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Fracture behavior of high-density polyethylene composites

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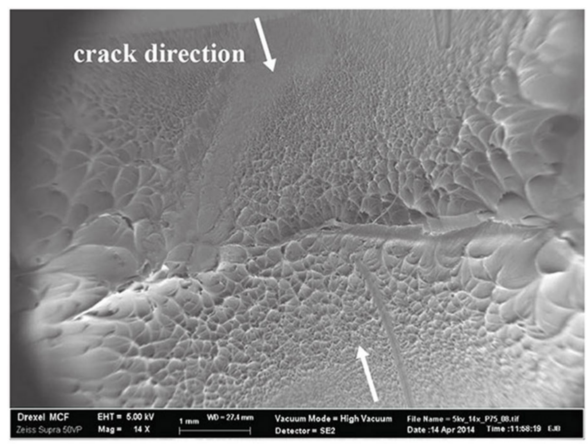
The essential work of fracture concept was used to study the effect of nanoclay on the plain-strain fracturing of pristine and recycled blends.

With the increased use of high-density polyethylene (HDPE) in civil engineering infrastructures and consumer products, concerns have been raised about the long-term fate of the plastic waste generated in its production (i.e., because of its permanence in the environment). The reutilization of recycled plastics offers many benefits for managing plastic waste products and can thus be used to enhance the sustainability of plastic materials. Recycled HDPE materials, however, tend to possess inferior properties compared with their pristine counterparts. For instance, we showed in a previous study[1] that bottle-grade recycled HDPE has a significantly lower fracture toughness than pristine HDPE. Caution should thus be taken when blending recycled HDPE with pristine resin, particularly for engineering applications.

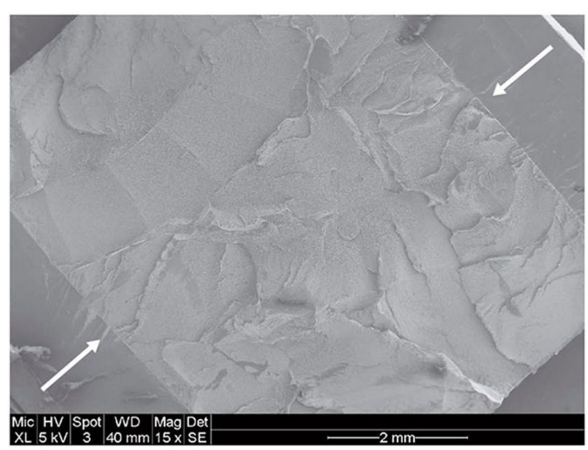
In recent years, polymer clay nanocomposite (PCN) materials have received considerable attention because of their potentially enhanced material properties compared with polymers in their pristine state.[2–8] One particular feature of PCNs is that they can exhibit significantly improved mechanical properties, with the addition of only small amounts of nanoclay. However, the fracture behavior of PCNs—especially of recycled PCN blends—has not yet been characterized and is less understood.

In this study,[9] we have therefore investigated the effect of nanoclay on the fracture behavior of pristine HDPE and on recycled HDPE blended materials under a plane-strain condition. We prepared our pristine/recycled HDPE blends by mixing recycled HDPE pellets with pristine HDPE resin. The resin was produced in a twin screw laboratory-scale extruder to have weight fractions of 25, 50, and 75%. We then mixed the appropriate amount of our nanoclay master batch with the pristine and pristine/recycled blends at 2, 4, and 6wt% to produce the PCN materials.

To determine the fracture behavior of our samples, we used the essential work of fraction (EWF) concept.[10–12] In this framework, fewer



(a)



(b)

Figure 1. *Scanning electron microscope images illustrating the fracture surface morphology of (a) the 75% pristine/25% recycled high-density polyethylene (HDPE) sample (P75R25) and (b) P75R25 with a nanoclay content of 6wt%.*

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rigorous criteria are required and it has a simpler test protocol than conventional methods (e.g., the J-integral test). In addition, we applied an energy partitioning method[13] so that we could extract the plane-strain fracture energy from the total fracture energy we measured in the EWF test. Our results indicate that failure in the EWF test transitioned from ductile-type to brittle-type when we added 6wt% nanoclay to the pristine HDPE and 2wt% to the recycled blends.

To further study the failure mode of the failed EWF test specimens, we used a scanning electron microscope (SEM) to examine the fracture morphologies. The SEM image of our 75% pristine/25% recycled HDPE (P75R25) sample—see Figure 1(a)—shows ductile failure. The fracture surface is covered by fibril structures that promoted the plane-strain fracture toughness of the material. In contrast, for the P75R25 sample with 6wt% nanoclay, we observe a rough fracture surface with shorter fibrils—see Figure 1(b)—and that brittle fracture occurred.

Our results demonstrate that—in general—the surface roughness of the samples increases, whereas the fracture toughness decreases, with increasing nanoclay content. We found that the increased roughness compensated for the reduced fracture toughness because of the decreased size of the fibrils when we added 2wt% nanoclay to the recycled HDPE blends. It is therefore possible for the fracture toughness value to remain unchanged. When we added more than 2wt% nanoclay to the blends, however, the fracture toughness decreased significantly. This is because the fibril sizes were reduced substantially and thus created a featureless cleavage surface. Therefore, we find that 2wt% is the maximum nanoclay content for our tested recycled HDPE blends. A transition map that captures the relationship between the failure mode and the associated changes in fracture morphology of our tested materials is shown in Figure 2.

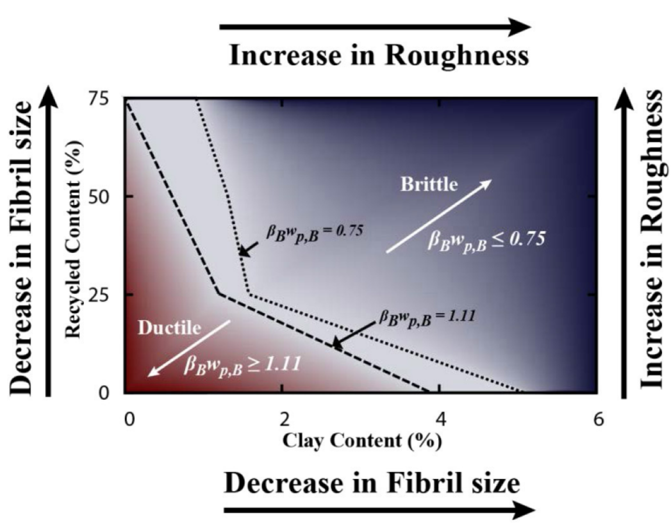

Figure 2. *Transition map illustrating the potential failure mode and associated changes in fracture morphology with respect to the content (wt%) of recycled HDPE and nanoclay in a pristine HDPE resin.* $\beta_B w_{\rho,B}$: *Specific non-essential work of fracture.*

In summary, we have produced a set of pristine and pristine/recycled HDPE blends to study the effects of nanoclay on the fracture behavior of the materials. Incorporating nanoclay has previously been shown to enhance the basic engineering properties of such polymers. We have shown, however, that it can also compromise the fracture properties, particularly at high nanoclay contents. Caution should therefore be exercised when using nanoclay as a reinforcement in HDPE, especially for applications that require a high fracture toughness. We are currently investigating the effect of nanoclay on the long-term failure behavior of these materials. For instance, we are studying the slow crack growth of pristine/recycled HDPE blends.

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