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Hybrid composites based on polyethylene and carbon fibres

Part IV Influence of hybrid design on impact strength

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Hybrid composites possess unique features that can be used to meet different design requirements with respect to strength, stiffness and impact resistance. A key parameter in hybrid composite structures is the arrangement of fibres within the hybrid, as demonstrated by studies on hybrid systems based on carbon, glass or aramid fibres. It was shown that the hybrid design strongly affects a variety of flexural properties such as the modulus [1], strength [2], fracture energy [3–6] and fatigue behaviour [7]. Hybridization of relatively brittle carbon fibres with tough, high-performance polyethylene (HP-PE) fibres has proven to be highly effective in improving the impact properties of carbon fibre-reinforced composites [8–10]. By varying the HP-PE/carbon fibre ratio, laminate design and adhesion level of the HP-PE fibres, impact properties of such hybrid composites can be tailored to a specific application requiring either improved energy absorption or damage tolerance. Previous studies on layered HP-PE/carbon hybrids were directed towards optimizing impact properties with respect to improved elastic energy absorption and enhanced damage tolerance [8, 10]. Related studies showed that intermingled hybrids, incorporating HP-PE fibres possessing low levels of adhesion exhibited a strong positive hybrid effect, i.e. a positive deviation from the properties predicted by the rule of mixtures, with reference to the total energy absorption under Charpy impact conditions [9]. These type of hybrids, exhibiting synergistic effects with respect to energy absorption, are quite promising for applications requiring kinetic energy dissipation such as crash-impacts. In this letter the influence of the fibre arrangement within the hybrid on this positive synergistic effect is discussed.

In order to study this influence, hybrids were prepared, varying greatly in degree of hybridization, but with a constant total fibre volume fraction and a constant carbon/HP-PE fibre ratio. Consequently, any change in the impact properties can only be the result of a difference in degree of hybridization. The following laminate constructions were prepared (Fig. 1): (1) plain HP-PE (A) and plain carbon composites (B), as a reference to determine the rule-of-mixtures behaviour; (2) sandwich constructions with three layer exchanges with either a carbon core (C) or HP-PE core (D); (3) hybrids with a more intimate stacking with respectively nine (E) and 16 (F) layer exchanges and, finally, (4) intermingled hybrids (G) with the highest degree of hybridization,

Figure 1 Schematic representation of the cross-sectional area of the composites constructed. (□) HP-PE and (■) carbon.

in which the carbon and HP-PE fibres were dispersed on the level of the individual strands.

Hybrid composites were made of epoxy resin (Araldite, Ciba-Geigy, LY 556/HY 917/DY 070) reinforced with HP-PE fibres (Spectra 1000, 7.22 g cm^{-1}) and surface-treated carbon fibres (Grafil, XA-S/3K). In the case of the HP-PE fibres no surface treatment was carried out. Composites were manufactured from prepreps that were prepared using a drum winding technique. Intermingled prepreps were prepared by simultaneous winding of HP-PE and carbon yarns. The laminated composite structures were prepared by stacking the prepreps unidirectionally into a mould in the desired lay-up. These laminates were cured, using a vacuum bag, for 90 min in a hot press at 110°C and a pressure of 700 kPa. Finally, the composites were post-cured for 12 h at 110°C . The composite plates, with a thickness of 5 mm, had a total fibre volume fraction of 55% and in the case of hybrids a carbon/HP-PE fibre ratio of 1:1. From these plates, samples were cut with a length of 60 mm and a width of 10 mm, using a diamond cutting wheel.

Charpy impact tests were conducted utilizing a hydraulic tensile machine (Zwick Rel) equipped with a Charpy impact test-configuration. The samples were loaded on the lower side, over a span of 40 mm at a velocity of 3 m s^{-1} . The tensile machine

instrumentation produced a load–time curve of the impact event from which the initiation, propagation and total energy absorption could be determined. The Charpy impact energies were calculated by dividing the total absorbed energies by the cross-sectional area of the sample. The experimental accuracy of all quoted impact energy values is within 8%. A dimensionless parameter called the “ductility index” (DI) has also been calculated. This DI is defined as the ratio of propagation energy to initiation energy [11], and it is an indication of the brittleness or ductility of a material. High values represent ductile materials and low values represent brittle behaviour.

Fig. 2 shows the load–time traces of the various laminate constructions. Fig. 2a clearly demonstrates the differences in failure mode between the brittle carbon composite and the more ductile HP-PE composite. Fig. 2b shows that the behaviour of the plain carbon and HP-PE composites is retained more when these components are positioned in the

Figure 2 Load–time traces for: (a) plain HP-PE (A) and plain carbon (B) composites, (b) sandwich hybrids with carbon core (C) and HP-PE core (D), and (c) alternated (E,F) and intermingled (G) hybrids.

core of the hybrid. This is caused by the shear-dominated failure mode due to the low span-to-depth ratio of 8:1 in this dynamic three-point bending test. Since the highest shear stresses occur at the midplane of the composite beam, properties are controlled more by the properties of the core under these types of loading conditions.

Fig. 3 shows the test specimens after the impacts, revealing interlaminar delaminations especially at the interface of carbon and HP-PE, due to differences in stiffness between both components. Other energy-absorption mechanisms are the breakage of carbon fibres and debonding of HP-PE fibres. However, almost no HP-PE fibre fracture occurred in the HP-PE and hybrid specimens.

Fig. a and b shows the initiation energy and total impact energy, respectively, versus the number of layer exchanges in the hybrid. It shows that in this test set-up plain carbon composites (B) absorb more energy than plain HP-PE composites (A). Since HP-PE composites have a low shear strength compared with carbon composites, the carbon composite will have a higher total energy absorption. The first general observation with respect to the hybrid composites is that the initiation energy exhibits a negative hybrid effect (Fig. 4a), whereas the total absorbed energy shows a significant positive hybrid effect (Fig. 4b).

The effect that the energy absorption shifts from the initiation to the propagation phase results in an increase in DI-values as listed in Table I. In the case

Figure 3 Test specimens after impact, showing delaminations.

Figure 4 (a) Initiation impact energy as a function of the number of layer exchanges and (b) total impact energy as a function of the number of layer exchanges. (■, ●) Carbon core and (□, ○) HP-PE core. Dotted rules show the rule-of-mixtures value.

TABLE I Ductility index values for HP-PE, carbon and hybrid composites

Specimen	Number of layer exchanges	Ductility index
A	0	11.1
B	0	0.2
C	3	1.0
D	3	4.9
E	9	6.6
F	16	7.0
G	Intermingled	7.4

of an intimately mixed hybrid, failure by delamination involves creating a larger amount of new surface than in a segregated hybrid. Since the positive hybrid effect is a result of an increase in damage, the amount of increase will be dependent on the number of sites that can initiate shear failure. Sandwich hybrids have the lowest number of layer exchanges and consequently the lowest energy absorption, whereas intermingled hybrids have the maximum number of shear failure sites and consequently the optimum composition for numerous delaminations and maximum energy absorption capability.

The hybrid composites with 16 layers (F) demonstrate, contrary to the other hybrids with a high degree of hybridization, a low energy absorption. This is caused by the test set-up. Upon loading, the HP-PE layers will fail at relatively low loadings, leading to a stacking of partly separated thin carbon layers. The stiffness is now reduced to such an extent that the sample will be flexible enough to be pushed simply through the span without fracture of the carbon layers. Consequently, the carbon layers are not fully loaded until failure, which will lead to a lower energy absorption.

This short investigation shows that the impact performance of carbon-epoxy composites can be significantly improved by hybridization with HP-PE fibres. Hybridization leads to a significant positive hybrid effect in the absorbed impact energy, due to an increase in the amount of damage. This positive hybrid effect is influenced by the degree of hybridization. When the degree of hybridization is increased, the hybrid effect approaches a constant maximum value, which is obtained in the case of an intimately mixed hybrid.

References

1. H. D. WAGNER, I. ROMAN and G. MAROM, *J. Mater. Sci.* **17** (1982) 1359.
2. S. FISHER and G. MAROM, *Compos. Sci. Technol.* **28** (1987) 291.
3. P. K. MALLICK and L. J. BROUTMAN, *J. Testing Evaluation* **5** (1977) 190.
4. G. DOREY, G. R. SIDNEY and J. HUTCHINGS, *Composites* **9** (1978) 25.
5. G. MAROM, S. FISHER, F. R. TULER and H. D. WAGNER, *J. Mater. Sci.* **13** (1978) 1419.
6. G. MAROM, E. DRUKKER, A. WEINBERG and J. BANBAJI, *Composites* **17** (1986) 150.
7. G. MAROM, H. HAREL, S. NEUMANN, K. FRIEDRICH, K. SCHULTE and H. D. WAGNER, *ibid.* **20** (1989) 537.
8. A. A. J. M. PEIJS and P. J. LEMSTRA, in "Integration of Fundamental Polymer Science and Technology", Vol. 3, edited by P. J. Lemstra and L. A. Kleintjes (Elsevier Applied Science, London, 1989) p. 218.
9. A. A. J. M. PEIJS, P. CATSMAN, L. E. GOVAERT and P. J. LEMSTRA, *Composites* **21** (1990) 513.
10. A. A. J. M. PEIJS, R. W. VENDERBOSH and P. J. LEMSTRA, *ibid.* **21** (1990) 522.
11. P. W. R. BEAUMONT, P. G. RIEWALD and C. ZWEBEN, in "Foreign Object Impact Damage to Composites" (ASTM, Philadelphia, 1974) p. 134.

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