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The mode of deformation of oriented polypropylene in compression at low temperatures

When an oriented polymer is stretched or compressed a deformation band is sometimes obtained, its formation being dependent on the temperature, rate of testing and the direction of the tensile or compressive axis. The deformation bands have been observed in various oriented polymers: nylon rods [1], polyethylene sheets [2-5], polyethylene terephthalate [6] and polypropylene [7].

In a previous note [8], we showed, quantitatively, the effects of the orientation on the yield behaviour of oriented polypropylene and the results of tests at room temperature suggest clearly that the modes of deformation in tension and compression are different. However, in this communication a new mode of deformation of oriented polypropylene is proposed based on observations of deformation bands formed at yield in compression tests at low temperatures.

All tests were conducted using a conventional Instron machine provided with a cooling chamber. Compression tests were made using a compression cage to produce a compressive load on the specimen with the machine in its tensile mode. Tests were done at $-50°C$, (achieved by blowing cold carbon dioxide gas around the specimen) at a strain-rate of 1.67×10^{-3} sec^{-1}. The compression specimens were machined from an extruded rod of deformation ratio 5.5:1 and birefringence of order $\sim 2.4 \times 10^{-2}$ to produce blocks of dimensions $6 \times 5 \times 10$ mm^3. Specimens were cut at different angles, θ, to the orientation direction.

At $-50°C$ deformation bands were observed at all orientations. The geometry of the bands may throw some light on the stress system which causes the deformation. Fig. 1 shows photographs of deformation bands formed at different angles to the orientation direction in oriented polypropylene. The level of strain at which the

band formed varied in magnitude with respect to θ. At $\theta = 90°$, the overall strain as the band formed was about 6%, while at $\theta = 0°$ or 45°, the strain was at least 20 to 25%. The approximately constant value of the band angle (angle between the band direction and the compressive direction) of $45° \pm 5°$ implies that deformation occurs on planes of maximum shear stress which make 45° to the compressive axis. The geometry of deformation bands, as shown in Figs. 1 and 2, varies in a complex manner according to the value of the angle θ. At small values of θ (approximately $0° < \theta < 20°$) the maximum shear strain occurs on planes whose normals lie in the compressive axis/orientation direction plane similar to the deformation bands formed in oriented polymer sheets. The shear stress on these planes causes slip of one side of the specimen relative to other, making the fibrils kink, i.e. a kinky band appears. This shear stress is nearly parallel to a diagonal direction of the face containing the compressive axis and the orientation direction, and we will call it for brevity the "diagonal" shear stress.

When $\theta = 90°$ the deformation process is clearly defined, on planes of maximum shear stress again making an angle of about 45° with the compressive axis but containing the orientation direction (or molecular direction). The band locates on a specimen face which is perpendicular to the orientation direction. The shear stress in this case is normal to the orientation direction and we call it the transverse shear stress. The mode of deformation can be understood by a lateral slip of fibrils upon each other in a shear plane under the effect of the transverse shear stress.

Thus the geometry of deformation band can clearly throw some light on the deformation mechanisms taking place over a range of θ from 0° to 90°. At $\theta = 0°$ the diagonal shear stress process is operative, at $\theta = 90°$ the transverse shear process is operative. The mode of deformation at intermediate angles, $0° < \theta < 90°$ is
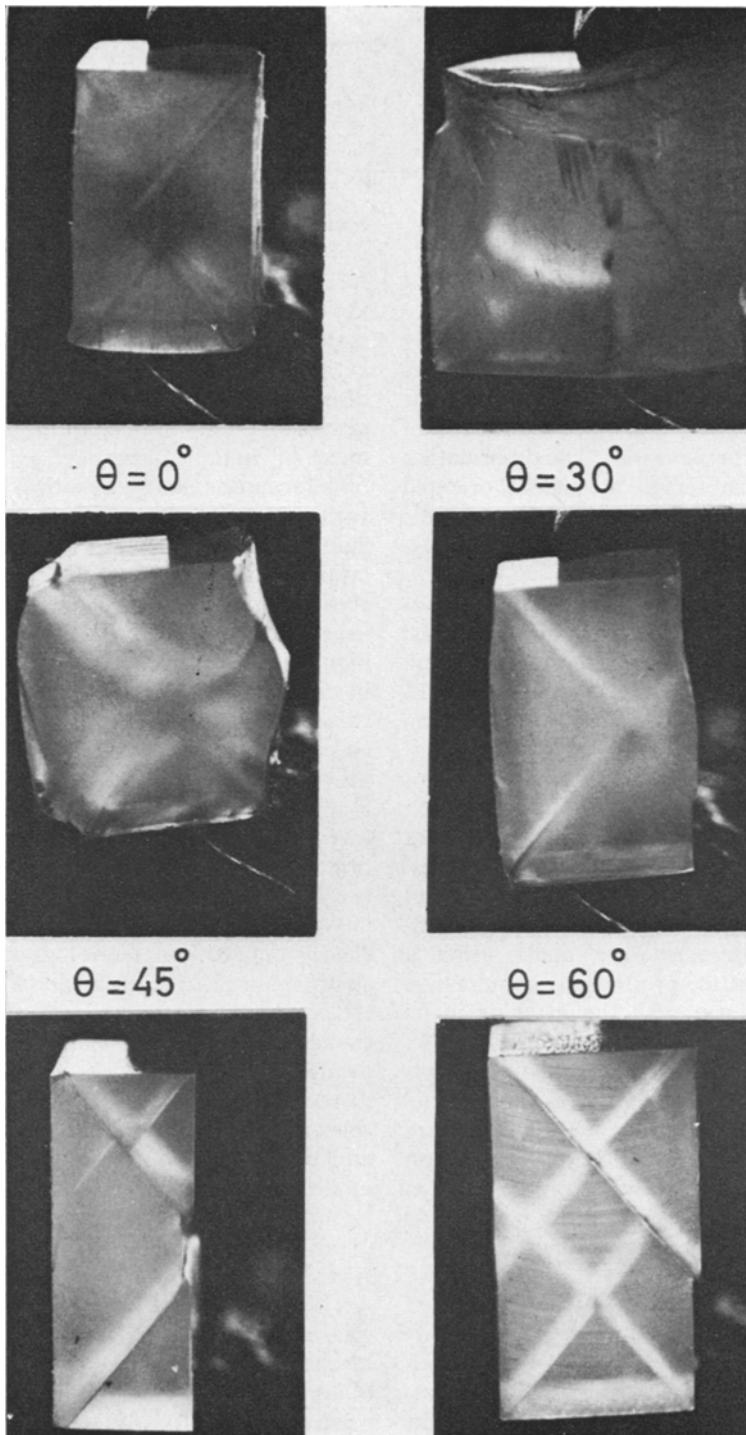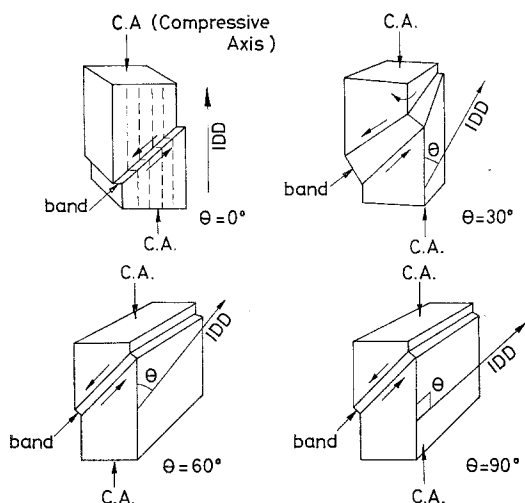
Figure 1

DEFORMATION BANDS AT DIFFERENT ORIENTATIONS

Figure 2

activated by both diagonal and transverse shear stresses and the shear strain at a given θ will be controlled by the resultant of the two. It seems that the structural conformation of polypropylene tends to make the transverse shear mode comparable with the diagonal mode when θ reaches a value about 20°, a result which makes the bands form on a specimen face which does not contain the compressive axis and the molecular direction. Of course this combination of the modes of shear deformation leads to distorted deformation bands at $\theta < 50°$. In the deformed specimens at values of $\theta \sim 30°$, we observed a rotation of the two ends of the specimen relative to each other about the compressive axis during plastic deformation. This rotation is direct evidence that the diagonal and transverse shear modes are both operative. After this range, the transverse shear stress is the dominant mode and the bands become very straight and well defined with slip steps on the specimen surfaces.

This proposed scheme of deformation of extruded polypropylene in compression below the glass transition temperature, in terms of the diagonal and transverse shear stresses or a mixture of both was suggested from direct observations on the geometry of deformation bands formed at low temperatures. It is supported by further extensive measurements of the yield anisotropy of extruded polypropylene in tension and compression undertaken at Leeds [9]. The proposals are also consistent with those of Shinozaki and Groves [10], from their compression data at room temperature where, however, no direct evidence of the shear modes is available due to the absence of deformation bands at that temperature. It should be noted that the directions in which the deformation bands form can be predicted approximately using Hill's theory of anisotropic plasticity [11] which is essentially a "continuum" theory. There is no indication that the mode of deformation is related to the crystalline nature of the polymer.

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