Polymer Vol. 37 No. 4, pp. 699–701, 1996
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0032-3861/96/$15.00+0.00

polymer communications

Tensile behaviour of unidirectional polyethylene–glass fibres/PMMA hybrid composite laminates

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Unidirectional hybrid composite laminates based on high-performance polyethylene fibres and glass fibres were prepared with partially polymerized methyl methacrylate at room temperature, followed by heating at 55 °C (well below the softening point of polyethylene fibres) for a stipulated time. It was observed that the tensile strength, modulus of elasticity and hybrid effect of the laminates depend on the relative proportion of both the fibres.

(Keywords: polyethylene fibres; glass fibres; poly(methyl methacrylate) matrix; hybrid composite; hybrid effect; tensile properties)

Introduction

There is increasing interest in hybrid composite materials made by combining two or more different types of fibre in a common matrix because these materials offer a range of properties that cannot be obtained with a single kind of reinforcement.

Glass fibres (GF) are the most common of all reinforcing fibres for polymeric matrix composites. The principal advantages of GF are low cost, high tensile strength and high chemical resistance. The disadvantages are, low modulus of elasticity, high specific gravity and sensitivity to abrasion with handling, which frequently decreases its tensile strength. A relatively new, tough reinforcing fibre is high-performance polyethylene fibre (PEF), currently produced based on solution (gel)-spinning of ultra-high molecular weight polyethylene, possessing unique mechanical properties in terms of high strength-to-weight ratios and stiffness-to-weight ratios[1]. Moreover, these PEFs possess a high elongation at break leading to high values of work to break compared with other reinforcing fibres such as carbon, aramid and GF[2]. By hybridizing two types of fibres such as GF and PEF, it may be possible to create a structural material possessing the combined advantages of both the fibres.

A few workers have used PEF as one of the reinforcing fibres in hybrid composites, but these are mainly based on the thermoset matrix[2–6]. Composites based on thermoplastic polymeric matrices potentially offer several advantages compared to those based upon thermosetting resins[7,8]. Thus, one could expect a unique structural material based on poly(methyl methacrylate) (PMMA) as the matrix in PEF–GF reinforced hybrid composites.

This work reports the undirectional (UD) hybrid laminates based on PEF and GF. The objective of the present study is to investigate the variation of hybrid effect, tensile strength and modulus of elasticity with hybrid composition.

Experimental

Methyl methacrylate (MMA) (Western Chemical Corporation, Calcutta, India) was purified by standard technique[9,10] and benzoyl peroxide (Bz_2O_2) was recrystallized from chloroform [11] and dried *in vacuo*. The purification of *N,N*-dimethyl aniline (NDA) was achieved by distillation under reduced pressure before use.

The PEFs (Spectra 900, Allied-Signal Corporation, Petersburg, USA) used for the preparation of composites were treated with chromic acid following refs 2, 12, 13. The surface of GFs (433 BF-225, Owens Corning Fiberglas Corporation, Ohio, USA) had already been treated by standard methods, and used directly for making composites. The wetting characteristics of PMMA on treated and untreated PEF and GF have been studied by contact angle determination[14–16]. Improved wetting was found when the treated fibres were investigated [17].

The UD plies were made in a dust-free chamber on a glass sheet using partially polymerized MMA as the resin with an amine–peroxide (NDA-Bz_2O_2) initiator system in bulk at room temperature[17,18]. The pre-impregnated plies were used for multiple-layer systems. Laminated structures were prepared by stacking plies of PEF and GF unidirectionally in the mould and the composites were made using the same resin at room temperature until they solidified within the mould and shrinkage was controlled using extra resin in the mould. Finally, the composite was heated to a temperature of 55 °C for a stipulated time in order to ensure completion of MMA polymerization. UD laminates were prepared using a total of four plies of respective fibres and their hybrids. The lay-up sequence of the plies is given in *Table 1*.

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Tensile testing of the samples was carried out at ambient temperature, using a dumb-bell shaped test specimen in an Instron Universal Testing machine. The specification of the dumb-bell is as follows: gauge length 20 mm, width 6 mm and thickness 1.70 mm with end taps, which were loaded parallel to the fibres with serrated jaw wedge grips. A displacement rate of 5 mm min^{-1} was used throughout the investigation. The total volume fraction of fibres was held constant at 35.6% and the proportion of PEF in the composite was varied from 0 to 100% with steps of approximately 25%.

Results and discussion

It was observed that the failure strain of the hybrid laminate appears to be greater than that in laminates containing all low-elongation fibres, i.e. GF reinforced laminates. This enhancement of strain is referred to as the hybrid effect. *Table 1* shows the hybrid effect with the hybrid composition. It is found that the hybrid effect increases as the relative proportion of GF is decreased. The axial coefficients of thermal expansion of the two fibres are different. This means that residual thermal strain is introduced into the hybrid laminates during cooling to room temperature. This hybrid effect may be due to the residual thermal strain as explained by earlier workers[2,19–22].

Figure 1 shows the stress–strain behaviour of the hybrid laminates. When the relative volumes of PEF are 25.4% and 50.6%, the ultimate strength is determined by the GF, that is, the PEF will not continue to sustain the stress after failure of GF. But in the case when the relative volume of PEF is 74.7%, then the PEF is capable of carrying the extra load transferred to it by the failure of the GF at point F.

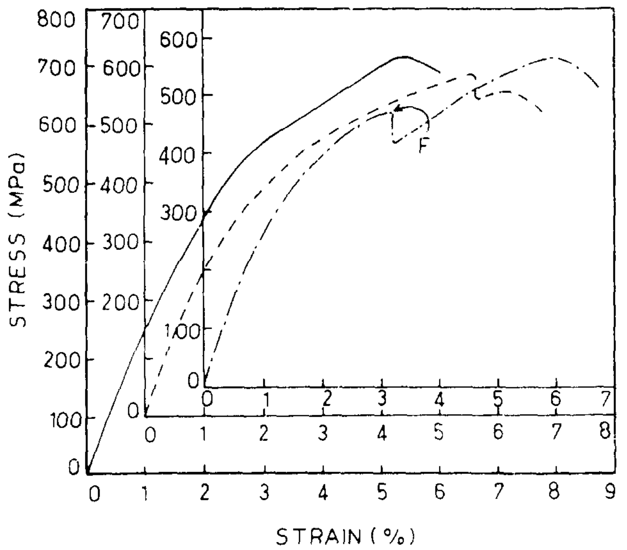

Figure 1 Stress–strain curves for hybrid laminates: (—) 25.4% PEF; (– – –) 50.6% PEF; (· – · –) 74.7% PEF

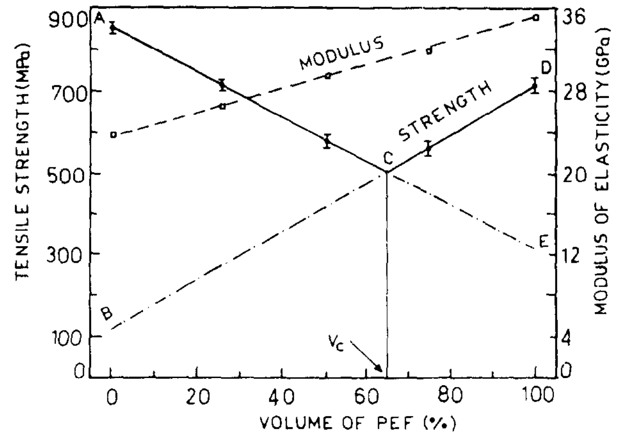

Figure 2 Variations of tensile strength and modulus of elasticity of the hybrid laminates with PEF content

The strength variation in hybrid laminates as a function of relative fibre content was explained by Manders and Bader[22]. *Figure 2* shows the tensile strength and modulus of elasticity of the PEF–GF composites as a function of composition. Point A represents the tensile strength of the all-GF reinforced composite and point D that of the pure PEF reinforced specimen. The line ACD represents the tensile strength of the hybrid laminates. The first failure event in the hybrid is assumed to occur when the strain in the hybrid exceeds the failure strain of the GF reinforced composite. Based on this assumption, the strength of the hybrids are given by two straight lines, AE and BD, depending on whether or not PEF is present in sufficient proportion to sustain the load after failure of GF. The line AE represents the stress in the hybrid composite assuming that the PEF carries no load. Thus, if the relative PEF content is less than V_c, the ultimate tensile strength of the hybrid laminate is controlled by GF. If the PEF content is higher than V_c, the ultimate tensile strength is determined by PEF, even though the GFs have failed at stress levels given by the line CE.

Figure 2 also shows the modulus of elasticity of the PEF–GF composites as a function of composition. It can be observed that the stiffness increased linearly with the PEF content. This behaviour is due to the fact that the modulus of elasticity of PEF is higher than that of GF.

Table 1 Hybrid effect dependence on hybrid composition

Lay-up*	PEF fraction (%)	Tensile failure strain Mean (%)	Coefficent of variation (%)	Hybrid effect, with respect to low elongation fibre (GF) (%)
[GGGG]	0 (All GF)	5.1	5.5	
[GSGG]	25.4	5.4	6.6	5.9
[SGSG]	50.6	5.6	6.3	9.8
[SSGS]	74.7	5.9	5.9	15.7
[SSSS]	100 (All PEF)	7.0	5.8	

*G = GF ply and S = PEF ply

Conclusions

The main conclusions can be summarized as follows:

1. The composite laminate as a whole has been made at room temperature, casting requiring a minimum amount of energy which may be regarded as the advantage of the system[17].
2. The results of this work have clearly confirmed the existence of the hybrid effect. Its extent is dependent on the ratio of the two fibre types. A higher hybrid effect is observed when GF occupies a lower proportion of the volume.

3. The tensile strength of the hybrid laminates also depends on the relative proportion of the two fibres. After a certain volume fraction of PEF, the tensile strength of the hybrid is determined by the PEF, and below this volume fraction, tensile strength is determined by the GF.
4. The stiffness of the hybrid laminate increases linearly with relative proportion of PEF.

Acknowledgement

The award of a CSIR, Indian Fellowship (SRF) to Nirmal Saha is sincerely acknowledged.

References

1 Lemstra, P. J., Kirschbaum, R., Ohta, T. and Yasuda, H. 'Developments in Oriented Polymers-2', Elsevier, London, 1987, pp. 39–77

2 Peijs, A. A. J. M., Catsman, P., Govaert, L. E. and Lemstra, P. J. *Composites* 1990, **21**, 513

3 Peijs, A. A. J. M., Venderbosch, R. W. and Lemstra, P. J. *Composites* 1990, **21**, 522

4 Peijs, A. A. J. M. and De Kok, J. M. M. *Composites* 1993, **24**, 19

5 Adams, D. F. and Zimmerman, R. S. *Proc. 31st Int. SAMPE Symp.* 1986, pp. 1456–1468.

6 Poursartip, A., Riahi, G., Teghtsoonian, E. and Chinatambi, N. *Proc. 19th Int. SAMPE Tech. Conf.* 1987, pp. 503–514

7 Kodokian, G. K. A. and Kinlock, A. J. *J. Mater. Sci. Lett.* 1988, **7**, 625

8 Hoggatt, J. T., Oken, S. and House, E. E. U.S. Air Force Report AFWAL-TR-80-3023, April, 1980

9 Ghosh, P., Mitra, P. S. and Banerjee, A. N. *J. Polym. Sci., Polym. Chem. Ed.* 1973, **11**, 2021

10 Ghosh, P. and Banerjee, A. N. *J. Polym. Sci., Polym. Chem. Ed.* 1975, **12**, 375

11 Ghosh, P., Biswas, S. and Niyogi, U. *J. Polym. Sci., Part A: Polym. Chem. Ed.* 1986, **24**, 1053

12 Ladizesky, N. H. and Ward, I. M. *J. Mater. Sci.* 1983, **18**, 533

13 Ladizesky, N. H. and Ward, I. M. *J. Mater. Sci.* 1989, **24**, 3763

14 Yamaki, J. I. and Katayama, Y. *J. Appl. Polym. Sci.* 1975, **19**, 2897

15 Sellitti, C., Vargiu, S., Martuscelli, E. and Fabbro, D. *J. Mater. Sci.* 1987, **22**, 3477

16 Tissington, B., Pollard, G. and Ward, I. M. *J. Mater. Sci.* 1991, **26**, 82

17 Saha, N., Banerjee, A. N. and Mitra, B. C. *Polym. Adv. Technol.*, to be published

18 Ghosh, P. and Mukherjee, N. *Eur. Polym. J.* 1979, **15**, 797

19 Bunsell, A. R. and Harris, B. *Composites* 1974, **5**, 157

20 Zweben, C. *J. Mater. Sci.* 1977, **12**, 1325

21 Marom, G., Fisher, S., Tuler, F. R. and Wagner, H. D. *J. Mater. Sci.* 1978, **13**, 1419

22 Manders, P. W. and Bader, M. G. *J. Mater. Sci.* 1981, **16**, 2233