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of different structure](image)

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Abstract

Full Text

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EFFECT OF MICROSCOPIC STRUCTURES ON THE MECHANICAL BEHAVIOR OF CRYSTALLINE POLYPROPYLENE

Recent investigations have shown that the mechanical behavior of crystalline polymers is determined to a substantial degree by their macrostructure ([1–4]). In this connection, the study of possibilities for creating definite types of structures during the processing of polymeric materials and for finding the mechanical characteristics for each type of structural formation becomes important. Our earlier study of structure formation in bulk ([5]) and in films ([6]) of polypropylene during slow cooling from the melt made it possible to realize, for this polymer, a large number of diverse crystalline structures.

Fig. 1. Dependence of elongation on load for polypropylene films of different structure

The present work is devoted to elucidating the influence of various structural formations on the mechanical behavior of crystalline films of isotactic polypropylene.

For the investigation, films were selected that contained crystalline structures of the type of spherulites and long intergrowths of various sizes. A structural description of such formations was given in a previous work ([6]). Films with thicknesses from 30 to 130 μ were prepared by pressing at a melt temperature of 230° and at various cooling rates (from 5 to 0.2° per min). Mechanical tests were carried out on a Shopper-type dynamometer with a self-recording device for recording the stress-strain relationship. Test specimens were prepared in the form of dumbbells with a working-section length of 5 mm and a width of 3.2 mm. The tests were carried out at room temperature at a rate of 2 mm/min. The films were first examined in a polarizing microscope, and regions with crystalline structures homogeneous in size and orientation were selected for testing.

The results of the mechanical tests are presented in Fig. 1. Curves 1 and 2 correspond to the stretching of films containing small spherulites (up to 30 μ in diameter), intergrown with one another, and thin spherulitic intergrowths up to 20-40 μ in width. In the latter case the direction of stretching coincided with the direction of the long axis of the intergrowths. As can be seen from the graph, in this case it is possible to realize all three portions of the stress-strain curve characteristic of crystalline polymers. The dependence of stress on strain for

To the article by G. P. Andrianova, N. F. Bakeev, V. A. Kargin, p. 331

Fig. 2. Microphotograph of a stretched polypropylene film containing spherulites up to 30 μ in diameter; *a*—region of transition of the initial structure into a neck, *b*—fracture region.
130×

Fig. 3. Microphotograph of a polypropylene film containing spherulites up to 80 μ in diameter, after stretching; *a*—region of transition of the initial structure into a neck, *b*—structure of the neck and fracture region. 130×

Fig. 4. Structure of brittle fracture of films containing: *a*—spherulites of the second type up to 300-400 μ in diameter. 130×; *b*—spherulites of the first type. 750×

films containing larger structures—spherulites up to 40-60 μ in diameter and intergrowths whose width reached 60-80 μ—are represented by curves 3 and 4, respectively. In this case rupture of the films always occurs in the second region of the curves, at elongations of the order of 50-300%. It should be noted that the reproducibility of the results for such structures is considerably worse than in the first case. On curve 3, rupture may occur at any point of the dashed line.

Optical investigation of the structure of deformed specimens makes it possible to explain the different behavior of crystalline films as a function of the sizes of the initial structures. Films containing small, mutually penetrating spherulites and thin long intergrowths give, upon deformation, a homogeneous microfibrillar neck (Fig. 2a). Rupture of such a homogeneous neck occurs at considerable elongations, of the order of 600%, and is accompanied by disintegration of the neck into thin threads, in accordance with the fibrillar character of its structure (Fig. 2b). The strength of films containing the indicated structures is the same for both types of structural formations and amounts to 310 kg/cm^2. The presence in the films of larger spherulites and intergrowths determines a different deformation mechanism. In this case, upon stretching of the films, fibrillization of the spherulites and intergrowths occurs with preservation of their individuality, i.e., of the interfaces (Fig. 3a). With further deformation there is a gradual orientation, along the direction of stretching, of fibrils within the spherulite that are perpendicular to the direction of stretching. But even at considerable elongations the neck does not have a homogeneous character; elongated spherulites and intergrowths can easily be detected in it. The preserved interfaces of the structural formations are the most defective places in the films, along which crack formation and destruction of the specimen occur (Fig. 3b, see insert, p. 315).

A further increase in the sizes of the spherulites (to 250–400 μ) and intergrowths (to 220–250 μ) leads to a sharp increase in the brittleness of the films. As is seen from the graph in Fig. 1, where curve 5 corresponds to stretching of intergrowths, and curve 6 to spherulites of the second type, films containing large structural formations are destroyed at elongations of the order of 7-10%. As a rule, the formation of such structures already in the process of crystallization leads to the appearance of defective boundaries of spherulites and intergrowths, along which brittle rupture subsequently occurs (Fig. 4a).

And finally, the lowest strengths and absence of the ability to undergo deformation characterize films containing spherulites of the first type (curve 7). As noted earlier ([6]), such spherulites are distinguished by a defective structure and extremely defective interfaces. Rupture in this case develops along the boundaries of the spherulites and more rarely within the latter, revealing at the same time the fibrillar structure of the spherulite (Fig. 4b).

Thus, as the results of the present work show, the sizes and morphology of crystalline structures exert a substantial influence on the ability to deform and on the strength properties of isotactic polypropylene. This, in turn, should lead to the fact that changing the macrostructure of the polymer during processing will make it possible to vary widely its mechanical properties, passing from readily deformable materials possessing considerable strength to very brittle specimens, incapable of any elongations whatsoever and destroyed under the slightest mechanical actions.

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Note: Figure translations are in progress. See original paper for figures.