$\mathbf{R}_3$, it seems that along the observed planar interfaces a kind of chemical ordering takes place presumably in the tetrahedral layers. Such an ordering might initiate the formation of precipitates within the $Ca_2(Al, Fe, Cr)O_5$ solid solution, and some electron diffraction patterns showing split spots (Fig. 4) support this presumption. Although chemical ordering is very likely responsible for the effects observed, further work is needed to confirm the existence of the precipitates and to clarify fully the role of chromium in the formation of the observed planar interfaces.

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*Received 26 July
and accepted 20 September 1979*

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Microstructural changes during large strain cyclic deformation of polypropylene

Polypropylene exhibits an excellent fatigue resistance during large strain cyclic deformation [1]. In the course of work on polypropylene deformed uniaxially beyond the gross yield point and subsequently cycled into compression, the following shape changes were observed: (a) the appearance of a neck in tension; (b) the disappearance of the neck as the specimen is compressed; (c) bulging of the specimen in the previously necked region.

The profiles of a specimen of polypropylene machined from sheets initially 1.27 cm thick to give cylindrical specimens 0.635 cm diameter and a gauge length of 1.25 cm are shown in Fig. 1.

To examine the microstructural changes occur-

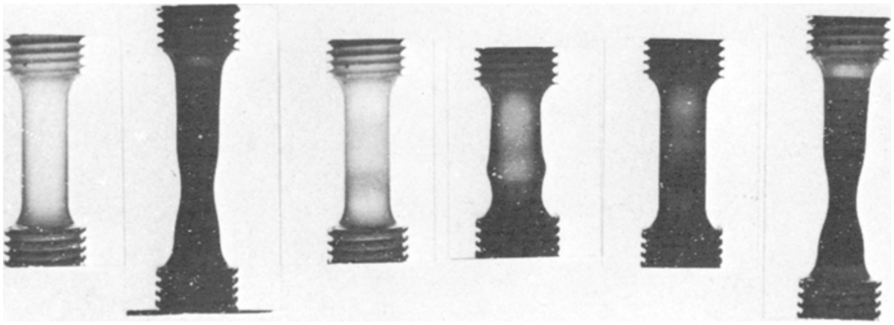

Figure 1 Unaxial cyclic deformation of polypropylene showing the microscopic shape changes which result in tension (necking) and in compression (localized bulging).

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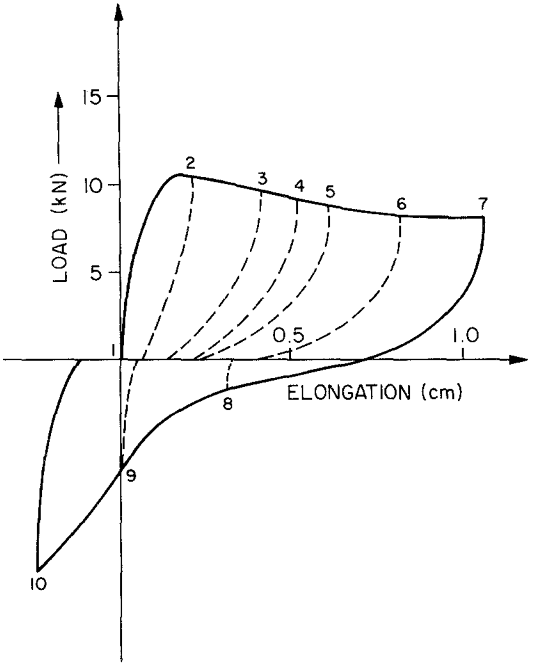

Figure 2 Tensile–compressive load–elongation curve for polypropylene between the limits +1.067 cm and −0.267 cm (solid line), showing the unloading curves for the 10 specimens which were subsequently sectioned and examined in the optical microscope (dotted lines).

Figure 3 Transmitted light micrograph with crossed polars showing the undeformed spherulitic microstructure with no cracks.

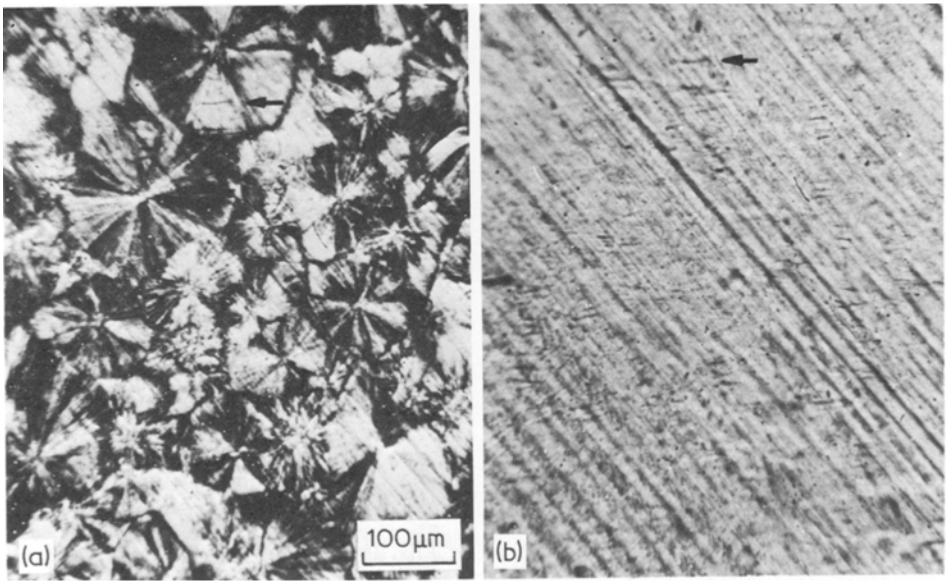

Figure 4 Transmitted light micrographs of a specimen deformed in tension (curve 5 on Fig. 2). (a) Taken with crossed polars showing spherulitic structure, (b) unpolarized light showing cracks normal to the tensile axis (arrowed).

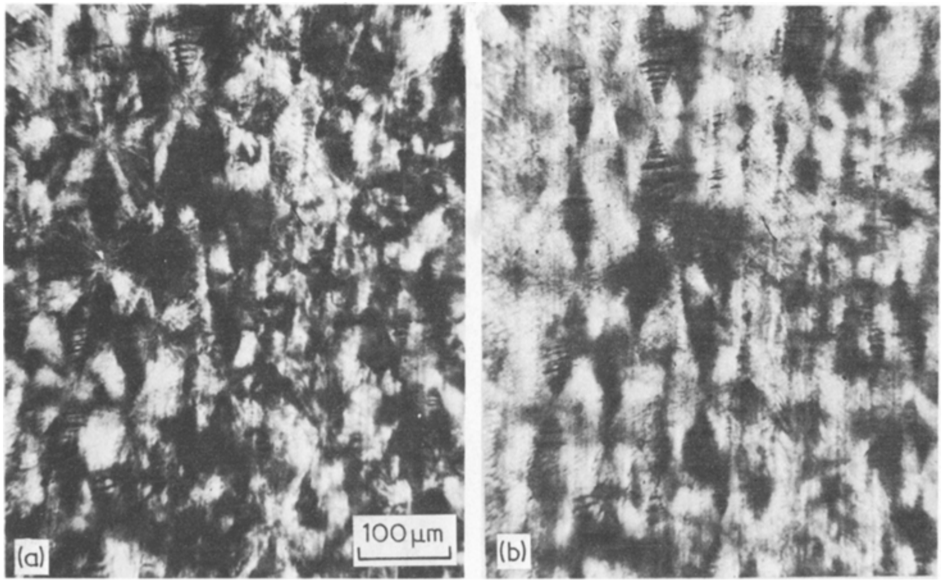

Figure 5 Transmitted light micrographs from necked region of specimen deformed in tension (curve 7 on Fig. 2). (a) Taken with crossed polars, (b) unpolarized light.

ring during this deformation, ten specimens were deformed to various stages of the load–elongation loop, microtomed longitudinally and examined. A composite of these load–elongation histories is shown in Fig. 2. Typical examples of the microstructures of these specimens are shown in Figs. 3, 4, 5, and 6. From the figures it is apparent that the spherulitic nature of the material is retained during the necking process. The aspect ratio of the spherulites reflects the microscopic strain in the neck. The deformation appears to be uniform down to the scale of the spherulites. Another

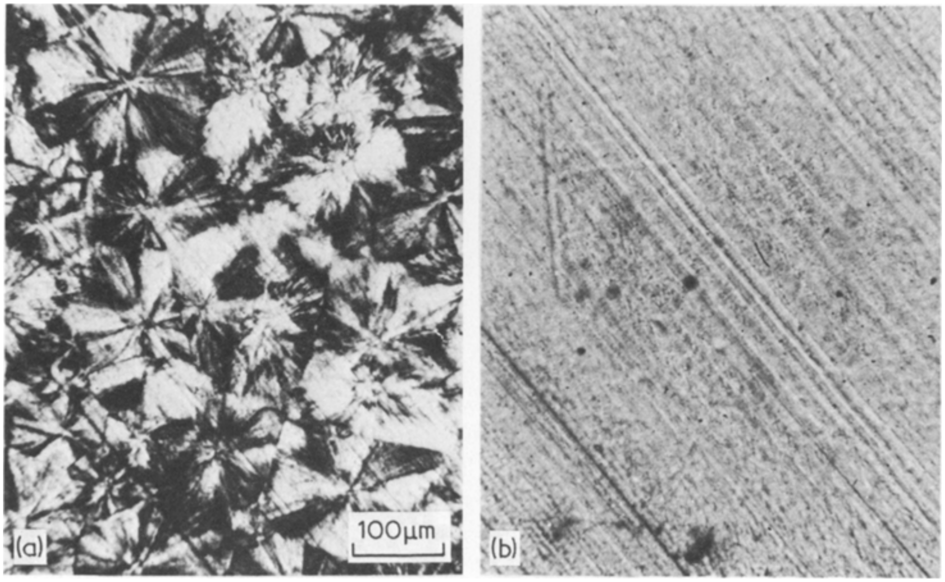

Figure 6 Transmitted light micrographs from central region of a specimen which has been necked in tension and subsequently deformed into compression (curve 10 on Fig. 2). (a) Crossed polars, (b) unpolarized light.

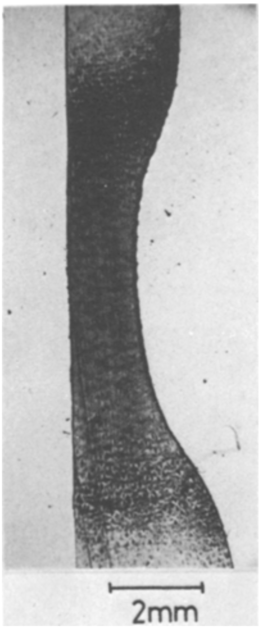

Figure 7 Low magnification transmitted unpolarized light micrograph of the necked region of a specimen deformed in tension (curve 7 on Fig. 2).

feature of the deformed microstructure is the appearance of cracks (or crazes) normal to the tensile axis in the longitudinal sections of the spherulites. These "cracks" were noticed at the smallest strains and their density increases with increasing tensile strain (cf. Figs. 5b and 6b). Accompanying this cracking is an increase in the opacity of the specimen which is particularly noticeable in the cold drawn region. The phenomenon of stress-whitening is apparently related to these microstructural changes.

On reversing the sense of the deformation the spherulites regain their former shape, the cracks disappear and the stress-whitening is removed (Fig. 7). This appears to happen as the specimen regains its former shape.

These observations are consistent with a previously published model for the deformation of spherulitic HDPE at smaller strains [2–4], which interprets the deformation behaviour of crystalline polymers in terms of Asaro's work on plastically inhomogeneous solids [5]. (Asaro's model relates the shape of the reverse stress–strain curve to the reversibility of the "structures" formed during forward plastic flow.) Plastic inhomogeneity implies the building up of internal stress during forward plastic deformation. This internal stress serves to aid the applied stress during reverse plastic flow and thus manifests itself as a Bauschinger effect. The bulging would seem to be a reflection of this effect [6].

The observation of deformed spherulites in the necked region indicates that the cold-drawing process is but a continuation of plastic deformation behaviour prior to the gross yield point, with no apparent change in mechanism taking place. The return of the spherulites to their undeformed shape supports this viewpoint and confirms the applicability of Asaro's model to the cold-drawn material. With no gross structural changes occurring during cyclic deformation, accumulation of damage is unlikely to occur and this may be the reason for the fatigue resistance of this material.

Acknowledgement

The authors gratefully acknowledge the financial support provided for this work by the National Research Council of Canada.

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Received 3 August
and accepted 20 September 1979.

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