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Numerical Investigation of Impact and Compression after Impact Performance of 45° Biaxial Composite Laminates †

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Abstract: A meso-micro analysis technique established on the basis of micro-mechanics of failure in combination with progressive-based damage criteria of the composite material constituents (i.e., fiber and matrix) is demonstrated to predict the impact and compression after impact (CAI) performance of biaxial composite laminates. Damages in the composite material constituents are calculated using different failure models. The analysis technique is then used to investigate the impact and CAI behavior of 45° biaxial composite laminates, for both thermoset and thermoplastic resin systems. The results were presented in the form of damage propagation contours for both impact and compression after impact and a comparison of graphs showing displacement-time, internal energy-time, velocity-time, and contact force-time for both thermoset and thermoplastic resin.

Keywords: multi-scale; micromechanics of failure; impact; compression after impact; biaxial composite laminates

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1. Introduction

Recently, an exceeding growth of the application of biaxial composite laminates have been observed due to a high ratio of strength to weight, an ability to tailor the material for different applications and resistance to damage due to impact load [1]. Due to the recent advancements in the aircraft-based industry and increased claim for the composite laminate based structures, the demand of accurate failure prediction models has also increased.

For the design and development of structures based on composite materials, the numerical investigation can play a vital role in the reduction in resources such as cost and time. For accurate numerical analysis and prediction of complex failure phenomenon due to impact, dependable failure theories and models based on progressive damage are required to accurately investigate the failure mechanism in the composite laminates-based structures [2]. Therefore, predictive tools requiring a smaller quantity of essential mechanical tests are becoming more significant.

The failure models dependent on the micromechanics technique have exceedingly developed expediency for investigators by accurately developing the complex mechanisms in the composite laminate based structures; having an advantage in investigating the failure prediction at constituents-based level [3]. Due to the combination of meso-level and micro-level representative unit cells, this multi-scale technique takes the accuracy and efficiency of both micromechanics and macro-based analysis.

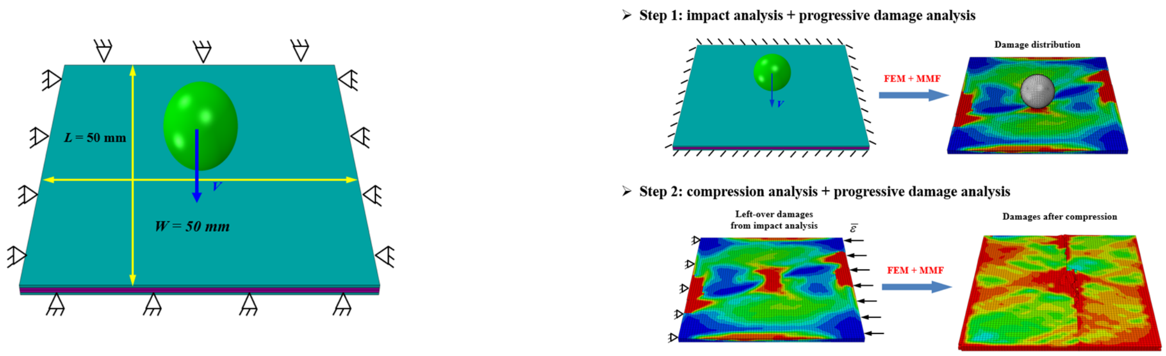
A meso-micro analysis technique established on the basis of micromechanics of failure (MMF) technique [4] and progressive based damage analysis is used to predict the impact and compression after impact (CAI) performance of biaxial (BX) laminates. MMF is dependent on progressive damage models for constituents, i.e., fiber and matrix, in which there is a transfer of data from micro-scale to meso-scale and back again. In view of the advantage of accurate MMF predictions [4], MMF based technique is applied to predict the impact and CAI behavior of BX 45 laminates made with a thermoset and thermoplastic resin system.

2. Methodology

For impact analysis, an explicit model-based scheme was used to perform the simulation of the impact loading using ABAQUS 6.14 (Dassault Systèmes, Vélizy-Villacoublay, France), where dynamic explicit solver was used. An algorithm was established for combining MMF and a progressive damage model and was implemented using VUSDFLD.

In this study, two types of resin systems, i.e., thermoset and thermoplastic were investigated for BX 45 composite laminate. The used fiber (T700) behaves as transversely isotropic material, having five independent material properties [5], whereas the matrix behaves isotropically, having two material properties [5].

The geometry, dimensions and the boundary conditions are given in Figure 1a. The ply thickness for all investigated models was taken as 0.125 mm. The radius of the impactor model was taken as 5 mm. The starting location of the impactor was established above the BX laminate model. Four sides of the composite laminate were constrained using fixed boundary conditions. After the impact analysis, CAI was performed, in which the left-over damages from impact analysis were introduced to the laminate and a compression test was performed. The procedure showing the methodology is shown in Figure 1b.



(**a**) (**b**)

Figure 1. (**a**) Geometry and Boundary Conditions (**b**) Methodology adopted for impact and CAI.

In the developed FE geometries, the plies were made with the help of an eight-node linear brick element, i.e., C3D8R. [6]. Mesh sensitivity analysis, which is an important step in the simulation process, was performed and it was concluded that the selected mesh remained a compromise amid the quality of output and computational time.

3. Results and Discussion

The impact resistance and CAI behavior of the BX 45 composite laminate made with thermoset and thermoplastic resins were quantitatively assessed by a visual examination of the contours induced by damage, as they are exposed to an impact of 50 m/s. The Figure 2a–f shows the damage contours of impact and CAI for the BX 45 composite laminate along with the displacement, velocity, internal energy and contact force time histories for V = 50 m/s.

The results shown in Figure 2a are the ply-by-ply damage contours, indicating the damage propagation for the impact case. The damage contours are shown at the time step of t = 0.05 s and t = 0.1 s. As a result of the visual examination, it is qualitatively concluded, due to the use of thermoplastic resin, that BX 45 laminates caused an improved dispersal of the impact-based energy; a lesser damage area due to deletion of elements, and, therefore, an enhanced resistance due to impact.

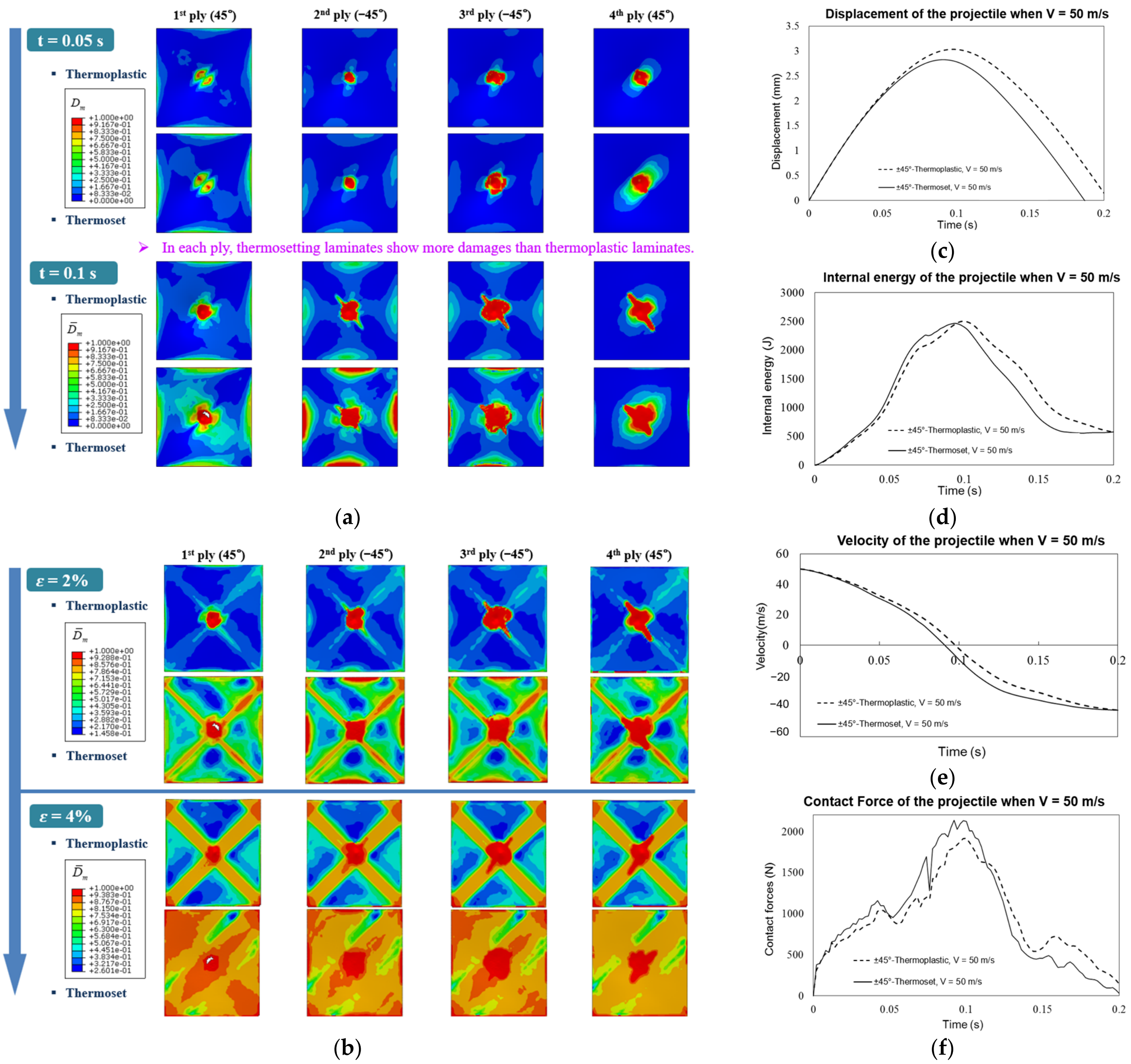


Figure 2. (**a**) Damage contours for Impact; (**b**) damage contours for CAI; (**c**) Displacement vs. time graph; (**d**) internal energy vs. time graph; (**e**) velocity vs. time graph (**f**) contact force vs. time graph for BX 45 composite laminates.

Figure 2b shows the results for the CAI case, in which the damaged biaxial composite laminate due to impact is subjected to compression strain of 2% and 4%. The damage contours for the CAI case shows that less damage is induced in the thermoplastic case as compared to the thermosetting case, thus indicating there is more residual strength in the case of thermoplastic resins based biaxial composite laminates.

To further investigate resistance due to the impact of BX 45composite laminate, the assessment of absorption of impact energy was performed and results are shown in Figure 2c–f. The evaluation includes the investigation of reduction in displacement and velocity of projectile after impact. The absorption capacity of impact energy for composite laminates is investigated by analyzing the decrease in residual velocities against the incident impact velocity. The results show that the decrease in residual velocity was higher in the case of thermosetting resin than the thermoplastic reason. The higher the decrease in residual velocity of the projectile, the higher the impact energy absorption. On the basis of the assessment of impact damaged areas, it can be deduced that BX 45 composite modeled using thermoplastic resin shows enhanced resistance due to impact compared to the BX 45 composite modeled using thermosetting resin.

4. Conclusions

In this research, a multi-scale technique dependent on MMF in combination with a progressive damage model is demonstrated, and later applied on the 45-degree biaxial composite laminate, made of thermosetting and thermoplastic resin system. The full penetration of an impactor with a velocity of 50 m/s was simulated, followed by a compression after impact simulation. The impact resistance was assessed based on the quantitative analysis using damage contours for both impact and CAI and also on the basis of impact energy absorption. Results showed that the BX 45 composite laminates with thermoplastic resin results in enhanced resistance due to impact compared to composite laminates with thermosetting resin. The demonstrated methodology for investigating the impact resistance of composite laminates is relatively general as it initiates with the vital composite material's constituents, fiber and matrix. As soon as the material properties are attained, the proposed technique can be used to investigate any material and structure, subjected to different types of loadings.

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