Finite Element, Impact Behavior

INTRODUCTION

The tempered glass used in automobiles, buildings and electronic equipment is coated using film to protect the surface and to protect against external impacts. However, there is still a lot of research left on the optimal design of coating glass to protect the fragile material from impact. Thus, in this study, the effects of coating film are analyzed when coating materials are subjected to external impacts by applying the generalized power law [1] and more sophisticated higher-order theory [2] without the use of the Hertz contact law [3] and a general plate theory [4].

NUMERICAL SIMULATION

1. Finite element model

For numerical analysis, the glass thickness and the coating film thickness are assumed to be h and h_f respectively, and the steel ball with a radius of R is subjected to impact at initial velocity V_0. However, the initial velocity is such that the glass layer is not destroyed. The displacement components at a point at any distance z from the reference plane (middle plane of the plate) are as follows [2]

[HSDT]

$$u(x, y, z, t) = u_0(x, y, t) + z[\varphi_x - (4z^2/3h^2)(\varphi_x + w_{,x})]$$
$$v(x, y, z, t) = v_0(x, y, t) + z[\varphi_y - (4z^2/3h^2)(\varphi_y + w_{,y})] \quad (1)$$
$$w(x, y, z, t) = w_0(x, y, t)$$

where (u_0, v_0, w_0, φ_x, φ_y) are unknown functions to be determined.

And a generalized power law [4] of contact force and indentation relation is as follows

$$F = CE_s\delta^p \quad (2)$$

where F, δ, p and CE_s are the contact force, indentation, power and contact stiffness, respectively.

Next simulation processes are discussed in Ref. [5, 6].

2. Wave propagation model (WPM)

By wave propagation model [7], the contact force is given by

$$F = [k^2M^3V^6]^{1/5}\overline{\alpha}^{3/2} \quad (3)$$

The wavefront a in the x-direction is calculated using

$$a = 2\sqrt{\pi}\left(\frac{D_{11}}{m}\right)^{1/4}\left[2(A+1)\right]^{1/8}\sqrt{t} \quad (4)$$

where $A = (D_{12} + 2D_{66})/(D_{11}D_{22})^{1/2}$

The wavefront b which provide an estimate of the size of the deformed zone in the y-direction is located at

$$b = a/(D_{11}/D_{22})^{1/4} \quad (5)$$

where D_{ij} are the bending stiffness.

3. Energy balance model (EBM)

By the energy balance model [7], the maximum contact force and the contact duration are given by

$$F = \left(\frac{5}{4}\right)^{3/5}\left[M^3V^6K^2\right]^{1/5} \quad (6)$$

$$T = 3.2145\left[\frac{M^2}{VK^2}\right]^{1/5} \quad (7)$$

RESULTS AND DISCUSSION

To verify the reliability of this simulation result, first the two theoretical analyses (WPM and EBM) are presented by comparing maximum contact force and contact duration in Table 2. Table 2 shows that there are some errors in maximum contact force but the overall trend is well matched, and the contact duration is pretty much the same.

Table 2: Comparison of present result and wave propagation model and energy balance model: Max. contact force & Contact duration

PET thickness (mm)		Max. contact force (N)		
		Present result	Wave propagation model (WPM)	Energy balance model (EBM)
		HSDT	HSDT	HSDT
MG	0.0	2,130	2,180	5,200
CG	0.2	369	292	320
	0.4	371	301	328
	0.6	373	313	335

PET thickness (mm)		Contact duration (μs)		
		Present result	Wave propagation model (WPM)	Energy balance model (EBM)
		HSDT	HSDT	HSDT
MG	0.0	50.0	28.0	28.8
CG	0.2	450.0	469.0	469.0
	0.4	445.0	458.0	458.0
	0.6	440.0	448.0	448.0

Fig. 1 shows the results [the histories of contact force, plate deflection, ball displacement and indentation for Monolithic Glass(MG) and Coating Glass(CG)] obtained from the present analysis by HSDT. From Fig. 2 it is shown that the maximum contact forces for MG and CG in h_f=0.2mm occur at 25μs and 225μs and the contact durations are 50μs and 450μs after the impact, respectively. It shows a typical wave-controlled impact phenomenon as shown in Fig. 2 where maximum contact force does not occur on the same phase as maximum deflection. And also the maximum contact force at MG is about nine times that of CG. In case of MG the deflection appears to be very vibrating, but in case of CG it is gradually increased. This is due to the great strength of the MG material.

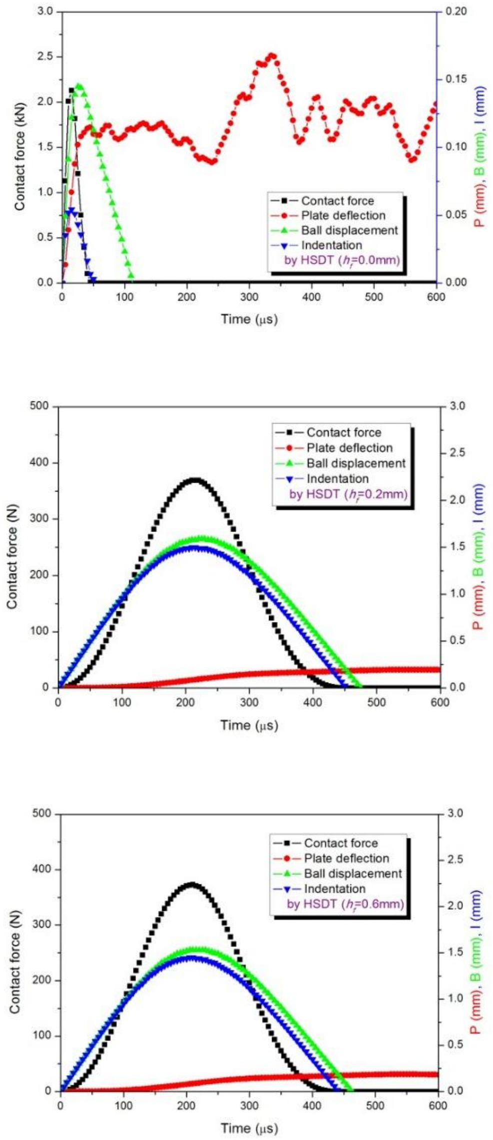


Figure 1. Histories of contact force, deflection, displacement and indentation of MG and CG by HSDT

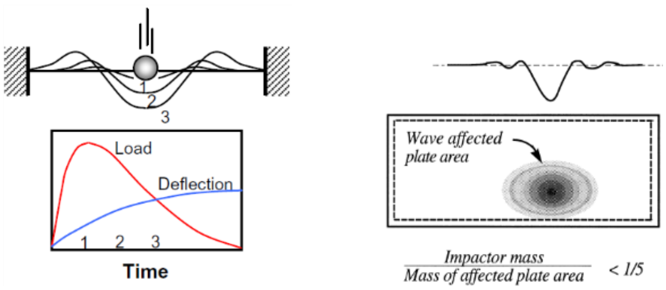


Figure 2. Wave-controlled impact phenomenon (Olsson[8, 9]).

Fig. 3 shows the contact force and plate deflection histories of MG and CG in film thickness variation by HSDT. Although the contact force and deflection histories between MG and CG show a large difference, it can be seen that there is little change from the analysis results in film thickness variations of CG. And Fig. 4 shows the stress histories of MG and CG in film thickness variation by HSDT. This also shows the same tendency as the results of contact force and deflection histories. Fig. 5 shows the stress histories on each layer of CG (h_f=0.2*mm*) material by HSDT. Fig. 5 shows the maximum compression stress (-40*MPa*) on the surface S2, maximum tension stress (38*MPa*) on the surface S3, and near zero stress on the surface S1. In case of MG the maximum stress on both sides of the glass causes rapid damage, but in case of CG the minimum stress is generated at the top of the glass S2, below the impacted film, to minimize the damage. Fig. 6 depicts the maximum stress on each surface in film thickness changes. From Fig. 6, MG shows maximum (150*MPA*) and minimum (-125*MPA*) stresses on both sides of the glass since there is no film, and CG shows very small stresses (45*MPA* and -45*MPA*) on both sides of the glass as opposed to the film surface. And since there is little change in maximum stress even after changing film thickness, In order to protect the glass from impact, it indicates that the presence of film in CG materials is very significant but film thickness has not a significant influence in side of impact behavior. The maximum stress generated in CG represents 1/3 times of the maximum stresses of the MG and thus quantitatively predicts the impact absorption effects of the film, which can contribute significantly.

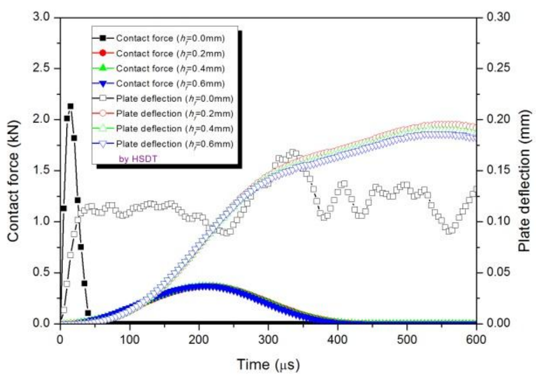
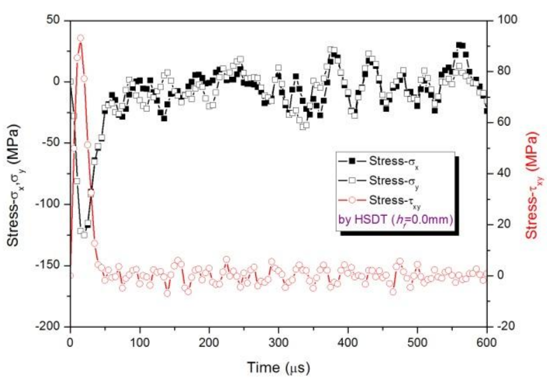
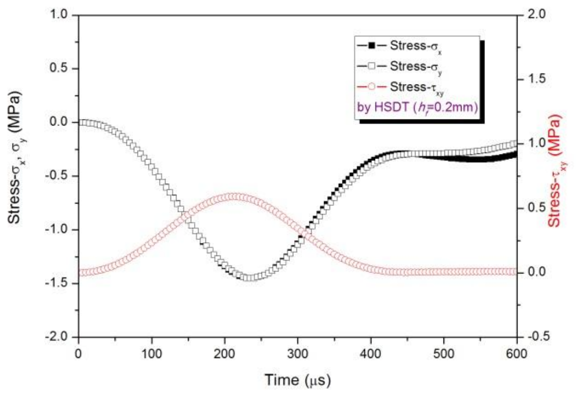


Figure 3. Histories of contact force and plate deflection of MG and CG in film thickness variation by HSDT



(a)



(b)

Figure 4. Histories of stress of MG and CG in film thickness variation by HSDT

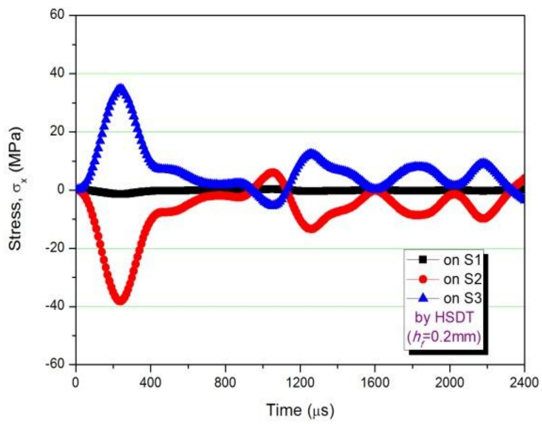


Figure 5. Histories of stress in x-direction on each layer of CG

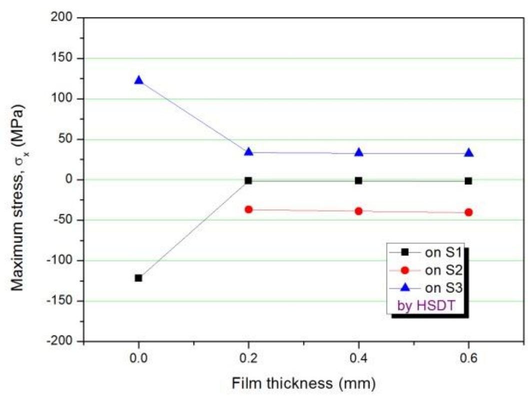


Figure 6. Relationship of maximum stress in x-direction and thickness of coated film on each layer of MG and CG

CONCLUSION

In this study, the effects of coating film are analyzed when coating materials are subjected to foreign object impact by applying the generalized power law and more sophisticated higher-order theory. And this higher-order theory was applied to the impact analysis and compared with the two theories to demonstrate reliability and validity. Through the analysis by the higher-order shear deformation plate theory, the behaviors like contact force, deflection and in-plane stress in monolithic glass plate are more sensitive than those of coating glass plate and prone to more fracture risk. But we can also see that variation in thickness of coating film does not affect impact behaviors very much.

ACKNOWLEDGEMENT

This work was supported by Gyeongnam National University of Science and Technology Grant 2018.

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