Influence of the interface on the performance of polyethylene fiber reinforced composites

INFLUENCE OF THE INTERFACE ON THE PERFORMANCE OF POLYETHYLENE FIBRE REINFORCED COMPOSITES

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This study investigates the effect of fibre surface treatment on the performance of polyethylene fibre reinforced composites. Polyethylene/epoxy composites have been studied, emphasizing basic mechanical properties such as tensile, compressive, flexural and interlaminar shear strength as well as fatigue and impact behaviour. Results showed that impact properties are strongly reduced with improved adhesion, whereas with respect to structural behaviour, properties are dominated by the anisotropy of the fibre rather than by the interface.

Keywords: polyethylene fibres; surface treatment; mechanical properties

INTRODUCTION

Since it is generally recognised that the level of fibre/matrix adhesion is an essential factor in optimum transfer of fibre properties to composite properties, many attempts have been made to improve the structural applicability of composites based on high performance polyethylene (HP-PE) fibres by increasing the interfacial bond strength between fibres and matrix using various surface treatments including oxidizing acids [1], corona and plasma [2]. In these studies the effect of fibre surface treatment was mainly evaluated by fibre pull-out tests and interlaminar shear strength (ILSS). The present study had two objectives: first, to evaluate the effect of improved adhesion on mechanical performance under static, dynamic and impact conditions and second to obtain more insight in the role of fibre anisotropy on the performance of HP-PE/epoxy composites.

STATIC MECHANICAL PROPERTIES

In this study we used a HP-PE fibre (Spectra 1000, 650 den) of Allied Signal and an epoxy system based on bisphenol A and an anhydride curing agent. All composites were cured for 4h at 80 °C and post-cured at 110 °C for 12h. To study the effect of improved adhesion, composites incorporating untreated and chromic acid treated fibres were manufactured. Improved adhesion was obtained by immersing HP-PE fibres in chromic acid for 15 min. Specimens used for static mechanical testing were prepared by a modified pultrusion process, except for the double cantilever beam (DCB) specimens used for mode 1 fracture toughness testing. These specimens were machined from laminated plates which were moulded from woven fabric. Fibre volume fraction in all composites was 50%. Test results are summarized in Table 1. Although most properties are improved with fibre surface treatment, structural properties such as ILSS and compressive strength are still very low compared to those of composites based on other advanced reinforcing fibres.

IMPACT

Through penetration impact performance was measured on 4-ply laminated plates manufactured from woven fabric (Satin 8H, 255 g/m^2) and tested at a velocity of 4.5 m/s using a hemispherical dart of 10 mm. Figure 1 shows typical load-time curves recorded during penetration of HP-PE laminates. After surface treatment, impact properties are strongly reduced due to a more brittle failure mode, resulting in a decrease in maximum force and consequently a reduction in energy absorption by almost a factor of two.

FATIGUE

Tension-tension fatigue tests on UD-composites were performed in order to determine the effect of improved adhesion on the *S-N* curves. To avoid clamping problems and slip-out of the specimen due to the relatively low shear strength of HP-PE composites, filament wound rings were manufactured and tested on a split-disk loading device (ASTM D 2290) at a frequency of 5 Hz and R=0.1. Although the static strength of the filament wound rings decreased after fibre treatment, chromic acid treatment resulted in improved fatigue performance of the composite, as revealed by a decrease in slope of the *S-N* curve, indicating that the fatigue behaviour of the composite becomes more fibre dominated instead of interfacial dominated. Damage initiation occured in the form of longitudinal cracking along the edges of the specimen.

OFF-AXIS STRENGTH

UD-laminates were moulded from prepregs which were manufactured using a drum-winder. Test specimens were cut from the laminated plates at the desired load angles ranging from 0° to 90°. Plasma treated fibres were used to study the effect of improved adhesion.

Damage

During tensile testing of 90° test specimens, acoustic emission (AE) was used for real-time monitoring of damage initiation and development. Figure 3 shows the cumulative plots of hits versus time for both types of HP-PE composites. Fibre surface treatment resulted in an onset of damage initiation at approximately 55% of the failure strain, whereas in untreated HP-PE composites, AE initiation occured at approximately 15% of the failure strain. After fibre surface treatment, the total number of AE hits is reduced by a factor of 10 which is likely the result of a more localized fracture behaviour with less micro-cracks.

Influence of fibre anisotropy

Besides adhesion, another even more important aspect of HP-PE fibres, with respect to structural composite applications is their pronounced anisotropic character. In the case of chain-extended polyethylene the mechanical properties are derived from the polymer backbone, whereas shear and transverse properties are dependent on the much weaker Van der Waals interactions. Experimentally found maximum values for shear- and transverse strength of HP-PE/epoxy composites, incorporating surface treated fibres, are caused by a change in failure mode from debonding to fibre splitting with increasing levels of adhesion [3]. Consequently composite properties are fibre- instead of interface dominated. Also in compression the composite strength is strongly controled by the low off-axis strength of the fibre. HP-PE fibres fail via kinkband formation which is a shear induced process.

More quantitative information about the role of fibre anisotropy on the strength of HP-PE composites would be attained if off-axis fibre data was available. In view of experimental difficulties with respect to off-axis fibre testing, ultradrawn ultra-high molucular weight polyethylene (UHMW-PE) tape was prepared and used as an alternative for HP-PE fibres to investigate the off-axis strength of oriented polyethylene structures. Figure 4 shows off-axis data for both plasma treated HP-PE/epoxy composites and ultradrawn UHMW-PE tapes. From this data it can easily be concluded that the off-axis tensile strength of treated HP-PE composites is strongly dominated by the off-axis strength of the fibre. In the case of perfect adhesion and assuming a simple 'strength-of-materials' model, transverse composite strength is limited by the strength of the fibre (Figure 5), since this value of approx. 14 MPa is significantly lower than that of the epoxy matrix ($\sigma = 80$ MPa).

REFERENCES

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Table 1 Static mechanical properties of HP-PE/epoxy composites

	Untreated HP-PE	Treated HP-PE
Tensile strength (GPa)	1.16	1.27
Tensile modulus (GPa)	52	49
Tensile failure strain (%)	3.33	3.42
Compressive strength (MPa)	73	91
Flexural strength (MPa)	161	176
Flexural modulus (GPa)	38	40
ILSS (MPa)	14	29
G_{1c} (KJ/m^2)	1.00	1.35

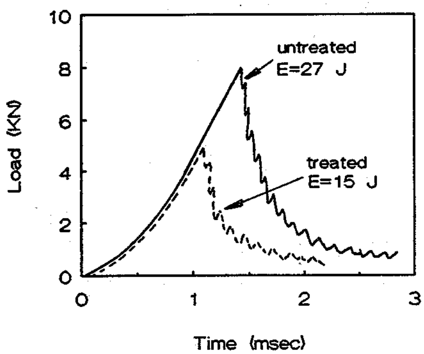

Figure 1 Impact load-time curves

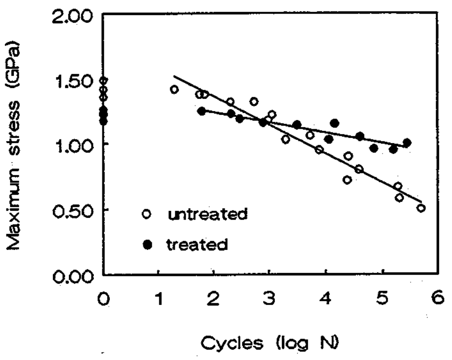

Figure 2 S-N curves of UD-composites

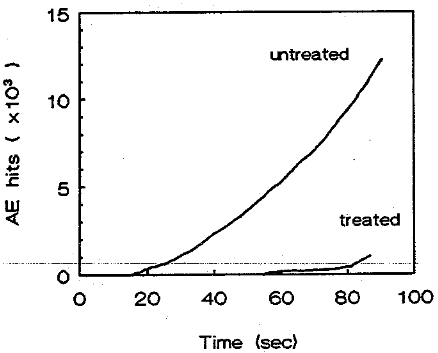

Figure 3 Cumulative AE plots of transverse tested composites

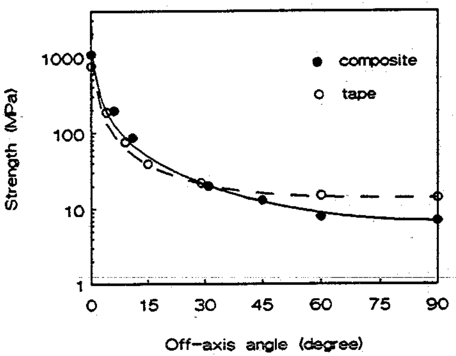

Figure 4 Off-axis strength of treated HP-PE composites and tapes. Drawn lines are Tsai-Hill predictions

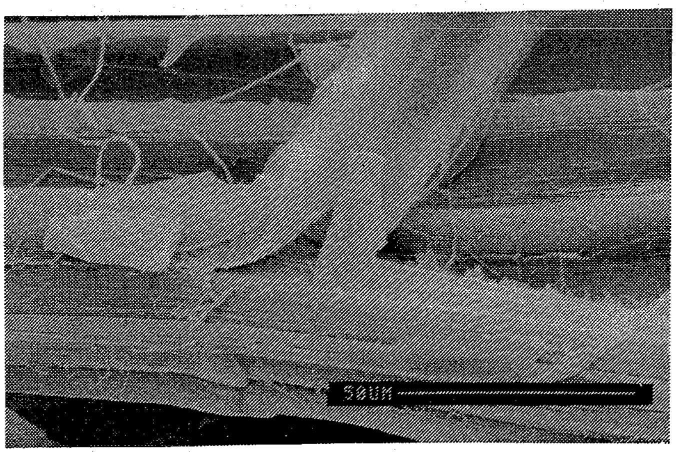

Figure 5 Scanning electron micrograph of transverse fracture surface of treated HP-PE/epoxy composite showing fibre splitting