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Delamination of laminated fiber reinforced plastic composites under multiple cylindrical impact

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Abstract

In the present paper a 3D finite element analysis has been performed for assessing delamination at the interfaces of graphite/epoxy laminated fiber reinforced plastic composites subjected to low velocity impact of multiple cylindrical impactors. Eight nodded layered solid elements have been used for the finite element analysis of fiber reinforced plastic laminates. Newmark-β method along with Hertzian contact law has been used for transient dynamic finite element analysis and an algorithm has been developed for determining the response of the laminated plate under the multiple impacts at different time. Appropriate delamination criterion has been used to assess the location and extent of delamination due to multiple impacts. A study has been carried out to observe the effects of important parameters on the impact response of the laminate and the delamination induced at the interfaces. It has been observed that the contact force magnitude as well as delamination at the interface are greatly influenced by the time interval between successive multiple impacts.

Keywords: Delamination; Graphite/epoxy; Impact; Multiple impacts; Finite element method

1. Introduction

Fiber reinforced plastic (FRP) laminated composites has been extensively used in aerospace and allied industries due to their inherent advantages like high strength to stiffness ratio. In spite of having these advantages, these materials are also susceptible to damages under transverse impacts and the nature of damage induced due to such impacts are entirely different than that in case of conventional metallic materials. In laminated FRP components, the damage mode usually consists of local permanent deformations, fiber breakage, delamination, matrix cracking, etc. Especially, in the case of impact low velocity impact, the resulting damages like, delamination occurs at specific interfaces of the laminate. These defects are sub surface in nature and cause considerable reduction in structural stiffness leading to growth of the damage and final fracture. Therefore, the impact response of laminated FRP composites has been an important area of research for long time. A large number of analytical as well as experimental works have already been reported in literature in this direction and some of the important works are discussed here.

Sun and Chattopadhyay [1] studied the contact force history of a simply supported laminate with initial stress subjected to impact loading by solving a non-linear integral equation. Sun and Chen [2] studied the impact response of initially stressed laminate using a 2D finite element analysis and reported the effects of impactor velocity, impactor mass and the initial stress on the impact response of the laminate. Wu and Chang [3] performed transient dynamic finite element analysis of laminated FRP plate subjected to impact of foreign objects and presented the stress and strain distribution through the laminate thickness during the impact. Choi and Chang [4,5] developed a model for damage initiation and the extent of damage as a function of material property, laminate configuration and impactor mass. Lee et al. [6] studied the impact response of hybrid-laminated composites under low velocity impact. Choi

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and Hong [7] studied the frequency response of impact force history from modal analysis and compared the same with the natural frequency of the system where the mass of the impactor was lumped to the plate. Goo and Kim [8] studied the impact behavior of curved composite plates using penalty finite element method. Johnson et al. [9] developed a continuum damage mechanics model for studying the impact response and the delamination due to impact of a steel ball on a carbon/epoxy laminate. Guinard et al. [10] studied the localized damage due to transverse impact using a damage meso model for low velocity impact of laminated plates. Sung et al. [11] used acoustic emission along with wavelet transformation to detect matrix cracks and free edge delamination in graphite/epoxy laminates. Luo et al. [12] presented an approach for evaluation of impact damage initiation and propagation in composite plates using stress based delamination criterion.

McLaughlin and Santhanam [13] developed a 2D finite element model for simulating damage growth in cross ply symmetric laminates. Li et al. [14] developed a finite element based model for simulating low velocity impact induced damage in laminated composites and also used adaptive finite element analysis for increasing computational efficiency of the model. Duan and Ye [15] developed a 3D finite element model incorporating frictional contact for studying the delamination at the interfaces due to low velocity impact and showed excellent agreement with experimental results. Moura and Marques [16] performed numerical analysis and also conducted experiments to predict damages in carbon epoxy laminates subjected to low velocity impact. Zou et al. [17] developed a continuum damage model to study the delamination at the interfaces between constituent layers and compared the results with available experimental results. Tay et al. [18] developed an finite element code incorporating element failure algorithm to simulate dynamic crack propagation and impact damage in laminated composites subjected to low velocity impact. Krishnamurthy et al. [19] investigated the impact response of laminated composite cylindrical shell by classical as well as finite element method and studied the impact induced damage detection using finite element model. Shyr and Pan [20] investigated the damage characteristics and failure strengths of composite laminates at low velocity impact by performing experiments using a guided dropweight test rig and observed that fiber breakage had occurred prior to the major damage. Aslan et al. [21] conducted experiments and also performed 3D finite element analysis to evaluate the delamination damage of E-Glass/epoxy laminated composites subjected to low velocity impact for evaluating delamination at various interfaces. Zhang and Taheri [22] performed experimental and numerical investigations for evaluating the damage in carbon epoxy laminated beam subjected to axial impact and observed that the density and length of delamination depend upon the stacking sequence. Mahanta et al. [23,24] performed adaptive finite element analysis for predicting contact force and delamination at the interfaces of laminated FRP components. Most of the works reported in the direction of impact response of laminated composites, are based on response under single impact only. Lam and Sathiyamoorthy [25] presented theoretical method to analyze the impact dynamics of a system, which consists of a laminated beam and multiple spherical masses by obtaining equation of motion using Lagrange equation.

Literature review reveals that many works have already been reported in the areas of assessment of delamination initiation under transverse impact in FRP composites. However, not many works are reported in the direction of study of delamination under multiple cylindrical impacts and the subsequent delamination due to multiple impacts on a laminated composite plate.

Therefore, the present work aims at performing a 3D transient dynamic finite element analysis of multiple impacts on FRP laminated plates for assessing the delamination at the interfaces. A code has been developed in C to study the contact force history, plate displacement and velocity history and impactor displacement and velocity history. The code developed has the capability to allow impactors of different masses striking with different velocities at different locations of the plate surface at different interval of time. Effect of various important parameters like impactor mass, impactor velocity and time interval between successive impacts on the impact response has been studied. Delaminations at interfaces between the constituent layers due to multiple impacts have been studied using the present code.

2. Problem definition

In the present work, response of a FRP composite plate subjected to multiple cylindrical impact (line-loading) impacts has been studied. Fig. 1 shows a laminated FRP composite plate of length L, width W and thickness h consisting of N laminae of different fiber orientation, clamped at its four edges and impacted by n number of cylindrical impactors of mass m_i and striking with an initial velocity of V_i $(i = 1, 2, 3 \ldots n)$. Appropriate contact laws have been assumed for the force–deformation relationship. The computation of contact force has been carried out for multiple impacts of different impactors striking the plate at different interval of time with different impactor velocities. Even though any location of the cylindrical impacts can be considered, in the present study, two impactors striking at symmetrical locations have been considered.

3. Finite element formulation

3.1. 8-Noded layered solid element

Three dimensional 8-noded isoparametric layered solid element was used for full 3D modeling of the laminated plate (Fig. 2). The shape function defining the geometry and displacement are