Increasing the "Natural" Draw Ratio by Hot Nip Drawing

M. P. LAUGHNER and I. R. HARRISON, *Polymer Science Program, Department of Materials Science and Engineering, Pennsylvania State University, University Park, Pennsylvania 16802*

Synopsis

The drawing of polymers into high strength films or tapes is an important process in industry. A method of local heating and drawing of plastic sheets into high strength films is discussed, and the preliminary results of this new technology are presented.

INTRODUCTION

The production of high modulus films and fibers by various methods of deformation of thermoplastics has become common place in industry. Deformation processes such as roller-drawing,[1] hydrostatic extrusion,[2,3] solid state extrusion,[4] and gel spinning/hot drawing have been employed to try and achieve the highest possible strength and modulus. The gel spinning/hot drawing technique currently produces the highest strength and modulus fibers of polyethylene (PE). The modulii of these fibers have been reported to be as high as 120 GPa,[5] with a breaking tensile strength just over 4.0 GPa.[6]

Gel spinning is an excellent method for producing high strength fibers but has a number of inherent problems. Generally speaking, the technique is a high technology method requiring specific polymer molecular weights and distributions. In addition, extensive solvent removal schemes must be used, and the resulting cost for such polyolefin fibers is comparable to acid-spun high-temperature aromatic polyamides. In contrast, methods which avoid solvents typically produce materials with significantly lower mechanical properties and/or the rate of production does not offer much hope of being commercial in the foreseeable future.

Recently, Kaito et al.[1] have proposed a hot roller-drawing method of forming high-modulus high-strength films. They are attempting to produce films with large draw ratios that can be controllled by roller spacing and draw velocity.

For the past four years we have been producing films with similiar properties through tensile drawing with a heating device. It is desirable that such a process be both continuous and applicable to either thin film or thicker sheet. Certainly our method can be readily modified to accomplish this goal; further, control of the draw ratio is possible by adjusting the draw velocity and/or the draw temperature. With a specially designed heating device, the neck region is allowed to form at a "natural" rate and with "natural" dimensions. In contrast, roller-drawing forces the resulting film to form at the rate at which the crosshead is moving and with a thickness which is presumably largely determined by the roller gap.

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EXPERIMENTAL

Material

The samples in these hot draw experiments were 20 cm long by 5 cm wide strips cut from translucent extruded sheets of polypropylene (PP) approximately 0.80 mm thick. The PP designated as PP 5225 (M_n = 50,000, M_w = 600,000) was produced by the Shell Development Co. and contains no plasticizers but does contain small amounts of stabilizers.

Hot Nip Drawing

Each sample was marked with a felt tip pen every centimeter along its length so that a draw ratio ($\lambda = l/l_0$) could be obtained at the end of the experiment. These samples were then creased across their width and mounted in specially designed grips that can hold samples up to 18 cm wide. After the samples were mounted, the heating device (Fig. 1) was attached to the top of the film so that it rode on the slight indentation made by the crease. The film was then drawn at a constant velocity (10 cm/min) by an Instron tensile tester. The neck produced traveled downward, presumably due to the weight of the heating device, which stayed in contact with the newly forming neck. To determine the draw ratio, two or three measurements of the new separation of marks were taken from near the center of the drawn sample and averaged. This separation (cm) was divided by the original length of 1 cm to yield λ.

RESULTS AND DISCUSSION

Appearance

The optical properties of the hot drawn films ranged from transparent to

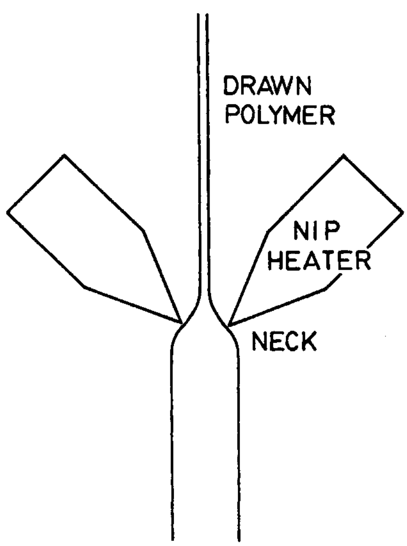

Fig. 1. Nip heater riding on the shoulder of a necking sheet sample. Both heaters are maintained at the same temperature.

opaque, depending on the draw temperature. Lower draw temperatures yielded opaque films while the higher draw temperatures produced transparent material. The opaqueness of the films is presumably due to the formation of microvoids in the deformation region.[7] Transparent films produced at higher temperatures do not have these microvoids. Either these films never form the microvoids or the voids are closed as soon as they are formed due to the lower viscosity/higher polymer mobility at the higher draw temperatures.

Draw Ratio

The λ's of the films were measured and plotted against the draw temperatures (Fig. 2). This temperature was measured by placing an RTD probe (platinum resistance thermocouple) in a hole drilled into the heating device. The λ goes through a maximum at approximately 90°C when the draw velocity is 10 cm/min. At temperatures below 90°C, polymer chains are less mobile and cannot orient or rearrange themselves as rapidly; this effect presumably results in the observed lower draw ratio. As the temperature is increased above 90°C, chains are more highly mobile, and one would anticipate that they should be more easily aligned. This may be the case; however, the increased mobility also implies a higher driving force to return to their undeformed state (elastic recovery). The maximum at 90°C therefore represents a balance between ease of alignment and retractive forces in this system. Details of this balance are still open for discussion. However, the general features of deformation seem to be in line with previously proposed deformation mechanisms for semicrystalline polymers.[8,9]

There is one other feature of the drawing behavior of these films which is worth noting. Most hot drawing processes produce films which exhibit considerable "neck-in" in the width direction. In contrast, films drawn either cold or using the local hot nips described earlier show little neck-in. In practice, neck-in is largely independent of the starting width of the samples. It is approximately 0.5 to 1.25 cm for samples ranging from 5 to 18 cm initial overall width.

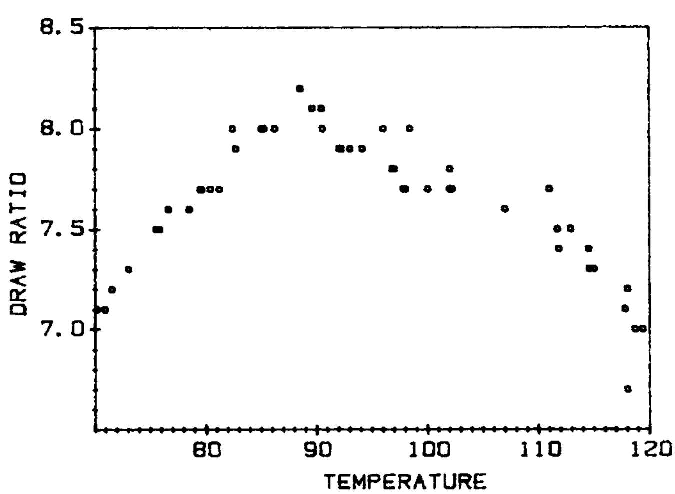

Fig. 2. Draw ratio (l/l_0) vs. nip heater temperature (°C). Sheet was drawn at 10 cm/min.

CONCLUSION

The heating device described in this article can help increase the "natural" draw ratio by controlling the temperature at a given draw velocity. The draw ratio is a function of the temperature of the heating device with the highest draw ratio produced at an optimum temperature. These results are preliminary; future work will examine the effects of different draw velocities over a range of temperatures.

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