The Effect of Target Thickness on the Ballistic Performance of UHMW Polyethylene Composite

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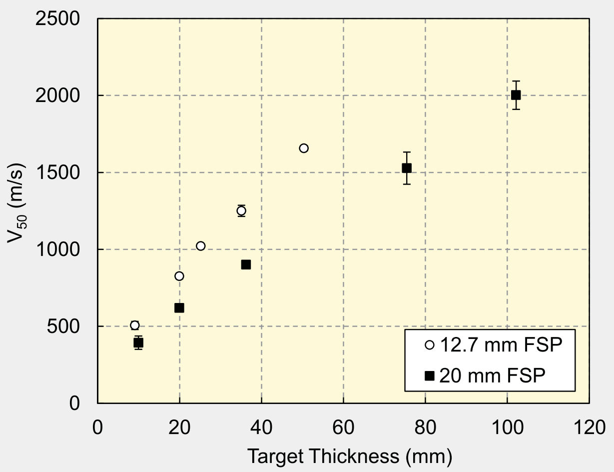
Introduction

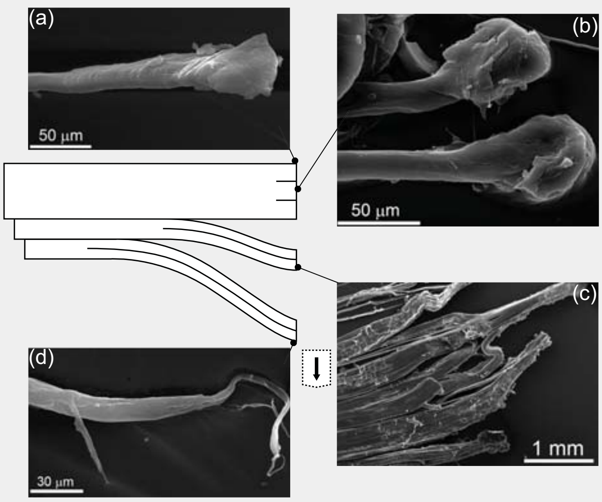
Ballistic limit tests was performed on ultra-high molecular weight polyethylene (UHMW-PE) composite for panels up to 100 mm thick against MIL-DTL-46593B spec 12.7 mm and 20 mm calibre fragment simulating projectiles (FSPs). The results were used to investigate the effect of target thickness on the ballistic performance and identify the penetration mechanisms of thick UHMW-PE composite. An analytical model for the ballistic limit is developed based on energy, momentum and classical yarn impact theory. Analytical predictions of the ballistic limit are compared with experimental results to demonstrate the capacity of the model to predict ballistic performance across the range of target thicknesses investigated.

Experiment

Ballistic limit tests was performed on Dyneema® HB26. The V_{50} was determined from an even distribution of partial penetration (PP) and complete penetration (CP) results as per MIL-STD-662F. The failure mechanisms was investigated using fractographic techniques.



Ballistic performance of Dyneema® HB26 against FSP



Micrographs showing the evolution of fibre fracture throughout the penetration cavity of a 35 mm thick target impacted by 12.7 mm FSP.
(a) fibre on target front face, highly compressed and failing in shear,
(b) fibres 9 mm from the front face, failing in shear,
(c) bundles of fibre 18 mm from the front face failing in tension, and
(d) fibre on the back face, failing in tension.

Perforation Model

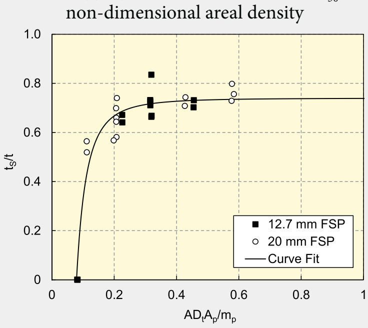
Penetration of thick UHMW-PE composite targets occurs in two stages:
1. Shear plugging and failure by fibre shearing
2. Bulging and failure by fibre tension

The ballistic limit equation below describes these mechanisms.

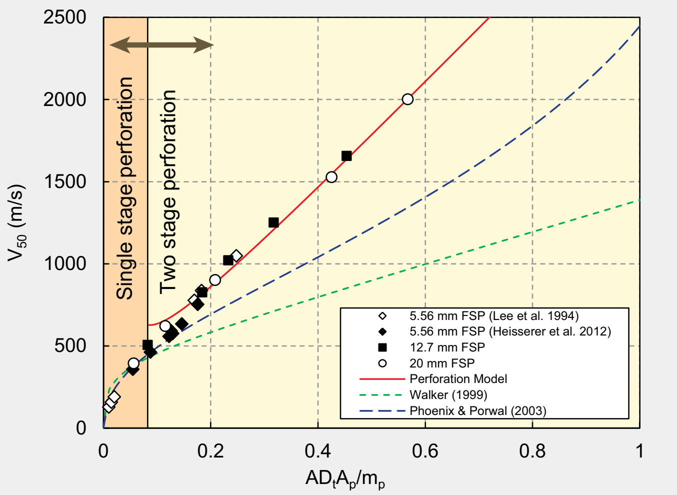
$$V_{50}=\sqrt{\frac{2}{m_p\rho_t^2}\tau_{\max}\pi r_p k^2 AD_t^2+\left(1+\beta^2(1-k)\frac{AD_tA_p}{m_p}\right)^2\frac{E_f}{\rho_f}\frac{v_f}{2}\left(2\varepsilon_{\max}\sqrt{\varepsilon_{\max}+\varepsilon_{\max}^2}-\varepsilon_{\max}^2\right)}$$

A_p	Projectile presented area
AD_t	Target areal density
$C_{1,2,3,T}$	Empirical constants
E_f	Fibre elastic modulus
k	Shear plugging thickness ratio
m_p	Projectile mass
r_p	Projectile radius
t	Thickness
t_S	Shear plugging thickness
v_f	Fibre volume fraction
β	Radius multiplier
$\varepsilon_{\max}$	Fibre failure strain
ρ_t	Target density
ρ_f	Fibre density
$\tau_{\max}$	Through thickness shear strength

Shear plugging thickness ratio close to V_{50} vs non-dimensional areal density



$$k=\frac{t_S}{t}=C_1\left(\frac{AD_tA_p}{m_p}\right)^{C_2}+C_3 \qquad \frac{AD_tA_p}{m_p}\geq C_T$$



The plot above compares the model predictions with the experimental V_{50} data for UHMW-PE composite against three different calibre FSPs. The V_{50} is plotted against the non-dimensional areal density term proposed by Cunniff (1999). The perforation model provides very good agreement with experimental ballistic limits for thick targets that experience two stages of perforation. For thin composites which display a single stage of penetration (bulging), the fabric membrane models from Walker (1999) and Phoenix and Porwal (2003) are more suitable.

Conclusion

The ballistic performance for UHMW-PE composite is determined for panel thicknesses up to 100 mm against 12.7 mm and 20 mm calibre FSPs. Post-test analysis showed penetration of thick UHMW-PE composite occurs in two stages: an initial shear plugging stage followed by bulging of the back face. A two-stage perforation model based on conservation of energy and momentum was developed that describes the shear plugging and bulging stages for thick UHMW-PE composite. The two-stage perforation model provides very good agreement with experimental ballistic limit results for thick targets (> ~10 mm).

Find out more

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