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SHORT COMMUNICATION

Ballistic Applications of Glass and Kevlar Fibre Vinylester Composites

S.P. Panda and N.G. Navale

Institute of Armament Technology, Pune-411 025

and

M.N. Saraf and R.K. Gupta

Defence Materials & Stores Res.& Dev. Establishment, Kanpur-208 013

and

R.A. Goel

Terminal Ballistics Research Laboratory, Chandigarh-160 020

ABSTRACT

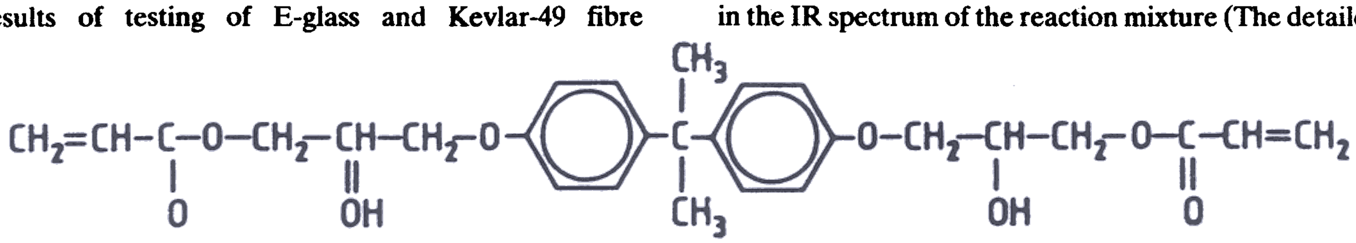
Void-free E-glass and Kevlar-49 fibre reinforced vinylester laminates prepared under compression moulding were found to have Charpy impact strength of 576 KJ/m^2 and 304 KJ/m^2, respectively. Ballistic immunisation tests carried out on the glass reinforced vinylester laminates with thickness ranging from 12 mm to 54 mm against 7.62 mm rifle bullets produced an exponential relationship between the per cent attenuation in bullet velocity and the areal density of the laminates; whereas the relationship was linear for 9 mm carbine fire with laminate thickness varying from 5.5 mm to 12 mm.

1. INTRODUCTION

E-glass and Kevlar-49 fibre reinforced vinylester laminates are light, tough[1] and mouldable at room temperature with low cure exotherm[2]. They exhibit very good fibre-matrix bond strength due to the presence of pendant-OH groups in the resin[3] and provide a considerable resistance to high velocity perpendicular impact. The materials thus possess excellent potential for being used in body armour, vehicular armour and composite tank armour with FRP laminates sandwiched between steel plates. This communication reports results of testing of E-glass and Kevlar-49 fibre reinforced vinylester laminates against Charpy impact and 9 mm carbine and 7.62 mm rifle bullet fires.

2. MATERIALS AND METHODS

The divinylester of diglycidylether of bisphenol A (VE of DGEBA, Structure I) was prepared by reacting diglycidylether of bisphenol A with acrylic acid in the molar ratio of 1:2 in the presence of benzyltrimethylammonium methoxide as a catalyst at 110 °C for about 1 hr. The completion of the reaction was marked by disappearance of 915 cm^{-1} epoxide peak in the IR spectrum of the reaction mixture (The detailed



Structure I, VE of DGEBA

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procedure is reported elsewhere[4]). The number average molecular weight of the resin was 359 when measured in a Herbert-Knauer vapour pressure osmometer with universal probes using 1,4-dioxane as a solvent. E-glass fibre and Kevlar-49 fibre, obtained from Unnati Corporation, Ahmedabad and Fothergill Engineer Fabrics Ltd, US, respectively, were used as reinforcement in the form of plain woven rovings expected to give the best ballistic performance[5]. The specifications of the fibres as provided by the suppliers

Property	E-glass fibre	Kevlar-49 fibre
Mass/area (g/cm^2)	360	218
Thickness (mm)	0.35	0.31
Breaking strength (MPa)		
Wrap	180	384
Weft	160	288

The vinylester system containing 67 parts by weight of VE of DGEBA resin and 33 parts by weight of styrene was mixed with 0.27 to 0.45 parts by weight of cobalt octoate accelerator and 0.9 to 1.5 parts by weight of methylethyl ketone peroxide catalyst. Layers of plain woven rovings (13″ × 13″) were individually saturated with the matrix and combined to give the desired thickness with the warp of each layer of the woven rovings aligned in the same direction. The composite was placed in a hydraulic press provided with controlled heating arrangement and compressed under a pressure of 100 kg/cm^2 at a temperature of 120±2 °C at ambient pressure for 1 hr. The laminates were post-cured at 120 °C at ambient pressure for 1 hr. All the laminates, when examined by X-ray radiography, were found to be free from voids, delaminations or cracks.

The Charpy impact and the interlaminar shear strength tests followed the procedures described in BS-2872, Part 3, Method 351A: 1977. The flexural strength and modulus measurements were made according to BS-2782, Part 3, Method 335A:1978. Ballistic immunisation tests were carried out by firing the bullets perpendicularly from a 9 mm carbine or a 7.62 mm rifle onto the laminates, secured firmly at a distance of about 5 to 10 m. The impact and residual velocities of bullets were measured with the help of electronic counters connected to aluminium screens held in the path of the bullets.

3. RESULTS AND DISCUSSION

The mechanical properties of the laminates are tabulated in Table 1.

The Charpy impact strength obtained for E-glass fibre-vinylester laminates is not only higher than that for the Kevlar- 49 vinylester laminates but also exceeds the best values obtained for laminates for tank armour using modified phenolic matrix with E-glass reinforcement. This is mainly due to vinylester matrix forming a strong bond with glass fibre whose diameter can be as small as 0.0076 mm whereas Kevlar fibres have higher diameter (e.g. 0.11 mm). Under high velocity impact, the fibre breaks at its weakest point inside the matrix and is pulled out of the matrix for complete failure. The thinner the diameter the better is the impact resistance due to reversible bending and delamination of the fibre in the composite[6], and a highly adherent and flexible matrix needs very high fracture and debonding energy for complete failure of the composite. This explains the outstanding impact strength of E-glass fibre vinylester laminates as observed by us (Table 1).

Under the ballistic immunisation tests with 9 mm carbine bullets (impact velocity, 425 m/s), both E-glass

Table 1. Mechanical properties of laminates
(Matrix resin : VE Of DGEBA)

Reinforcement (plain woven rovings)	Specific gravity	Flexural strength (MPa)	flexural modulus (MPa)	Inter-laminar shear strength (MPa)	Charpy impact strength (KJ/m^2)	Fracture energy (KJ/m^2)	
						Initiation	Propagation
E-glass	1.846	313.13	17.24	30.22	576	20.6	554.8
Kevlar-49	1.263	188.86	15.58	17.00	304	16.8	287.0

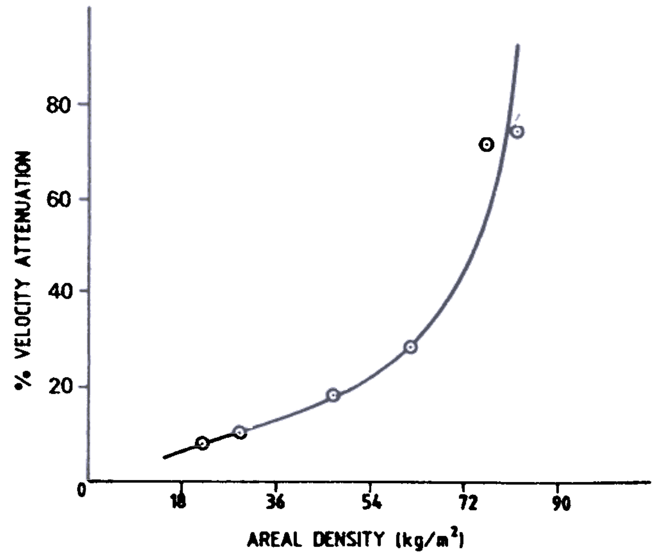

Figure 1. Per cent velocity attenuation as a function of areal density of glass fibre-vinylester laminates.

and Kevlar fibre-vinylester laminates completely embedded several bullets without any sizeable bulge at the back, with thickness of the laminates falling around 11.6 mm. This was not the case with similar laminates made with modified phenolic matrix when heavy delamination took place with a few firings. To stop 7.62 mm rifle bullets (with velocity 830 m/s) a much higher thickness of laminates than twice the thickness of the laminates stopping 9 mm carbine bullet was needed. By plotting the attenuated velocity of bullets of 7.62 mm rifle against areal density of the laminates, an exponential relationship was obtained as shown in Fig. 1, for E-glass fibre-vinylester laminates.

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REFERENCES

1 Young, R.E. Vinylester resins. *In* Unsaturated polyester technology, edited by P.F. Bruins. Gordon and Breach Science Publishers, New York, 1976. pp. 315-71.

2 Launikits, M.B. Vinylester resins. *In* Handbook of composites, edited by G. Lubin. Van Nostrand Reinhold Company, New York, 1982. p. 38.

3 Anderson, T.F. & Messick, V.B. Vinylester resins. *In* Development in reinforced plastics-1, edited by G. Pritchard. Applied Science Publishers Ltd, London, 1980. p. 29.

4 Mirza, M.S.; Navale, N.G.; Sadafule, D.S.; Kumbhar, C.G. & Panda, S.P. Photocrosslinkable vinylesters with unsaturated ketone groups in the backbone. *J. Macromol. Sci.-Chem., 1990, A 27(1)*, 1-22.

5 Krijger, R. Aramid fibres in ballistic materials. *In* Polymers in defence. Proceedings of the International Conference on Polymers in Defence, 18-20 March 1987, U.S. Department of Commerce, National Technical Information Service, 1987. pp. 20/1-20/16.

6 Outwater, J.O. Fibre-reinforced polymer composites. *In* Composites: State of the art, edited by J.W. Weeton and E. Scala. Proceedings of Sessions, 1971 Fall Meeting. The Metallurgical Society of AIME, Detroit, Michigan, 1974. pp. 12-21.