Investigation the Impact Response of Fiber Reinforced Composites with a Hole

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Abstract

The analysis of the fiber reinforced laminated composite plates is a complex task, due to the exhibition of poor resistance and strength in transverse direction and discontinuity of the mechanical characteristics along the thickness of the laminates. Thus a model that can address these complexities and also remains general in its approach is required for an accurate analysis of multi-layered composite structures under general condition of loading and supports. Present research is an attempt to develop an efficient and reliable 3D-FE model to simulate the low velocity dynamic response of composite laminates with a hole using ABAQUS software.
At first, dynamic response of a laminate subjected to impulse loading is studied using a developed FE code which is based on layerwise laminate theory. The problem is then modeled by employing ABAQUS software. The results obtained from software show good agreement with those of FE code and available solutions in literature. The verified ABAQUS model is then employed for simulation of laminates with discontinuous geometry subjected to a complex dynamic loading.
Different stacking sequences and boundary conditions are considered and the effects of projectile mass, initial velocity of impactor on the contact force history and plate response are investigated.

Keywords: Fiber reinforced composites, Impact response, Finite element method.

1. Introduction

In spite of many attractive qualities, composite materials do however suffer from poor resistance to impact loading on account of their relatively low strength in non-fiber-reinforced directions. This results in damage that can cause severe structural degradation such as reduction in compressive strength. The situation is more critical for low-velocity impacts which induce significant internal damage undetectable by visual inspection. In the low and intermediate incident energies, metals absorb energy through elastic and plastic deformation, but it causes some permanent structural deformation in composites [1]. Furthermore, the prediction of the post-impact load-bearing capability of a damaged composite structure is more difficult than for metals since the damage zone is generally complex in nature and, consequently, very difficult to characterize.

The complications introduced by the anisotropic features of composite materials make the use of closed-form solutions in understanding the transient response of composite structures subjected to impact loading more difficult than those of isotropic materials [2,3]. The Hertzian classical model for contact between an elastic sphere and elastic half-space used to model impact response of homogeneous isotropic materials has often been applied to those of composite materials [4,5]. However, most of the laminated composites in use are quite thin and cannot be adequately represented by a half-space. The strain rate, which is not accounted for by the Hertzian law, may have significant effects on the force/displacement relationship. It should also be noted that most of the Hertzian contact models were developed by using static indentation tests and may not therefore be applied accurately to dynamic analyses. In view of these features many analysts have resorted to numerical techniques such as the finite-element methods. The finite-element method (FEM) has been found to be a powerful numerical tool for the analysis of composite structures under static and impact loading [6,7].

Some FE results have been reported on the dynamic response of laminated composites subjected to impact by a foreign object. These include a 3D model that assumed a pressure distribution in the impact region [8], and hybrid models based on a Hertzian-type relation between the projectile and the laminate during impact [5,9]. As noted before, the Hertzian contact models are based on an assumed contact-force distribution and on an empirically determined pressure profile. But when a projectile impacts a laminate only the velocity of the projectile could be observed; the actual force distribution between the projectile and the laminate during impact is unknown. To solve this difficulty, an FEM model for composite laminates with discontinuous geometry is presented.

2. Finite-element contact procedures

The contact between an indenter and a laminate is a complex phenomenon. Local stresses in the contact region and overall deflection of the structure are introduced simultaneously. Therefore, it is important to give an accurate account of the contact behaviour in the analysis of the impact response of laminated composites. In most of the existing researches on the impact response of composite laminates, the loading of the laminates was assumed known. This is not actually the case since the loading is a consequence of the impact between the foreign object and the plate, and has to be evaluated. Therefore, the contact algorithm should be an integral part of the solution procedure. The ABAQUS [10] impact algorithm for dynamic contact is used in the present analysis. The procedure is based on the concept of a fully plastic impact. In the FE model, the momentum of the impacting bodies remains unchanged while the points that are contacting would instantaneously acquire the same velocity in the direction of impact.

3. Governing equations

In the analysis of the composite plate, it is assumed that the material of layers are linearly elastic and obey the generalized Hooke's law. In the present study, deflections of the plate are small in comparison to the dimensions of the plate, and hence the small-deflection theory is found to be valid for the impact analysis. For small-strain theory the equilibrium equation for a body in motion is written as

$$[M]\{\ddot{U}\}+[K]\{U\}=\{F\} \quad (1)$$

where $[M]$ is the global mass matrix, $[K]$ is the stiffness matrix, $\{F\}$ is the external force vector and $\{U\}$, $\{\ddot{U}\}$ are the nodal displacement and acceleration vectors, respectively.

3.1 Contact law

The knowledge of force vector is important for the solution of Eq. (1). The structure is expected to respond dynamically away from the impactor, where conventional theories of plates and shells can be applied to predict the behaviour of the structure [11]. It has been found that near the point of impact the inertia forces are small compared with those of impactor, so that although the dynamic response of the structure may be needed to find the impactor-force history, the nature of the stress field can be analyzed as if subjected to a quasi-static force. The first attempt to incorporate a theory of local indentation was based on a scheme suggested by Hertz [12], who viewed the contact of two bodies as an equivalent problem in elastostatics. The Hertz contact law can be expressed as $f = k\alpha^{3/2}$, where f is the scalar contact force and α is the difference between the displacement of the impactor and that of the centre of the plate and k is modified Hertz constant whose should be calculated experimentally or numerically.

4. Results and discussion

At first an FEM code is developed based on a layerwise theory for modeling impulse response of composite laminates. The results are compared with ABAQUS model presented for dynamic response and then, the verified model is employed for low velocity impact.

4.1 Transient analysis

An anti-symmetric (-45/45) composite laminated subjected to a transverse dynamic step load with intensity of q_0 and the following properties is considered. The results developed by FEM code is compared with those of ABAQUS solution.

$$a = b = 25\ cm, \quad h = 1\ cm, \quad \rho = 8 \times 10^{-6}\ Ns^2 / cm^4$$
$$E_1 = 52.5 \times 10^6\ N/cm^2, \quad E_2 = 0.04E_1 = 2.1 \times 10^6\ N/cm^2, \quad E_3 = E_2$$
$$G_{12} = G_{13} = 0.5E_2 = 1.05 \times 10^6\ N/cm^2, \quad G_{23} = 0.4E_2 = 0.84 \times 10^6\ N/cm^2, \quad \upsilon_{12} = \upsilon_{13} = \upsilon_{23} = 0.25$$

where *a*, *b*, and *h* are dimensions of plate in *x*, *y* and *z* directions, respectively. The nondimensionalized center transverse deflection $\varpi = \omega_0 (E_2 h^3 / q_0 a^4) \times 10^2$ of plate is shown in figure 1. It is clear that the ABAQUS model predicts the dynamic response precisely in comparison with the 3D-FEM code.

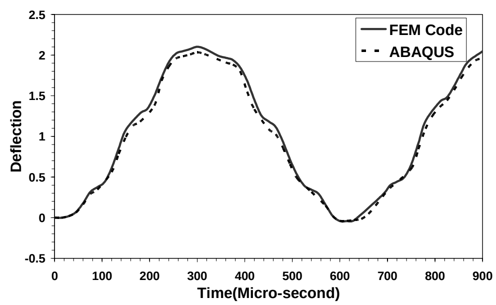


Figure 1: Comparison of results developed by FEM code with ABAQUS solution

4.2 Low velocity impact

A plate with sides *a=b=254*mm is considered, where *a* and *b* are dimensions of plate in *x* and *y* directions, respectively. It has a thickness of *h=6.35*mm. It is assumed that the plate is impacted at the center with an initial velocity of 2.54m/sec and the four edges are simply supported as shown in figure 2. The mass of impactor is 0.1kg and its radius is 6.35mm and the radius of hole is 6.35mm.

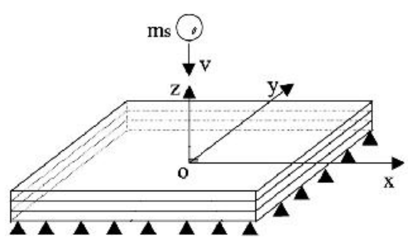


Figure 2: The coordinate system and the geometry of composite laminated plate

In all problems, composite plates with the material properties listed below are considered.

$$E_1 = 173\ \text{GPa} \quad E_2 = 33\ \text{GPa} \quad E_3 = 5.1\ \text{GPa} \quad G_{12} = 9.4\ \text{GPa} \quad G_{13} = 8.3\ \text{GPa}$$
$$G_{23} = 3.2\ \text{GPa} \quad \nu_{12} = 0.036 \quad \nu_{13} = 0.25 \quad \nu_{23} = 0.17$$

The impactor is assumed to be almost rigid and the R3D4 elements are chosen for modeling the projectile. In order to prevent possible chattering during the impact analysis an initial contact between the plate and impactor is initially established. The surface of the impactor is considered as a master surface while the predetermined contact surface of the laminate is assumed to be slave. To discretize the laminate, 3D continuum, linear brick elements C3D8R, having 8-node are employed (figure 3).

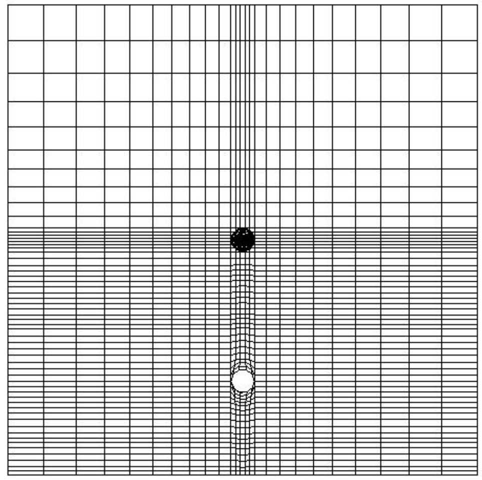


Figure 3: Finite-element model of the composite plate with a hole using ABAQUS

At first, the deflection of plate with and without hole is compared. According to figure 4, it is seen that the hole changes the pattern of plate transverse deflection.

4.3 Effect of the impactor mass

The time history for the contact force and plate response for three different impactor masses 0.5m, m and 2m of the striker presented in Fig. 5. It is found that larger masses cause both the contact forces and the contact durations to be increased. A larger mass of striker also enforces more sever dynamic response the composite plate. In fact larger masses carry a higher incident kinetic which causes larger deformation and longer times for energy dissipation.

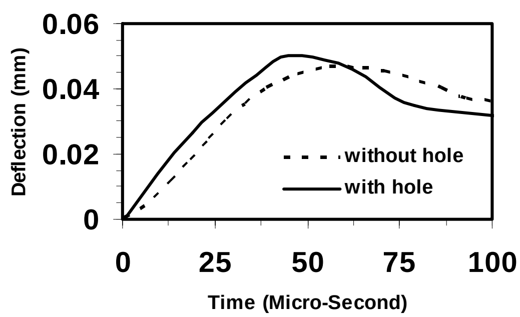


Figure 4: Comparision of plate deflection for (0/90/0) with and without hole

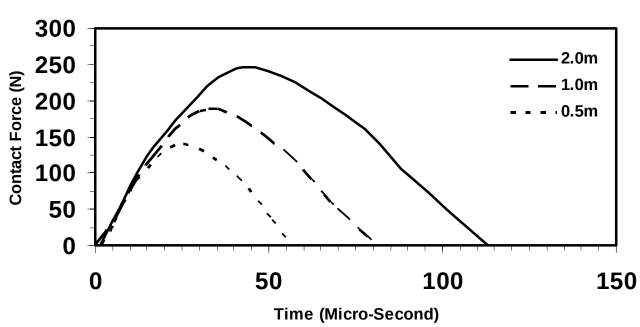
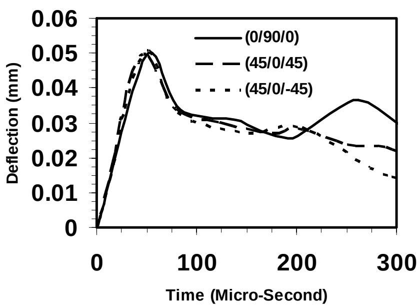


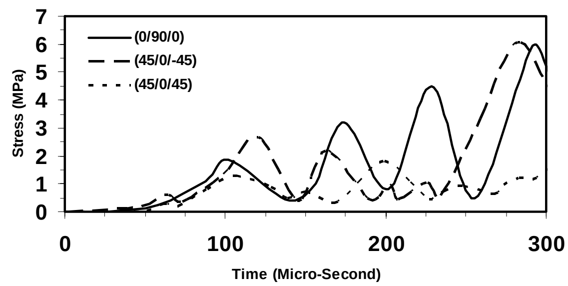
Figure 5: contact force on the (0/90/0) laminate for various projectile masses

4.4 Effect of fiber orientation

The effect of fiber orientation on the dynamic response of composite plate is studied. The transverse plate displacement and the stress as a function of time are developed for different orientation as shown in figure 6. The orientation has no significant effect on the deflection on the plate at early stage of contact duration, but the coupling effects change the pattern when the stress wave reaches to boundary.



(a)



(b)

Figure 6: Time history with different fiber orientations for (a) deflection (b) stress

4.5 Effect of boundary conditions

In this section three boundary conditions of SFSF, SSSS and CCCC are considered for the plate. The results are shown in figure 7. According to the results the boundary conditions has no significant effect on the stress at early stage of impact, but free boundary condition causes the interference of reversed stress waves. This effect resulted to produce a higher von Misses stress.

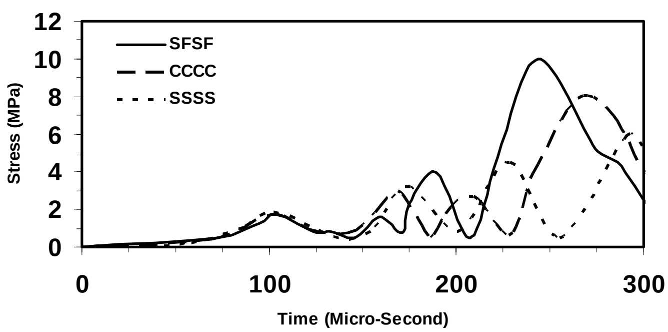
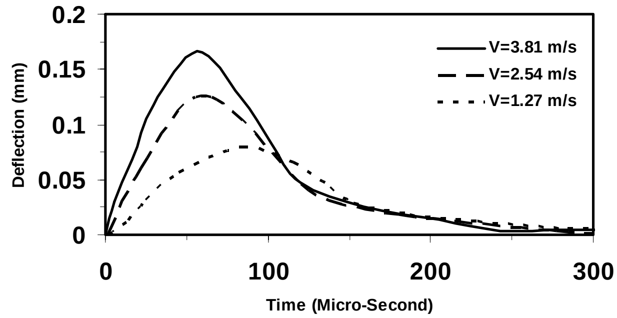


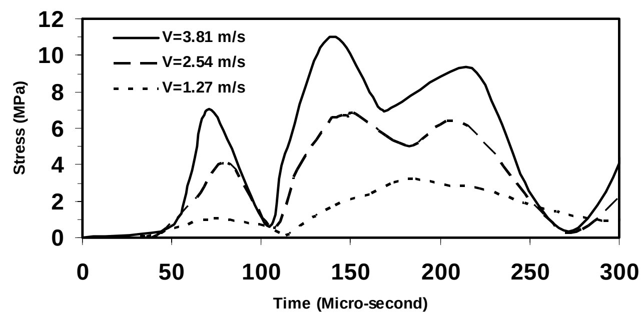
Figure 7: Comparision of von Misses stresses for (0/90/0) laminate with different boundary conditions

4.6 Effect of impactor velocity $(0/90/0/90/0)_2$

The effect of the initial impact velocity on the dynamic response of the composite laminate is studied. The transverse plate displacement and the stress as a function of time are developed for three different initial velocities 1.27, 2.54, 3.81*m/s* of the striker in Fig. 8. Since the impact velocity is the only variable, its affect on the dynamic response of the plate can be easily investigated in these figures. The von Misses stress and the plate displacements corresponding to different initial impact velocities are found to have similar trends but the maximum of them are approximately proportional to the amount of initial velocity.



(a)



(b)

Figure 8: Response of a 10 layered plate with various projectile velocities for (a) deflection (b) von Misses stress

5. Conclusion

To study the dynamic response of composite laminates, a 3D FEM code based on layerwise theory was developed. The results were compared with those of powerful ABAQUS software. Then the response of these laminates subjected to low velocity impact was considered using the verified ABAQUS model. The behavior of composite plates with a hole was successfully investigated. It was demonstrated that the hole changes the stress wave pattern and significantly increases the amount of stress. It was also found that the impact response is approximately proportional to the impact velocity. Furthermore, heavier projectiles increase the contact force and the contact time as well as the plate deflections.

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