FRACTURE OF UN-NOTCHED BIAXIALLY COLD ROLLED HIGH DENSITY POLYETHYLENE IN TENSION

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Abstract

The fracture surfaces of un-notched tensile specimens prepared from HDPE biaxially rolled at room temperature and drawn to failure in tension were analyzed using scanning electron microscopy (SEM). The HDPE sheets were reduced to a thickness of about 80% the initial during the rolling process and the tensile test was conducted at -40 ^{o}C and at a strain rate of 100%/min. In comparison to a melt processed sheet of the same material and thickness, the rolled material exhibited greater work hardening capacity, homogeneous yield behavior, and improved elongation to failure. The fracture surface manifested in a plane roughly 45 ^{o} to the draw direction, and revealed three distinct zones: 1) the damage zone, 2) a fracture surface associated with slow crack propagation, and 3) a fracture surface associated with rapid crack propagation. The cross-sectional dimensions of sub-microlayers observed from the fracture surface suggested that they could have resulted from the affine deformation of spherulitic crystals during the rolling process.

1. Introduction

Engineers are actively in search of scalable, economic, and environmentally friendly (e.g. solventless) processing methods for high specific strength and toughness materials. One technique that had been adapted to soft materials from steel manufacturing is cold roll milling. This approach has been used to induce orientation (either unidirectional or bidirectional) in both vitreous and crystalline solid polymers below their primary thermal transition temperature. The mechanism of toughening has been suggested to relate to the evolution of complex, hierarchical structures in both classes of polymers: the formation of shear-bands in glassy polymers [1] and the elimination of stress-risers associated with anisotropic plastic stress response in spherulites.[2] This work investigated the fracture surface of bidirectionally oriented HDPE after subsequently drawing to failure near the T_g of the interlamellar amorphous segments. The fracture surface was investigated to rationalize the evolution of hierarchical structure that took place during the rolling process as well as in subsequent drawing.

2. Results

The engineering stress strain curves of the rolled and undeformed HDPE are compared in Fig. 1 below. Notably, the latter does not exhibit any strain hardening but rather a large amount of strain softening at the yield point: [3]

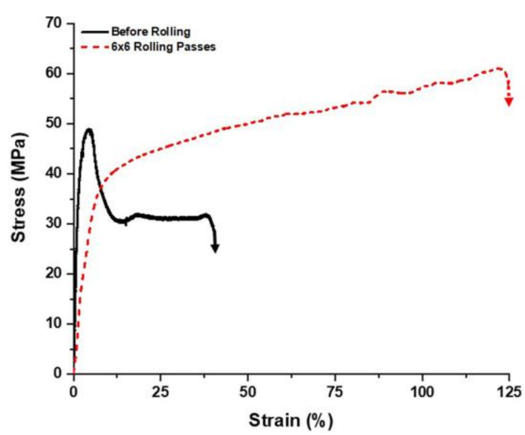

Figure 1: Engineering stress-strain curves of un-rolled and rolled HDPE when pulled in tension to failure at -40 C and a strain rate of 100%/min.

Density measurements, thermal and dynamic mechanical analysis, small and wide-angle x-ray scattering, as well as light transmission studies collectively suggested that a discontinuous reduction in the crystal size occurred at about 60% thickness reduction. Electron microscopy was used to further elucidate the development of structure upon roll deformation.

The following observations were made on the basis of SEM micrographs obtained of the fracture surface:

a. Three distinct zones were evident from the low magnification image of the fracture surface (see Fig. 2)
b. The damage zone (zone I in Fig. 2) consists of microlayers bridged by submicron fibrils (200-500 nm wide) (Fig. 3a). The transition zone between I and II is associated with an increasing prevalence of fibrils (Fig. 3b).
c. Zone II is wholly composed of submicron fibrils (270 nm) in a dense, interconnected network (Fig. 3c). In the transition zone between zones II and III (Fig. 3d), microlayers in the rolling plane are again observed.
d. Zone III (Fig. 3e) consists of wavy sub-microlayers (800 nm), which are assumed to have buckled due to transverse contraction after failure given the large elastic recoveries observed in length after failure (~23% of the terminal length at fracture).
e. Affine deformation would suggest that the original spherulite dimensions were 4 μm, which is a reasonable assumption for polyethylene. Additional microscopic evidence is needed to characterize the undeformed material.

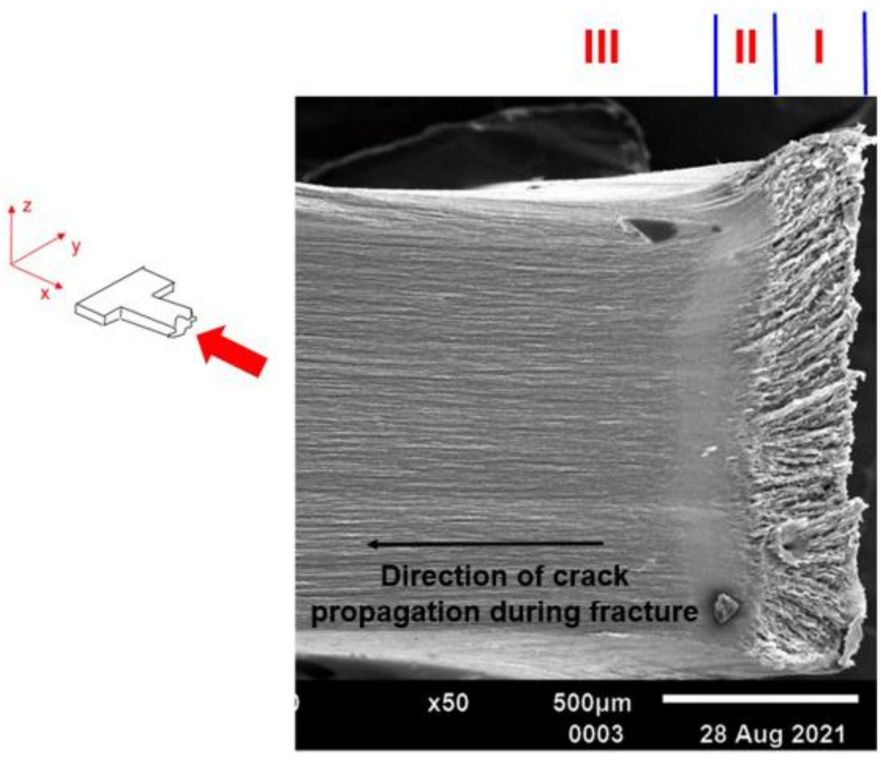

Figure 2: Overall view of fracture surface of cross-rolled HPDE fractured in tension. Three distinct zones associated with different propagation speeds were observed.

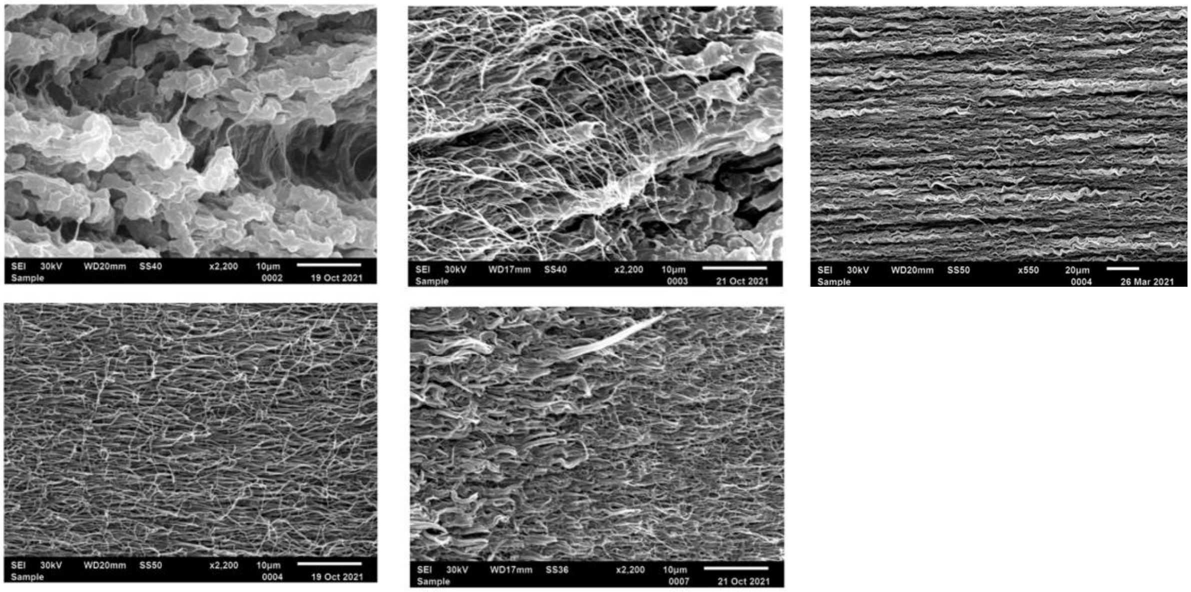

Figure 3: Magnified images of fracture surface, including a) the damage zone (top left), b) the transition between the damage zone and initial fracture zone (top center), c) the bulk slow crack propagation zone (bottom left), d) the transition between the slow and fast crack propagation zone (bottom center), and e) the zone of rapid crack propagation (top right).

3. Conclusions

Three distinct zones were identified from the fracture surface of bidirectionally roll oriented HDPE drawn to failure in tension. Slow crack propagation kinetics allowed sufficient time for fibrillation to occur, whereas rapid crack propagation resulted in an elastic contraction in the machine and transverse direction after uniaxial drawing and fracture. It is probable that affinely deformed spherulites were converted into the sub-microlayered structures identified from the fracture surface.

References

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