Morphology and mechanical properties
of some spin-oriented polypropylene fibers

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With 3 figures and 4 tables

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Melt spinning of polypropylene under conditions of high spin stress usually leads to oriented, crystalline fibers with a well defined lamellar morphology. Sheehan and Cole (1) have observed the formation of a less perfect structure, smectic polypropylene, when quenching melt extruded polypropylene in water of 50°C or below, close to the spinnerette. We confirmed these data obtaining oriented, crystalline fibers of polypropylene during spin orientation under normal quench conditions and a highly oriented smectic structure when applying a water quench. The small angle data of these two materials showed that the crystalline fiber had the typical lamellar morphology of an "as spun" hard elastic material, while the morphology of the smectic structure was basically fibrillar (2) (Fig. 1). It was therefore of interest to investigate, whether annealing treatments for both these materials

Fig. 1. X-Ray diffraction pattern of smectic and crystalline polypropylene. Smectic structure: 1a: WAXR; 1b SAXR. Crystalline structure: 1c: WAXR; 1d SAXR

Fig. 2. Annealing of lamellar structure. 2a WAXR annealed 70°C/30 min., 2b WAXR annealed 100°C/30 min., 2e WAXR annealed 130°C/30 min.; 2d SAXR annealed 70°C/30 min Exp. 3 hrs., 2e SAXR annealed 100°C/30 min., Exp. 3 hrs., 2f SAXR annealed 130°C/30 min. Exp. 2 hrs.
would lead to lamellar morphologies or whether the poorly defined smectic structure of the "as spun" and waterquenched material could be maintained, developed or would be destroyed.

In the case of the lamellar fibers, annealing at constant length between 70 and 130°C gradually changed the small angle pattern from a meridional streak to a sharp meridional spot with the 2nd order spot appearing at 130°C. (3) (Fig. 2). Table 1 gives the SAXR diffraction analysis showing that the position of maximum intensity, as expected, moves to higher values and that the half widths of the long spacing distribution become narrower; the lamellar dimensions become more uniform.

For the fibrillar structure annealing leads to a gradual increase in crystalline order; the perfection of the monoclinic structure is gradually developed. A characteristic of crystalline, spin oriented polypropylene, the presence of bimodal orientation, (c- and a'-axis oriented crystallites) (4) is, however, absent. Only c-axis orientation is observed (Fig. 3). The small angle streak, originally weak, increases in intensity, gradually shortens its lateral extent, its maximum moves to higher values, however its meridional half width does not change. This behavior is very similar to that of fibers drawn subsequently to spinning.

The meridional width at half maximum intensity was calculated from a meridional microdensitometer scan, calculating the two spacings on the basis of Bragg's law. In tables 1 and 2, the range column gives these values in Å, the Δ column gives their difference in Å.

The lateral halfwidth was calculated according to Bolduan and Bear (5). Here the lateral dimensions of the lamellae are considered disks of radius R. At half maximum intensity \( \pi \bar{v} R_k \xi = 0.83 \), where \( \bar{v} = 1/\lambda \), \( R_k \) is the effective radius of the diffracting object and \( \xi \) is a reciprocal radius. Knowing the reciprocal half widths of the diffracted beam and of the primary beam at the position of the film, \( R_k \) can be calculated. The halfwidth of the primary beam was 0.4 mm.

The tensile characteristics of the two types of materials as function of annealing temperatures are shown in the next two tables. The hard elastic material has a low tenacity, high elongation, the expected modulus and its elastic characteristics improve to about 90% (ER50). The fibrillar material has a higher initial tenacity and maintains it in the whole annealing range. The elastic properties improve with increasing annealing temperature, however, even at 130°C the properties are still considerably below those of a good, lamellar hard elastic material. In the fibrillar material a complete dimensional change of the morphological units occurs, the small angle long spacings after annealing at 120—130°C being completely outside the original "as spun" dimensions. This is not the case for the lamellar structure, where the meridional streak narrows but even at 130°C retains part of the original lamellar dimensions.

The mechanical properties of the fibrillar structures do not change to any large extent, perhaps indicating that in spite of the rather drastic changes in crystallinity and morphology, the load bearing units of the fiber have maintained their integrity.