FRACTURE TOUGHNESS OF BLENDS OF NYLON 6 WITH MALEATED ELASTOMERS

O. Okada*, H. Keskkula**, D. R. Paul**

*Bridgestone Corporation, 1 Kashio-cho, Totsuka-ku, Yokohama 244-8510, Japan

**Department of Chemical Engineering and Texas Materials Institute,

The University of Texas at Austin, Austin, TX 78712

Prepared for Presentation at the AIChE Annual Meeting, Austin, TX,

November 7 – 12, 2004

Parts of this paper have appeared in J Polym Sci Part B: Polym Phys 2004;42:1739-1758.

Introduction

The fracture behavior of rubber toughened nylon 6, in which rubber particles are dispersed in the matrix of nylon 6, is dependent on the morphology of the blends. Lower and upper limits on rubber particle size have been observed using standard impact tests such as Izod and Charpy which are commonly used because it is convenient for easy comparison among several materials. However, such standard tests provide limited information about fracture behavior, because results of such tests are the energy absorbed under fixed conditions of notch depth and ligament length. More detailed characterization of fracture behavior has been reported from this laboratory based on the essential work of fracture (EWF) model using instrumented Dynatup test in a single-edge notched three-point bend (SEN3PB) configuration [1-5]. It is the purpose of this paper to examine the fracture behavior of the blends of nylon 6 with maleated ethylene-propylene rubber (EPR-g-MA) and maleated styrene-hydrogenated butadiene-styrene triblock copolymer (SEBS-g-MA) using a single-edge notched three-point bend (SEN3PB) instrumented Dynatup test. The fracture behavior was analyzed with the essential work of fracture model and fracture mechanics method. The effects of rubber type, rubber particle size and ligament length on the fracture behavior for blends of nylon 6 and maleated rubber are examined.

Experimental

Blends of 80% nylon 6 and 20% total rubber based on various mixtures of maleated and non-maleated rubbers were melt mixed using a Killion single screw extruder (L/D = 30, D = 2.54 cm), outfitted with an intensive mixing head, operated at 240°C and 40 rpm. The rubber particle size was controlled by adjusting the ratio of non-maleated rubber to maleated rubber. The morphology of the blends were observed by a transmission electron microscope using ultra thin sections at an accelerating voltage of 120 kV. Impact behavior was examined by the standard Izod and instrumented Dynatup tests.

Results and Discussion

Blends where the rubber particles are smaller than 0.7 μm fracture in a ductile manner over the whole range of ligament lengths. However, blends with rubber particles larger than 0.7 μm show a ductile-to-brittle transition with ligament length; ductile fracture is observed for specimens with short ligaments while brittle fracture is seen for those with long ligaments. The transition ligament length depends on rubber particle size but is independent of rubber type.

The yield stress (σ_y) or the critical stress intensity factor (K_{IC}) was calculated from the relation between failure stress and normalized crack length using non-linear regression analysis. The failure mode is governed by the relative levels of failure stress given in terms of either K_{IC} or σ_y at a certain ligament length for a given material.

The ductile fracture behavior was analyzed using the EWF model. The limiting specific fracture energy (u_o) for EPR-based blends is slightly higher than that for SEBS-based blends, while the dissipative energy density (u_d) for the latter is much larger than that for the former. Larger fracture energies for the SEBS-based blends than the EPR-based blends can be explained by larger u_d of the SEBS-based blends.

The critical strain energy release rate (G_{IC}) was also calculated from the brittle fracture behavior. Both G_{IC} and K_{IC} parameters increase when the rubber particle size is decreased for both blend systems. When the rubber particle size is fixed, the G_{IC} and K_{IC} parameters have similar values regardless of rubber type. The transition ligament length increases with decreasing rubber particle size and is found to be near the size criterion for plane-strain conditions calculated from the fracture mechanics parameters for both blend systems. It is suggested that the brittle fracture occurs when plane–strain conditions are developed and the fracture stress is governed by K_{IC}. It is also suggested that the ductile-to-brittle transition with the ligament length agrees to the size criterion for plane-strain conditions.

References

[1] Wildes G. Keskkula H, Paul DR. Polymer 1999;40:7089.

[2] Kudva RA. Keskkula H. Paul DR. Polymer 2000;41:335.

[3] Okada O, Keskkula H, Paul DR. Polymer 2000;41:8061.

[4] Pressly TG, Keskkula H, Paul DR. Polymer 2001;42:3043.

[5] Laura DM, Keskkula H, Barlow JW, Paul DR. Polymer 2003;44:3347.