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Influence of roll embossing on polypropylene film

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Roll embossing is an intermediate stage, introduced between melt casting and drawing in a fibre-from-film extrusion line. The unit consists of a pair of temperature-controlled rolls, one of which is grooved circumferentially. The roll embossing process introduces an additional range of technological parameters, the potential of which and the load carrying behaviour of the resulting embossed films are the focus of this communication.

Experimental

The basic test material was a 4.5 *MFI* polypropylene (ICI, GWE27), and the process conditions were: extrusion temperature, 240°C; screw speed 38 rev min^{-1}; take-up speed 17 m min^{-1}; chill roll temperature 10°C; embossing roll width 500 mm; groove pitch 33 grooves cm^{-1}; groove depth 200 μm; roll speed 17 m min^{-1}.

Films were produced in 100, 150 and 225 μm thicknesses and subsequently embossed at roll temperatures between 70–105°C and at roll pressures between 2–10 MPa.

Material structure variations were identified using small-angle light scattering (SALS), small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS)[1].

Static and dynamic mechanical properties were determined using an Instron Universal Test Machine and a sonic apparatus[2].

Results

An increase in the thickness of as-cast film resulted in a greater degree of crystallinity (as indicated by density measurements, *Figure 1*), enhanced crystalline order and larger spherulite size (*Figures 2* and *3*), all resulting as expected, from a less effective quench as film thickness increases.

For 100 and 150 μm thick films–provided the temperature of the embossing roll was at least 90°C — both the amount of crystallinity and the order and size within the crystallites (as evidenced by monoclinic formation and sharpening of the diffraction rings) was greater than in the corresponding as-cast films. No such changes could occur in the 225 μm film, this already having an orderly crystalline structure.

Embossing caused some longitudinal crystalline orientation in 100 μm thick films (as indicated by WAXS and SAXS patterns, *Figure 2*). 150 μm thick film underwent some longitudinal spherulitic deformation and showed both longitudinal and transverse cyrstalline orientation. The 225 μm film showed a considerable longitudinal spherulitic orientation (as indicated by SALS patterns, *Figure 3*) but without any crystalline orientation, over the entire temperature and pressure range. The presence of some overall orientation in all samples was also demonstrated by an increase in sonic modulus.

Tenacity, yield strength and sonic modulus values were all found to increase with increasing embossing temperature or pressure; this increase being more pronounced with 100 and 150 μm thick films. Longitudinal elongation at break did not alter for 100 and 150 μm films but increased for 225 μm film. Transverse elongation was reduced for all but the 225 μm film.

Discussion

Roll embossing has been shown to improve the tenactiy of the final drawn tape by as much as 15%[3], and the aim of this work was to identify the mechanism through which this improvement is achieved. The increase in mechanical strength of embossed films is considered to result from improved crystalline structure and longitudinal orientation, particularly crystalline orientation. Under the same draw process conditions, the embossed film will achieve a greater degree of nett orientation[4] compared with non-embossed film, hence exhibiting greater tenacity.

A further contributory factor of the increased tenacity

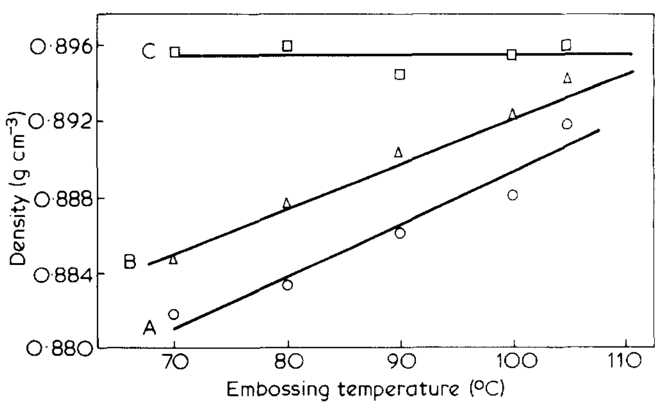

Figure 1 Density vs. embossing temperature for film thicknesses, A, 100 μm; B, 150 μm; C, 225 μm

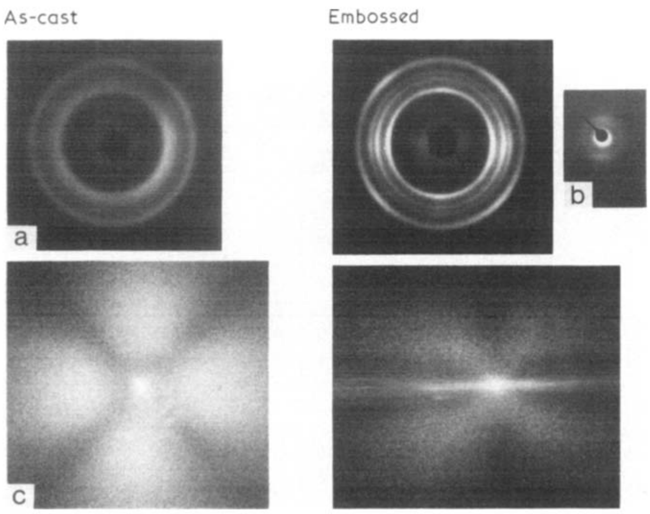

Figure 2 (a) WAXS; (b) SAXS; (c) SALS patterns for 100 μm thick films

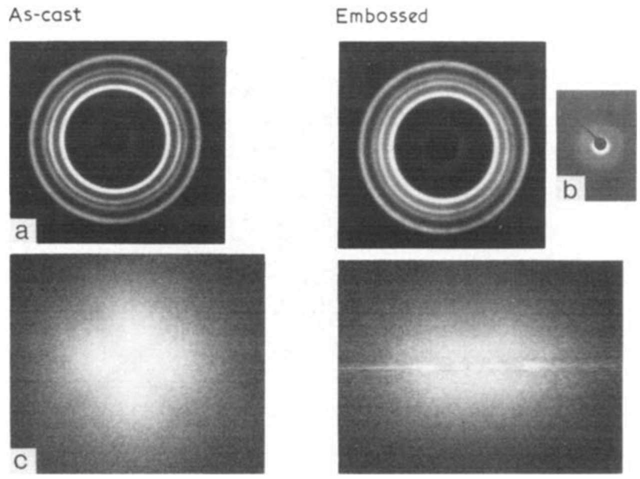

Figure 3 (a) WAXS; (b) SAXS; (c) SALS patterns for 225 μm thick films

may be the increased lamellar volume induced in the spherulites. During drawing the lamellae slip, tilt and finally unfold to give separate smaller structural blocks, which form the basis of microfibrillar structure. An increase in the initial lamellar volume results in a greater number of microfibrils in the drawn material. Microfibrillar structure induces greater axial strength by virtue of its fibrous features and dense packing.

In the case of the 225 μm film, embossing provides potential for further drawing, as indicated by the high value of the longitudinal elongation. Embossing causes orientation in the amorphous region, so improving the packing of the molecular chains and the degree of order. This orientation-induced order improves the load capacity of the intercrystalline regions and reduces the number of potentially weak regions in the system. The whole system behaves more homogeneously under load, free from stress concentrations, deforming more uniformly and to a greater extent. The distinct behaviour of the 225 μm thick film may be due to:

(i) a more orderly crystalline structure; (if this advantage is confirmed, then a convential heated roll could be included in the line prior to the embossing unit);

(ii) a change in the mechanism of embossing which is related to the ratio of groove depth to film thickness. These factors are being investigated further.

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