IMPACT RESPONSE OF THE FILM MECHANICAL PROPERTIES OF THE COATED GLASS PLATE

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ABSTRACT

The influence of film property on dynamic behavior of the coated glass plate under foreign object impact is studied by the developed numerical simulation program. To analysis the impact responses, a powerful numerical simulation in conjunction with the Reddy's theory and a generalized power method is suggested. The properties of films of coated glass, i. e. the elastic modulus, change, but not the properties of glass. Four typical film and glass combinations, namely, $\alpha=1, 2, 5$, and 10 are assumed. We can see that as α increases, the contact force becomes smaller and plate deflection increases. That is to say, the impact response in $\alpha=1$ is much faster than that $\alpha=10$. And also, we can observe that as the ratio α increases from the results of the stress analysis through the thickness, the risk of failure of the film and the glass interface is less.

KEYWORDS: Coated Glass Plate, Film Property, Elastic Modulus & Numerical Simulation

Received: Jan 17, 2019; **Accepted:** Feb 13, 2019; **Published:** Mar 12, 2019; **Paper Id.:** IJMPERDAPR201948

INTRODUCTION

A glass plate system coated with thin film on the surface of a glass plate has been developed to counteract external wind and impact loads, and the main object of this film is to provide shock absorption, thus reducing the excess stress on the actual glass plate to protect the glass. If a coated glass plate is impacted by an impactor with sufficient speed, the glass plate will be damaged. However, unlike glass of homogeneous material that breaks and splashes the papermaking, coated glass plates can act as a barrier to prevent risk because many fragments are attached by film layers. Compared to homogeneous materials, coated glass can achieve lightness compared to the same thickness.

Contact between two objects causes contact stress not only inside the object but also on the contact surface. Hertz [1] first presented the contact theory explaining the magnitude, deformation and stress of contact surfaces due to such contact. This theory is limited to simple forms such as spheres and cylinders, but it is very helpful to establish contact behavior. The key point of Hertz contact theory is that the pressure inside the contact surface is the maximum value at the center of the contact surface and, in an elliptical form, decreases to zero with the edge of the contact surface. And the maximum shear stress occurs at the point inside the object on the contact surface, not at the center of the contact surface.

Recently, some studies on the impact behavior of laminated and coated glass plate have been extensively conducted by numerical analysis [2-5]. However, coating the film on the glass makes the deformation and stress problems of the glass plate more complicated, so the classic Hertz method can no longer be applied to characterize the relation to the indentation of coated glass plate. And, the important pressing phenomena depend on the ratio (α)

of mechanical properties of film and glass and the impactor geometry. Kurapati[6] shows that the generalized contact rules for layered plates depend on film thickness and elastic modulus etc., and the validity of the rules is demonstrated by the results of numerical analysis.

In this paper, using the Reddy's theory and a power contact law, the impact reaction considering the different mechanical properties combination of coating glass is studied through finite element simulation. It also takes into account the film properties of coated glass, i. e. the four types of film and glass combinations ($\alpha=1, 2, 5$, and 10), whose elasticity coefficients change but whose properties do not change.

THEORETICAL BACKGROUND

For numerical simulation, the coated film thickness and the glass thickness are assumed to be h_f and h_g , respectively, and the steel ball with a radius R is subjected to impact at initial velocity V_0 . However, the initial velocity is such that the glass is not destroyed. Four film and glass combinations, namely, the elastic modulus ratio, $\alpha=1, 2, 5$, and 10 , are considered. A smaller α value means hard film/soft glass, and a larger value means soft film/hard glass. Displacement components of coated glass plate are well shown in the study of Reddy [7] and a generalized power law is known represented in the Ref. [6]. Next simulation processes can see in Ref. [2-5].

RESULTS AND DISCUSSIONS

Figure 1 shows the impact responses of deflection for coated glass plate according to various ratios of $\alpha (=E_g/E_f)$ obtained from the present finite element approach. And Figure 2 shows the results for maximum contact force and duration with changes in α . From Figure 1 and 2, the maximum contact forces (contact durations) from $\alpha=1$ to 10 become about 2.96 kN ($36\mu\text{s}$), 2.24 kN ($50\mu\text{s}$), 2.63 kN ($482\mu\text{s}$) and 1.1 kN ($138\mu\text{s}$), respectively. This means that the decrease in maximum contact force gives rise to the increase in contact duration and maximum deflection, and vice versa. That is, the greater the ratio α is, the smaller the contact force but the greater the duration and deflection.

Figure 3 depicts relation of contact force-indentation with changes in α at coated glass plate. Contact forces are assumed to be approaching elastic response during the unloading process after passing the maximum value of the loading process. All work performed on the coated glass plate by the impactor in the loading process is kinetic energy. The contact force is assumed to perform the unloading course after elastic passing the maximum value of the loading course. In Figure 3, analysis results by the generalized power method show that the corresponding power $p=1.53$ of $\alpha=1.0$ such as homogeneous material is similar to that of the Hertz's law ($=1.5$), but $p=1.79, 2.07$, and 2.14 are in consistent. Table 1 shows the relation of stiffness-power by this numerical simulation. We can see that the larger the value of α , the smaller the tangents that form the contact force and the indentation. This indicates that glass plates of $\alpha=5$ or 10 are more shock resistant than glass plates of $\alpha=1$ or 2 .

Figure 1: Histories of Deflection According to the Changes of α ($=E_g/E_f$)

Figure 2: Relation of Max. Contact Force, Contact Duration and α ($=E_g/E_f$)

Figure 3: Relationship of Contact Force and Indentation According to the Changes of α ($=E_g/E_f$)

Table 1: Results of Contact Stiffness and Power by Present Simulation

System	Film/Glass			
Film Thickness (h_f , mm)	0.4			
Glass Thickness (h_g , mm)	4			
Ratio of Elastic Modulus (E_g/E_f)	1	2	5	10
Contact Stiffness (CE_2 , N/mm ^p)	0.680E6	0.301E6	0.573E5	0.896E4
Power (p)	1.53	1.79	2.07	2.14

This figure shows a similarity to a typical wave control phenomenon, indicating that the maximum value in the contact force and displacement curve does not occur at the same time [8-10]. Figure 5 and 6 depict the relationship of ball velocity-energy curves according to α , respectively. In Figures 5 and 6, it can be seen that larger the α value of the coated glass plate, the greater the rebounded energy but the smaller the absorbed energy.

Figure 4: Relationship of Contact Force and Plate Deflection According to the Changes of $\alpha(=E_g/E_f)$ **Figure 5: The (a) Velocity and (b) Energy Histories According to the Changes of $\alpha(=E_g/E_f)$**

Figure 6: Relationship of Energy and α ($=E_g/E_f$)

Figure 7 shows the stress histories on surfaces S1 (1st surface) and S2 (2nd surface) of $\alpha=1, 2, 5$ and 10 . S1 and S2 in coated glass plate. It is shown that the larger the value of α in the coated glass plate systems, the smaller stresses σ_x at S1 and S2. From this Figure, at $\alpha=2, 5$ and 10 , the stress at the S1 quickly becomes smaller and smaller than the stress at the S2. However, stresses at the S1 at $\alpha=1$ are larger than the stress at the S2. The static analysis of coated glass plates with large α value showed that the maximum stress occurs just below the ball, while the small α value results in contact surfaces of film and substrate [6]. This impact results allow us to observe the opposite facts of the static analysis. In other words, the maximum stress on ($\alpha=2, 5$ and 10) occurs just below the ball when ($\alpha=1$) compared to the contact surfaces of the film and glass. Therefore, for ($\alpha=2, 5$ and 10), contact surfaces S2 of film and glass cause more damage than other surfaces, whereas for homogeneous materials ($\alpha=1$), the S1 is exposed to more damage risks than others. Figure 8 depicts well the difference in stress with changes in α and discontinuity between film and glass surface. And if α is 10 , it will approach stress 0 faster than in other cases, preventing glass damage. Figure 9 depicts relationship of stress according to the changes of α on surfaces S1, S2 and S3.

In Figure 9, it can be seen that when the α value increases, the stress σ_x of S1 shows a rapid increase between $\alpha=1$ and 2 , but not the same trend in S2 and S3.

Figure 7: Stress Histories on Surfaces (a) S1 and (b) S2 According to the Changes of α ($=E_g/E_f$)

Figure 8: Variations of (a) Stress σ_1 & σ_2 (b) σ_{12} Through the Thickness According to the Changes of $\alpha(=E_g/E_f)$

Figure 9: Relationship of Stress σ_x and $\alpha(=E_g/E_f)$ on Each Surface

CONCLUSIONS

The influence of film property on dynamic response of the coated glass plate under foreign object impact is studied by the developed numerical simulation. To analyze the impact responses, an effective numerical simulation based on the Reddy's theory and a generalized power method is suggested. The properties of films of coated glass i. e. the elastic modulus change but not the properties of glass. Four film and glass combinations, namely, $\alpha=1, 2, 5$, and 10 , are assumed. We can see that as α increases, the contact force becomes smaller and plate deflection increases. That is to say, the impact response in $\alpha=1$ is much faster than that $\alpha=10$. And also, we can observe that as the ratio α increases from the results of the stress analysis through the thickness, the risk of failure of the film and the glass interface is less. This impact results allow us to observe the opposite facts of the static analysis. In other words, the maximum stress on ($\alpha=2, 5$ and 10) occurs just below the ball when ($\alpha=1$) compared to the contact surfaces of the film and glass. Therefore, for ($\alpha=2, 5$ and 10), contact surfaces S2 of film and glass cause more damage than other surfaces, whereas for homogeneous materials ($\alpha=1$), the S1 is exposed to more damage risks than others. Concept of these studies will be a good guide in the basic design, considering the impact with changes in the properties of the coating material.

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