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Ballistic impact behaviour of woven fabric composites: Formulation

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Abstract

Resistance to high velocity impact is an important requirement for high performance structural materials. Even though, polymer matrix composites are characterized by high specific stiffness and high specific strength, they are susceptible to impact loading. For the effective use of such materials in structural applications, their behaviour under high velocity impact should be clearly understood. In the present study, investigations on the ballistic impact behaviour of two-dimensional woven fabric composites have been presented. Ballistic impact is generally a low-mass high velocity impact caused by a propelling source. The analytical method presented is based on wave theory. Different damage and energy absorbing mechanisms during ballistic impact have been identified. These are: cone formation on the back face of the target, tension in primary yarns, deformation of secondary yarns, delamination, matrix cracking, shear plugging and friction during penetration. Analytical formulation has been presented for each energy absorbing mechanism. Energy absorbed during each time interval and the corresponding reduction in velocity of the projectile has been determined. The solution is based on the target material properties at high strain rate and the geometry and the projectile parameters. Using the analytical formulation, ballistic limit, contact duration at ballistic limit, surface radius of the cone formed and the radius of the damaged zone have been predicted for typical woven fabric composites. The analytical predictions have been compared with the experimental results. A good correlation has been observed.

Keywords: Ballistic impact; Woven fabric composite; Energy absorbing mechanisms; Prediction; Ballistic limit; High strain rate; Stress wave attenuation

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Nomenclature

a	yarn width
A	cross-sectional area of fibre/yarn
A_{ql}	quasi-lemniscate area reduction factor
A_{di}	damaged area at time t_i
b	transmission factor
c_e	elastic wave velocity
c_p	plastic wave velocity
c_t	transverse wave velocity
d	projectile diameter
d_a,d_b	as explained in Fig. 12
dc_i	deceleration of the projectile during ith time interval
dV	volume of the circular element in Fig. 15
E_{KEi}	kinetic energy of the moving cone at time t_i
E_{SPi}	energy absorbed by shear plugging till time t_i
E_{Di}	energy absorbed by deformation of secondary yarns till time t_i
E_{TFi}	energy absorbed by tensile failure of primary yarns till time t_i
E_{DLi}	energy absorbed by delamination till time t_i
E_{MCi}	energy absorbed by matrix cracking till time t_i
E_{mt}	energy absorbed by matrix cracking per unit volume
E_{Fi}	energy absorbed by friction till time t_i
E_{TOTALi}	total energy absorbed by the target till time t_i
F_i	contact force during ith time interval
G_{IIcd}	critical dynamic strain energy release rate in mode II
h	target thickness
h_l	layer thickness
KE_{0p}	initial kinetic energy of the projectile
KE_{pi}	kinetic energy of the projectile at time t_i
M_{Ci}	mass of the cone at time t_i
m_p	mass of the projectile
N	number of layers being shear plugged in a time interval
P_d	percent delaminating layers
P_m	percent matrix cracking
r_{di}	radius of the damage zone at time t_i
r_{pi}	distance covered by plastic wave till time t_i
r_{t_i}	surface radius of the cone at time t_i, distance covered by transverse wave till time t_i
r_{t_1}	surface radius of the cone at time time t_1
r_{t_2}	surface radius of the cone at time time t_2
S_{SP}	shear plugging strength
t_a,t_b	as explained in Fig. 12
t_c	contact duration of the projectile during ballistic impact event
t_i	ith instant of time