Composite Structures 93 (2011) 548–556

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

An analytical model for perforation of ceramic/multi-layered planar woven fabric targets by blunt projectiles

S. Feli *, M.H. Yas, M.R. Asgari

Dept. of Mechanical Engineering, Razi University, P.O. Box 67149, Kermanshah, Islamic Republic of Iran

ARTICLE INFO

Article history:
Available online 21 August 2010

Keywords:
Woven fabric
Ceramic
Perforation
Impact
Projectile

ABSTRACT

An analytical model has been developed in this paper for perforation of ceramic/multi-layer woven fabric targets by blunt projectiles. In previous Chocron–Galvez analytical model the semi-angle of ceramic conoid is constant and the strain rate effects are also neglected in the stress–strain behavior of the yarns and only strain energy absorbed by the yarns is considered.

In this paper which is an improvement to the Chocron–Galvez analytical model for modeling the fragmented ceramic conoid, the Zaera–Sanchez-Galvez analytical model has been used and the semi-angle of ceramic conoid has been modified. For modeling the back-up woven-fabric material and deformation of yarns during perforation, the kinetic and strain energy of yarns has been determined. In the stress–strain relation of yarns, the effect of the strain rate is considered. Furthermore, a failure model based on the energy absorbed until failure by woven fabric is also used. Residual velocity, velocity–time history of projectile, residual mass of fragmented ceramic conoid, penetration depth until failure of yarns and energy absorbed by woven fabric are all estimated by new analytical model. Velocity–time history of the projectile shows a good agreement with the Chocron–Galvez numerical model. Also, near the ballistic limit velocity, prediction of residual velocity of new model is better than Chocron–Galvez analytical model.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

Ceramic backed by composite material are widely used in light weight vehicles, personal armours, helicopter, airplane and airplane protection. It has been accepted that two-layer ceramic–composite plates can play important part in ballistic protection. Ceramic has a high hardness and a low density and composite absorbs the kinetic energy of the fragments stopping them. Ceramic backed by composite armours have good performance against small and medium caliber projectiles and it outstanding especially when the weight is a design condition.

The complex problem of a projectile impacting a ceramic–metal target has been studied by Florence [1], Woodward [2], Den Reijer [3], Zaera–Sanchez-Galvez [4] and Feli et al. [5].

Florence [1] developed an analytical model for the ceramic–metal armour. The model assumed a ceramic hard facing and a ductile backing plate impacted by a rigid projectile. Woodward [2] proposed a one-dimensional model for the penetration of a projectile into ceramic–metal armour using a lumped mass approach, which takes into account the erosion of both projectile and target in a simple way. Den Reijer [3] developed an analytical model based on Woodward [2] method. Den Reijer [3] proposed a set of equations governing the main physical mechanism taking part during the penetration process.

There are many experimental and analytical studies on the ballistic impact behavior of composites [6–15]. Cunniff [6], Chocron-Benloulo et al. [7], Navarro [8], Lee et al. [9] Leigh Phoenix and Pankaj Porwal [10] published concise surveys of the analytical models of penetration of projectiles into woven fabrics, which covered the major works that had been published.

The earliest efforts were those of Roylance [11] on biaxial fabrics. They implemented a dynamic form of finite-element analysis and obtained many behavioral features seen in experiments.

Based on the energy principal, Hetherington [12] presented a way for calculation of optimum thickness of composite armour.

Naik et al. [13] studied ballistic impact behavior of typical woven fabric E-glass/epoxy composites. This analytical method is based on wave theory.

Wen [14] presented simple relationships for predicting the penetration and perforation of monolithic fabric-reinforced plastic (FRP) laminates struck normally by projectiles with different nose shapes over a wide range of impact velocities.

Gu [15] presented an analytical model to calculate decrease of kinetic energy and residual velocity of projectile penetrating targets composed of multi-layered planar woven fabrics. In this model the absorbed kinetic energy of projectile was equal to

* Corresponding author. Tel.: +98 831 4274535 9; fax: +98 831 4274542.
E-mail address: Felisaeid@gmail.com (S. Feli).

0263-8223/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compstruct.2010.08.025

Notation

A_p	cross-section area of projectile	V	velocity of rear part of projectile
C	longitudinal speed of sound	V_0	initial velocity of projectile
C_y	longitudinal speed velocity	V_{limit}	limit velocity
D_p	diameter of projectile	V_r	residual velocity of projectile
d_{layer}	thickness of woven fabric layer	V_s	impact velocity of projectile
E	Young's modulus of yarns	W	total absorbed energy of yarns
F	force	W_i	strain energy of ith yarn
h_c	initial thickness of ceramic	W_{KI}	kinetic energy of ith yarn
h_{ct}	thickness of fragmented ceramic conoid	W_{SY}	strain energy of yarns
i	Yarn number	$\dot{x}$	projectile–ceramic interface velocity
G_y	Shear modulus of yarn	Y_{c0}	compressive strength of intact ceramic
L_p	projectile length	Y_p	dynamic yield stress of projectile
M_c	mass of ceramic conoid	Y'_c	compressive strength of fragmented ceramic
n_1	the number of layers (woven fabric)	α_0	initial semi-angle of ceramic conoid
n_y	the number of yarn directly in contact with projectile	$\alpha_{(t)}$	semi-angle of ceramic conoid during perforation process
n_F, n_W	filling and Warp density of fabric respectively (per 10 cm)	ε	strain of yarn
r	half of yarn length	$\dot{\varepsilon}$	strain rate of yarn
S	cross-section area of yarn	ε_{ins}	instant strain
t	time	$\varepsilon_{\max}$	maximum strain
Tex	linear density of yarn (1 Tex = 1 g/1000 m)	θ	angle between yarn and impact direction
u	speed of transverse wave front	ρ_c	ceramic density
u_x, u_y	propagation speeds of transverse waves in x- and y-direction	ρ_p	projectile density
$\dot{u}_0$	ceramic–woven fabric interface velocity	ρ_y	volume density of yarn
u_{lab}	transverse wave speed in yarn relative to the laboratory	υ	volume of ceramic conoid
		σ	stress of yarn

kinetic energy and strain energy of planar fabric in impact-deformed region. The strain rate effect and the rate-dependent properties of fibers has been considered in this model.

The analysis of two-layer ceramic–composite armour, which is developed in this paper, is complex and hence has not been treated analytically by previous researchers. Chocron–Galvez [16] analytical model and Shokrieh–Javadpour [17] numerical model have been developed to describe this system so far.

Chocron–Galvez [16] analytical model has been developed to describe projectile impacting a ceramic backed by a composite plate. The perforation process has been divided into three phases. This model allows the calculation of residual velocity and length of the projectile and the deflection and strain histories of the back-up material.

Shokrieh and Javadpour [17], used Ansys/LS-Dyna software, to determined the ballistic limit velocity of boron carbide ceramic backed by Kevlar 49 fiber composite material. The Heterington [12] equation (optimum thickness of layers) was verified for constant thickness of the armour.

In the Chocron–Galvez [16] analytical model mentioned above, assumed that a conoid of comminuted ceramic with a semi-angle of about 65° is developed which pushes forward a circular area of the back-up plate with dimensions equal to the base of the ceramic conoid. In addition, the strain rate effects are neglected in the stress–strain behavior of the yarns. Also for modeling the absorbed energy of the back-up fabric material, only strain energy absorbed by the yarns is considered and kinetic energy of the yarns is neglected.

In this paper, an analytical model for perforation process of ceramic/multi-layer woven fabric targets based on Newton's equation and wave and energy theory has been developed. The new analytical model which extends the works of Chocron–Galvez [16], the above mention assumes is modified. Perforation of ceramic/multi-lager woven fabric has been divided into a three phases and governing equations have been derived. The equation of Tate [18] and Alekseevskii [19] has been used to model the erosion of projectile and fragmentation ceramic conid, during perforation. The deformation of woven fabric is simulated by the stress wave theory, by considering the strain rate effect, the kinetic and strain energy of yarns has been determined. If the sum of strain and kinetic energy of the multi-layered fabric and kinetic energy of the fragmented ceramic conoid equals to the kinetic energy lost by the projectile at any time t, then the failure of the multi-layer woven fabric will occurred. The improvements of model prove to be more accurate to the Chocron–Galvez [16] analytical model.

2. Theoretical model

After the impact of projectile to the ceramic face, depends on the relative velocity, some particles may be eroded and separated from interface and the tip of projectile start to move radially and mushroom like area have been created. Furthermore, a stress wave starts to propagation from the impact surface, producing, in the ceramic tile, a cracking front advancing in impact direction. This front produces cracks described in the literature circumferential and conical cracks [4,16].

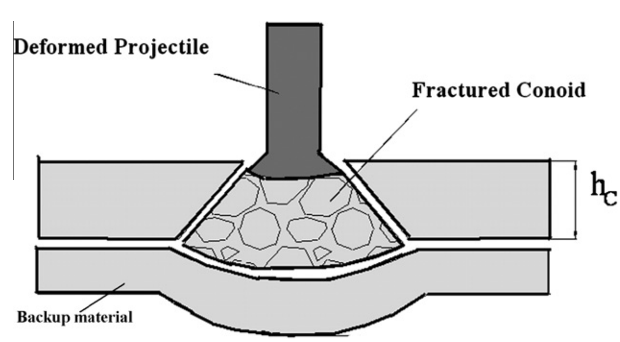

Fig. 1. Deformation of projectile and target.

Download English Version:

https://daneshyari.com/en/article/252806

Download Persian Version:

https://daneshyari.com/article/252806

Daneshyari.com