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Ballistic impact behaviour of thermoplastic Kevlar composites: Parametric studies

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Abstract

The objective of the present study is to investigate the ballistic impact behavior of Kevlar/Polypropylene (PP) composites through hydrocode simulations performed in ANSYS AUTODYN-2D/3D. The studies are carried out based on the experimental and numerical investigation of ballistic impact response of Kevlar/PP composites reported in our recent work [Bandaru et al. Ballistic impact response of Kevlar® reinforced thermoplastic composite armors, Int J Impact Eng 2016;89:1-13]. The interface between the Kevlar and PP matrix is improved by adding polypropylene grafted with Maleic anhydride. The numerical model is validated by evaluating the ballistic impact performance of Kevlar/PP composites when impacted with STANAG-2920 fragment simulating projectile (FSP). Kevlar/PP showed improved ballistic impact performance than that of the Kevlar/Vinylester composite reported in the literature. Numerical simulations are further extended to study the influence of the mass of the projectile on the ballistic impact performance of Kevlar/PP composite armors in terms of ballistic limit, energy absorption and residual velocity. It is observed that shear plugging is the dominant failure mechanism in thermoplastic composites.

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Keywords: Kevlar; Polypropylene; Ballistic impact; Ballistic limit

1. Introduction

Body armor is a protective piece of clothing which covers the torso (chest, abdomen and back) of a person. Fiber reinforced polymer composites have great potential in producing lightweight protective structures [1, 2]. Since last decade, significant research work was emphasized on the ballistic impact response of composite laminates (CLs)

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through experimental and numerical studies. Various studies are available on the ballistic impact response of E-glass/epoxy and S-glass/epoxy composites. [3-5]. These investigations were carried out through experimental studies, analytical formulations and numerical simulations. The ballistic response of these CLs impacting was evaluated in terms of ballistic limit, damage patterns and energy absorption. Several authors [6-8] investigated the ballistic impact response of Kevlar composites by performing parametric studies through hydrocode simulations. All these studies encourage the use of hydrocode simulations to model the ballistic impact response of composite targets.

Most of the authors studied the ballistic impact response of thermoset CLs. Thermoplastic polymers are superior in impact resistance as compared to the thermoset polymers due to their higher stiffness and low deformation [9,10]. Carilllo et al. [11] studied the ballistic impact behavior of Kevlar/PP composites. They reported interface problem between Kevlar and PP matrix and suggested for further improvements. Bandaru et al. [12] improved the interfacing property between Kevlar fabric and PP resin by adding Maleic anhydride grafted PP (MAg-PP) to PP. Only few studies are available on the Kevlar thermoplastic composites under ballistic impact. Implementation of numerical simulations can lighten the expenses made in the experimentations by saving time and money. Therefore, in the present study, a parametric study has been carried out to study the ballistic impact behavior of thermoplastic composites using hydrocode simulations.

In the present study, the ballistic impact behavior of Kevlar/PP composite has been evaluated using hydrocode simulations. First experimental findings are presented briefly. Then numerical simulations are validated based on the properties given in Bandaru et al. [12]. Initially, the ballistic impact response of Kevlar/PP composite is compared with the response of Kevlar/Vinylester composites reported in the literature. Later, simulations are extended to perform the parametric analysis of ballistic impact response of Kevlar/PP composites. Cylindrical flat nosed rigid projectile is considered for parametric study. The studies are carried out to study the influence of projectile parameters on the ballistic impact response in terms of ballistic limit, residual velocity and energy absorption.

2. Experimental findings

Procedure on the experimental studies were discussed clearly in Ref. [12]. Therefore, detailed discussion on experimental study are avoided in this section. Kevlar/PP composites with sixteen layers (approx. 2.5 mm thick) are manufactured using vacuum-assisted compression molding method. The composite armor is manufactured according to standard body armor dimensions of 301.6 mm x 253.8 mm. The necessary material properties are obtained by conducting conventional characterization tests as per ASTM standards.

The ballistic impact response of Kevlar/PP armor has been studied through ballistic impact tests. The tests are conducted at an army camp near Kapurthala, Punjab, India. The Kevlar/PP composites are tested against NIJ Standard Level IIIA projectile i.e. 9 mm full metal jacket (FMJ) projectile having a mass of 8g with an impact velocity of 426 m/s. Two armor panels are tested by constraining in all the directions and five rounds are fired on each sample. Full perforations are achieved. The damage patterns obtained from ballistic tests are in a cross shape on the front surface which are consistent with the damage patterns reported in [7]. Hydrocode simulations are carried out on the ballistic impact response of Kevlar/PP and the response is in good agreement with the ballistic test results [12].

3. Hydrocode simulations

The ballistic impact performance of Kevlar/PP is assessed using commercial hydrocode ANSYS-AUTODYN-2D/3D. Hydrocodes are high computer programs capable of modeling high strain rate ballistic impact phenomenon. These have been used extensively in the last decade to simulate ballistic impact response of composites. As the composite material is anisotropic in nature, the ballistic response of these materials is complex and requires huge material characterization. AUTODYN has the capability to couple the anisotropic nature of the material with nonlinear equation of state (EOS) [13].

The failure model implemented is material stress/strain that allows different tensile and shear failure stresses in principal (material) directions. When the stresses or strains meet this criteria, mechanical degradation of the material starts and depending on the extent of material degradation, the strength and stiffness properties of the material are updated continuously. An erosion algorithm is also implemented that allows removal of highly distorted elements