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Making an impact with nanocomposites

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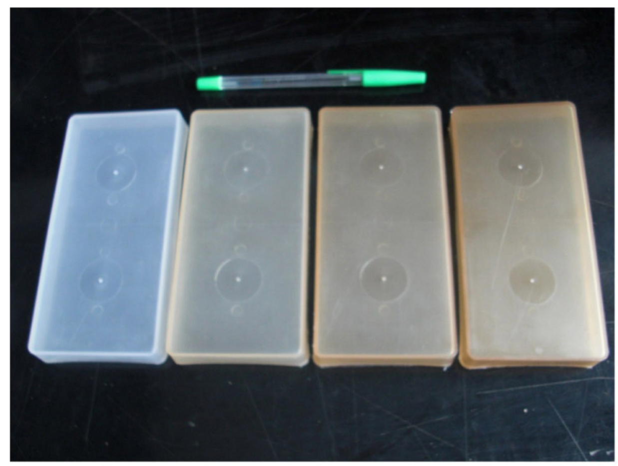
Nanoclays can improve the performance of injection-molded polypropylene components likely to be subjected to impact in service.

Polymer nanocomposites are new materials that show great potential in a variety of applications. By incorporating nanoscale particles of a filler material, the performance and properties of the bulk material can be drastically altered. Indeed, quite exceptional improvements can be achieved with small amounts of filler.[1,2] For example, polypropylene (PP), when filled with less than 5wt% of clay nanoparticles (nanoclay), is suitable for engineering applications.[3–5] Optimum performance relies on good dispersion of the clay nanoparticles and separation (exfoliation) of the clay layers within the nanoparticles.[6–8]

To make nanocomposites economically viable, their production must use common processing equipment, and additional processing steps should be avoided. It is possible to achieve this processing requirement by mixing a masterbatch of pure polymer with a nanoclay-polymer mix during injection molding.[9] We have used this method to prepare PP-nanoclay nanocomposites and have studied the performance of these nanocomposites in impact force tests. Our results show the effect of the molding process and of the nanoclay filler on the properties of PP. In particular, we investigated the material's structure and properties at the weldline, formed where the two injection flows meet.[10]

Rectangular boxes, 1.4mm thick, were injection molded using a hot runner mold with two injection points (see Figure 1, top). Emulating the expected industrial practice,[9] pure PP was mixed with various amounts of a commercially available masterbatch (MB) of PP containing 50% of organoclay, and processed at 235°C. Transmission electron microscopy images of the resulting blocks show that the clay platelets are uniformly dispersed, without signs of aggregation, and are oriented in the direction of the polymer flow (see Figure 2).

The impact properties of the moldings were assessed by uniaxial tensile and biaxial flexural tests. The former were carried out on rectangular samples taken from the weldline area and on another sample, taken from an area away from the weldline and aligned with the injection flow direction (see Figure 1, bottom). The biaxial impact tests were carried out on circular samples that were also taken at, and away from, the weldline area. The amount of energy required to cause the samples to fail was measured. This analysis gives a realistic view of in-service impact situations.[11,12]



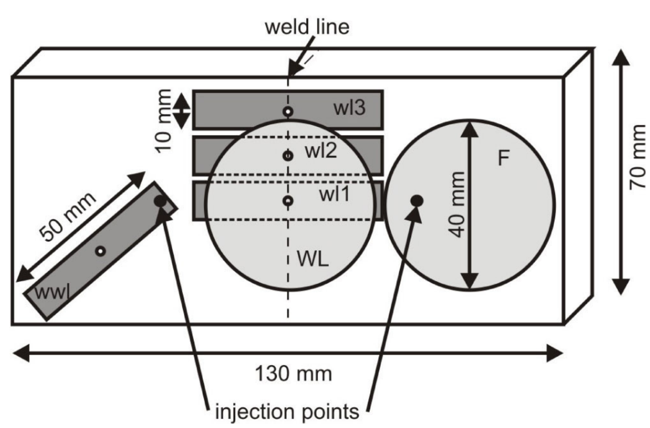


Figure 1. Molds (top) and location of test specimens (bottom). The rectangular sections indicate the location of the three weldline (wl) samples (wl1–3) and the bulk sample (wwl) used in tensile testing. The circular sections denote the weldline (WL) and bulk (F) samples used in flexural testing.

The two sets of test data give different information on the product's toughness (see Figure 3). In tensile testing, the weldline samples

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generally absorbed less energy before failing than the sample taken at a distance from the weldline. This is because, when the two injection flows meet, the polymer chains and the nanoclay platelets (if present) are forced to align themselves parallel to the weldline, and are thus perpendicular to the applied impact force. Moving away from the weldline in the flow direction, the sample strength increases, in agreement with previous results.[13] Weldlines formed at higher temperature and pressure showed better impact performance. In the uniaxial tests, the inclusion of nanoclay increased the toughness of the material at points away from the weldline.

In contrast, in biaxial testing on pure PP the weldline zone sample was tougher than the sample taken near the injection point.[14] The failures originate at the weakest point and propagate due to radial and hoop stresses.[15] Fracture patterns at the weldline and close to the injection points are significantly different (see Figure 4). In pure PP samples impacted near the injection points, there is bending along the clamping ring and a single split occurs in the melt flow direction. Conversely, in fractures at the weldline zone cracks run radially from the point of impact, while others follow a circular path around the same point, with evidence of plastic deformation. The inclusion of nanoclay did not improve the strength of the bulk sample relative to the weldline, with negligible differences in impact toughness between the weldline and the bulk for these samples.

In general, incorporating nanoclay improves PP's impact toughness, with best results for 3–5% nanoclay content. The nanoclay toughening effect is thought to be the result of the polymers that are intercalated within the host nanoparticle galleries having conformations different from those in the bulk, and also the mobility of the nanoparticles.[16] The formation of crazes is also important: as the matrix absorbs energy on deformation, nanosized free surfaces are necessary to initiate crazes. The delamination of clay particles provides those surfaces.[17] In the case of biaxial impact tests, with in-plane stresses, these toughening effects are negligible, and fractures propagate in the direction of nanoclay orientation.

Weldlines are detrimental to the impact performance of PP-nanoclay composites due to their effect on polymer and nanoparticle orientations. In tensile testing, their orientation at the weldline is perpendicular to the applied force, whereas away from the weldline the polymer molecules and clay platelets are oriented with that force. Under flexural testing, the moldings are more ductile and tougher close

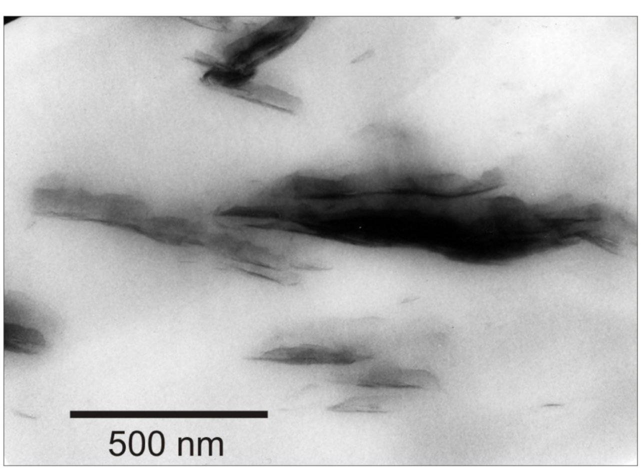

Figure 2. *Transmission electron microscopy images of nanoclay dispersion in the polypropylene (PP) nanocomposite containing 6% of the polymer-nanoclay masterbatch.*

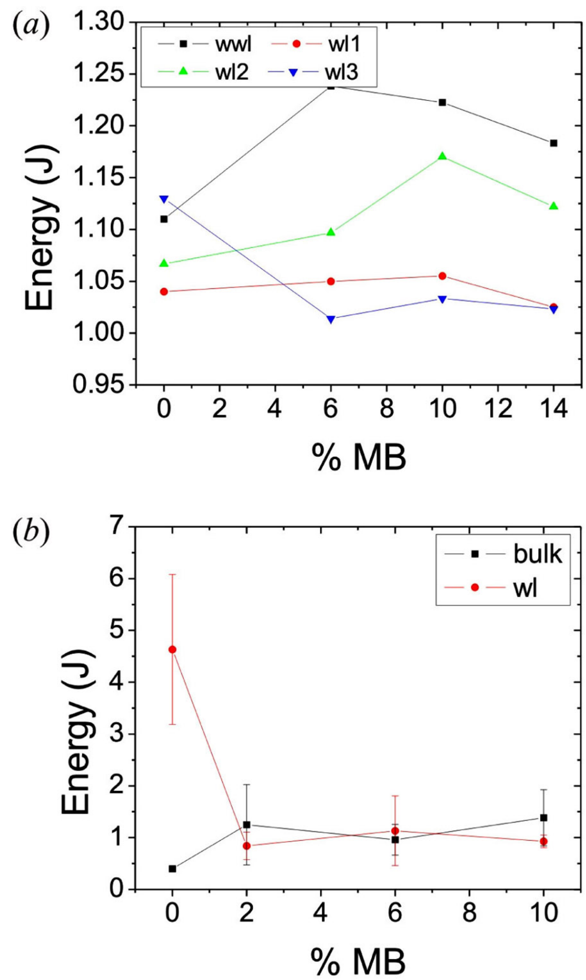

Figure 3. *Impact energy as a function of location and nanoclay content (%MB) for (a) tensile loading and (b) biaxial loading.*

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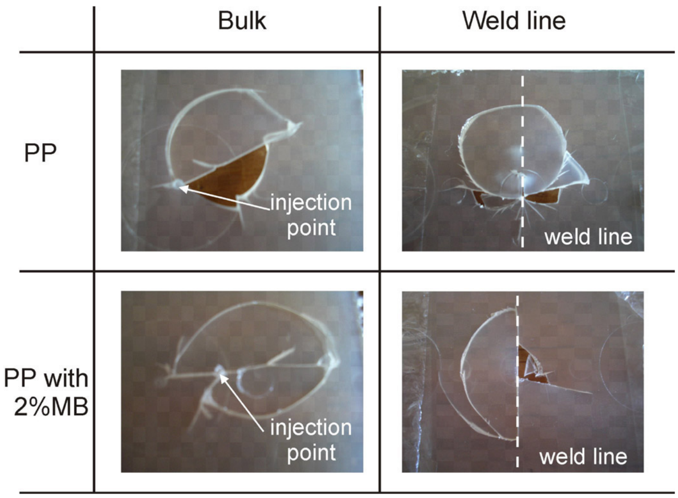

Figure 4. *Failure under biaxial impact loading of PP and nanocomposite (PP with 2% MB) moldings.*

to the weldlines than away from them. At the weldline, the weakness caused by the molecular orientation does not affect the nanocomposite toughness, and the difference between failure energies at the bulk and weldline zones is negligible.

The best impact performance was observed in moldings with 3% of nanoclay. With higher contents, as in microcomposites, intercalation is reduced and the tactoids act negatively as defects. It is clear that under biaxial stresses, nanoclay inclusion does not improve PP's impact performance. Future work will investigate nanocomposites based on a blend of PP with a thermoplastic elastomer as the matrix, and how organoclay exfoliation in these materials leads to significant improvement in stiffness and impact resistance.

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