polymer communications

Nylon 6–rubber blends: 9. Crack initiation and propagation under impact conditions

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Notched specimens, composed of layers of pure nylon and layers of nylon–EPR blend, were prepared. The specimens were fractured in an Izod impact test and were also fractured in tension, with the draw speed set to give a strain rate comparable to that of the Izod impact test. The data show that at these high deformation rates a brittle propagating crack can be stabilized when it reaches the ductile material (the blend).

(Keywords: nylon–rubber blend; crack propagation; impact strength)

Introduction

In order to study the importance of crack initiation and crack propagation on the complete toughening behaviour in nylon–rubber blends, a number of model studies were carried out. For these studies specimens were prepared which consisted partly of a tough material (a nylon-6–EPR blend) and partly of a brittle material (unmodified nylon). In this way it was possible to combine a ductile initiation with a brittle propagation and vice versa.

Experimental

The polyamide used was a nylon-6, type Akulon K124, obtained from AKZO. Relative viscosity η_{rel} in 96% $H_2SO_4 = 2.4$ and density $\rho = 1.14\,g\,ml^{-1}$; $M_n = 15\,000\,g\,mol^{-1}$.

The impact modifier was a maleic anhydride (MA) modified ethylene–propylene (75/25 wt%) copolymer, type Exxelor VA1801, kindly supplied by Exxon. The MA content was 0.7 wt%; $\rho = 0.89\,g\,ml^{-1}$.

The blend was prepared on a Berstorff ZE 25 corotating twin screw extruder with a screw diameter of 25 mm and length/diameter (L/D) = 33. The nylon and rubber (80 and 20 wt%) were fed in the fifth zone with a supply rate of $2\,kg\,h^{-1}$. The barrel temperature was 290°C and the screw speed $100\,rev\,min^{-1}$. The resulting weight average rubber particle size was 0.32 μm.

With a Brabender single screw extruder (screw diameter = 30 mm, $L/D = 25$) equipped with a film die, films of the blend and of the unmodified K124 were prepared with a thickness of about 1 mm. Strips were cut from these films and specimens with different stackings of nylon and blend strips (in total 10 strips) were prepared by compression moulding, with a mould temperature of 240°C. A notch was milled in these samples. Before testing, the specimens were dried at 110°C under vacuum for 18 h. The notched Izod was determined at room temperature for specimens with four different configurations of nylon and blend strips. Also, notched tensile impact (NTI) tests[1] were performed on similar specimens at room temperature, with a piston speed of $1\,m\,s^{-1}$.

Results and discussion

In *Figure 1* the stress–displacement diagrams measured with the NTI test are given. The unmodified nylon (specimen no. 1) shows brittle behaviour which follows from the low maximum stress and the very low propagation energy[1]. The blend (specimen no. 3) shows typical tough behaviour. The propagation energy is high and the maximum stress is determined by the yield stress as measured in unnotched specimens[2]. When one layer (thickness = 1 mm) of tough material is present ahead of the notch, while the rest of the specimen consists of brittle material (specimen no. 4) we see that the crack starts running at a much later stage than in the case of a pure nylon sample. The material ahead of the notch is able to relieve the high triaxial stress by cavitation of the rubber particles. This results in a very high maximum stress and initiation energy. The propagation energy, however, is close to zero (see *Table 1*). This suggests that when a tough propagating crack reaches a brittle material, it will accelerate until it shows the normal brittle crack characteristics. Despite the brittle fracture, the high stiffness results in such a high initiation energy that, with this size of specimen, the fracture energy (as measured with the NTI test) is higher than that of the ductile specimen no. 3.

When, on the other hand, a small layer of brittle material (i.e. with a high modulus, yield stress and cavitation stress) is present ahead of the notch while the rest of the material consists of ductile material (specimen no. 2), a kink in the stress–displacement curve is observed close to the stress where the pure nylon specimen fractured. This indicates that the nylon layer fractured at an early stage of the deformation process. However, the fact that the stress curve keeps increasing indicates that the sharp running crack is stopped when it reaches

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Table 1 Results of the notched Izod tests and the NTI tests on the specimens given in *Figure 1*

Specimen no.	Notched Izod ($kJ\,m^{-2}$)	Results of NTI test E_{total} ($kJ\,m^{-2}$)	$E_{initiation}$ ($kJ\,m^{-2}$)	$E_{propagation}$ ($kJ\,m^{-2}$)	Maximum stress (MPa)	Average yield stress (MPa)
1	1.5	6.6	6.3	0.3	27.6	94.5
2	37.7	89.1	57.8	31.3	46.3	47.5
3	64.5	123.1	64.1	59.4	59.7	54.3
4	41.5	134.7	133.3	1.4	90.8	89.5

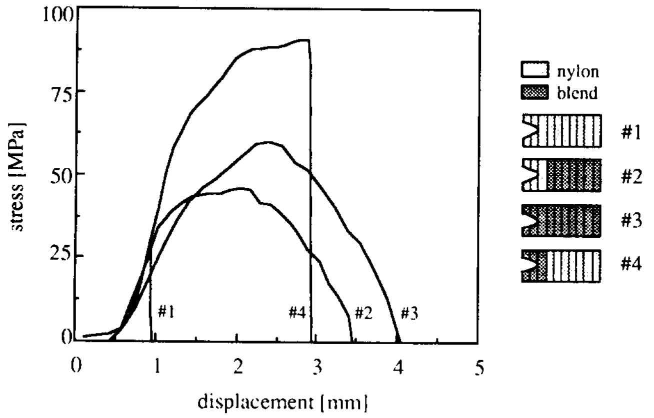

Figure 1 Stress–displacement curves of specimens composed of layers of unmodified nylon-6 and layers of nylon-6–EPR (20 wt%, rubber particle size = 0.3 μm). Layer thickness ≈ 1 mm. Layer configuration is given next to the graph. Test temperature is 20°C, piston speed is $1\,m\,s^{-1}$

the ductile material. The rest of the test continues as for the NTI test on specimen no. 3, but with a smaller cross-sectional area because of the fractured nylon layer. The clamp displacement at the point of complete fracture and the maximum stress both decreased proportionally with this decrease in cross-section.

As mentioned before, the maximum stress in a tough fracture is determined by the yield stress of the material. In other words, the crack starts to propagate when the whole cross-section of the specimen is able to yield and large local deformations are possible. When the fracture is brittle, the maximum stress is lower than the yield stress.

This is checked for the layered specimens, where the yield stress is taken to be the weighted average of the yield stresses of the composing materials[3]. For specimen no. 2 it is assumed that the nylon layer fractures before the maximum stress is reached and, consequently, will not bear any stress. This average yield stress is given in the last column of *Table 1*. It is clear that only for specimen no. 1, which failed in a brittle manner, is there a large difference between the maximum stress and the yield stress. For all the other specimens, the average yield stress and the maximum stress are very similar.

Conclusions

The results presented here show that a brittle propagating crack can be stabilized when it reaches a ductile material. Another important conclusion which can be drawn is that, with the given size of the specimen and of the notch, the crack initiation strongly influences the fracture energy. This is demonstrated by the fact that specimen no. 4, which fractures in a brittle manner (but has a ductile crack initiation), has a higher Izod impact strength than specimen no. 2 (with a relatively low yield stress) which behaves in a ductile manner during crack propagation. When measured with the NTI test, specimen no. 4 has a higher fracture energy than specimen no. 3, which has a ductile crack initiation and propagation.

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