Extrusion of stretched PP articles

FILM YARN

The molecular orientation of a polypropylene extrudate imparts high mechanical properties and, in particular, a high tenacity in the direction of stretch (“ stretch” is the action that artificially causes molecular orientation).

The service characteristics of “stretched” articles (film yarn) determine the choice of different polypropylene grades. The most suitable for this type of processing are those with Melt Flow less than 5.

Diversification of articles

Essentially, the following classification may be made:

- **Textile film yarns** - These have a denier count of not more than 1,100-1,200 and are used in the place of vegetable fibers (jute, coconut fiber, etc.) for the production of: bags, industrial (heavy-duty) fabrics, mats, furnishing fabrics and trellis-work
- **Film yarn for rope and twine** - They have denier counts ranging from 3,000 to 28,000. They are used in the place of the more classic vegetable fibers, like sisal, hemp and jute in the fields of: baler twines, packaging twines and ropes.
- Oriented film yarn is required to possess characteristics that differ with their intended end-use:
  - For textile film yarns, a tenacity of 5-5.5 g/den is necessary and, above all, a low splittability. Splittability could, in fact, cause frequent stoppages of the production looms.
  - In film yarn for ropes, a very high degree of splittability becomes an absolute necessity. To favor and enhance this characteristic, mechanical splitting devices are installed on the film yarn production plants. Hand” stiffness is also of great importance for these articles.
- **Equipment**
  Stretched tape, film yarn and monofilament are produced by a standard system, the only variation being the extrusion die. The equipment thus consists of
  - A extruder
  - A die
  - A cooling system (as described further on, which may be either air, water or chill roll, depending on the extrudate being produced)
  - A stretching unit
  - A stabilization oven
  - A wind-up station.

Extruder

- Compression ratio is between 3 and 3.5
- The extruders employed are of the single-screw type and experience has shown that the ideal L/D ratio is between 1:20 and 1:30.
- Advantageous use can also be made of extruders fitted with a venting device.
- Long-screw extruders, granted the greater length of the metering zone, aid the heating of polypropylene and improve melt homogeneity and flow uniformity. The lengths of the feed, compression and metering zones must be such as to ensure a correct pressure, an even feed and a regular and homogeneous heating along the entire length of the screw; removal of the air towards the hopper may be advisable to ensure the absence of air bubbles in the extrudate, since these cause breakages during the stretching operation. This is in any case assured with the adoption of correct screw compression ratios and a suitable temperature gradient.
- The die is mounted on the head and is flange-fastened to the extruder.
- A screen-pack should be placed between extruder and head to improve homogeneity and distribution of the melt in the die. The screens are arranged in series with the mesh size decreasing in the flow direction, as follows: 250-1500- (2500) mesh/cm^2 or 350-1500-(2500)-350 mesh/cm^2
- Figures 13 and 14 give examples of screws for polypropylene, with and without homogenizer.

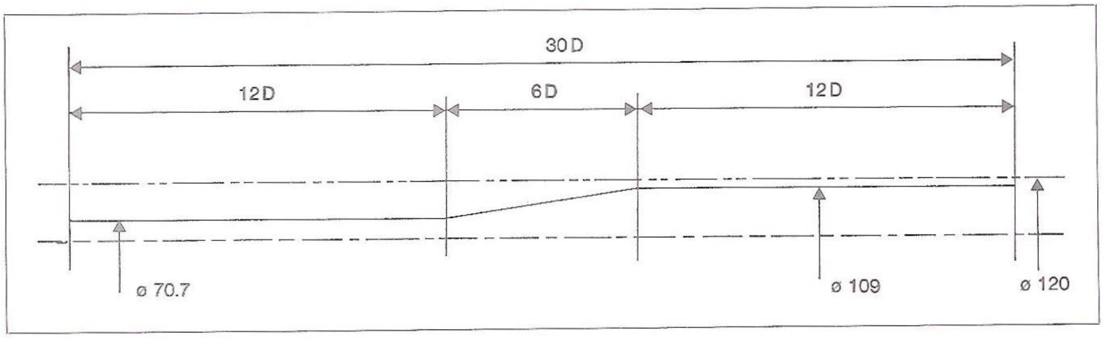

Fig. 13 - Example of a screw for polypropylene (o.d. 120 mm; feed zone root diameter 70.7 mm; metering zone root diameter 109 mm; compression ratio 3.5; L/D ratio 32; length of feed zone 12D; length of compression zone 6D; length of metering zone 12D; pitch 120 mm; number of flights 1; flight rib length 12 mm).

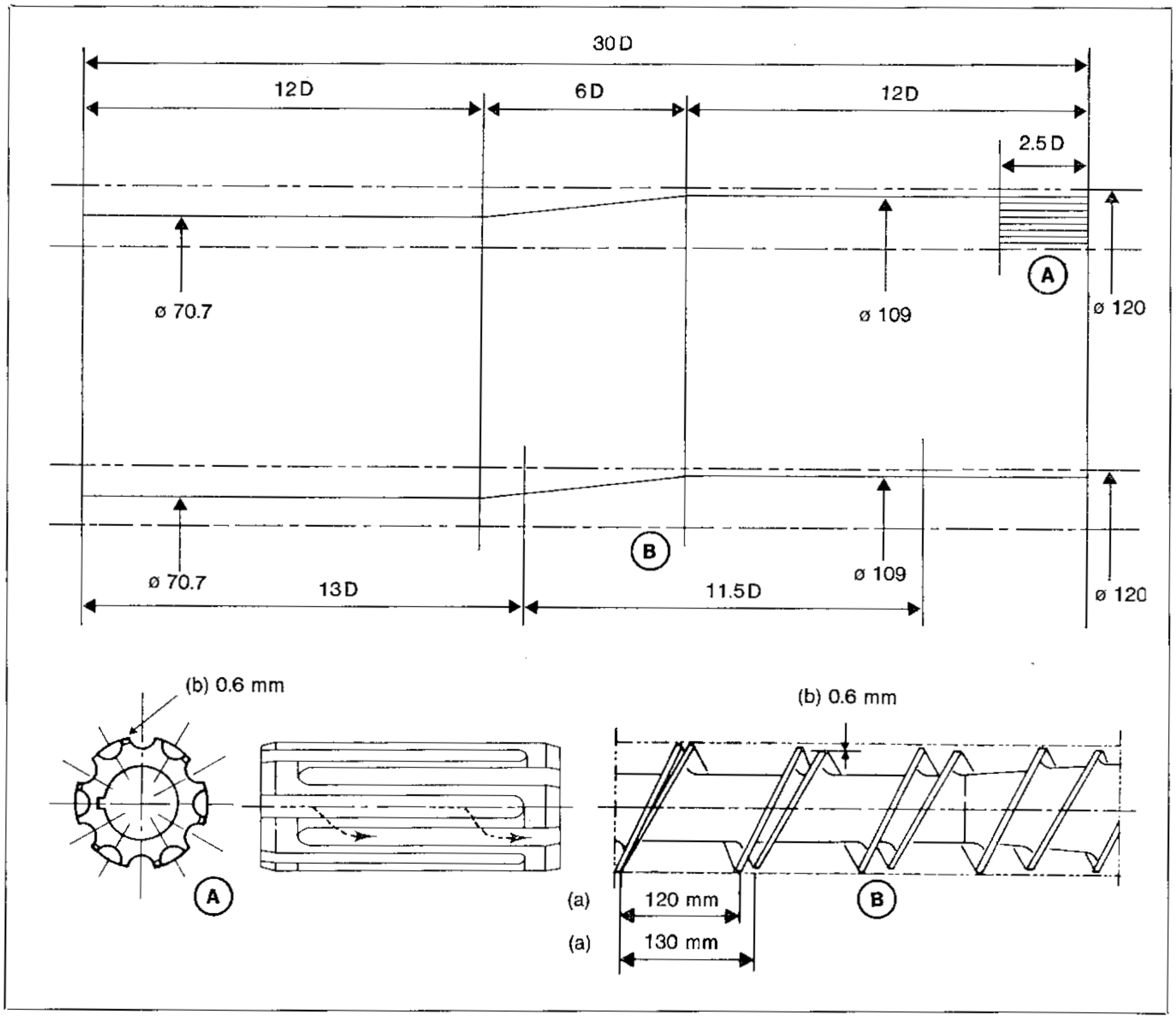

Fig. 14 - Examples of screw for polypropylene with homogeniser in the metering and transition zones (o.d. 120 mm; feed zone root diameter 70.7 mm; metering zone root diameter 109 mm; compression ratio 3.5; feed zone length 12D; compression zone length 6D; metering zone length 12D; pitch 120 mm) (a = pitch; b = radial clearance).

Film-forming process

- Film yarn can be produced either from flat or blown film
    - **Production of film-yarn from blown film** - Cooling is applied at the base of the bubble, using an air jet sent through a ring surrounding the die. The bubble may also be sent through a water-jacket. Blown film: die opening is again about using ring-dies
    - **Production of film-yarn from flat film** - In this case the film can be cooled by immersion in a heat-regulated tank (generally at 18-35°C) with water circulation (quenched film) or by chill-rolls: the film passes between two chromium-plated rolls, cooled internally by water circulation. Flat film: die-opening = about 0.8 mm

Cutting

For the production of film-yarn, since the starting material is blown or flat film, a strip-cutting operation becomes necessary. Since the thickness of the film is chosen as a function of the end-use, it is sufficient to adjust the cut to obtain primary strips of a given weight per meter. This operation is usually carried out with industrial blades or similar devices, spaced by means of cotters calibrated on a support whose axis is parallel to the axes of the hauler rolls. The cut is made on the tensioned film.

Stretching

The untreated strips from the previous step are conveyed to the oven by a group of three, five or seven rotating teed rolls, at linear velocity V1, through the oven in which hot air circulates; they are then drawn by a second group of rotating stretch rolls at linear velocity V2 > V1. The stretch ratio is given by:

- Ps = V2 /V1

  The relative stretching speed is given by the difference:

- Vs = V2—V1
- Stretching is the characteristic it is the **stretch that confers** the on the polymer, imparting:
  - **An increase in tenacity**. By the tenacity of a stretched article is meant its tensile strength: it is expressed in g/denier, the denier being the weight of a filament 9,000 meters long, and is thus a measurement of its count
  - **A decrease in elongation at break**
  - **A decrease in cross-section.** In the case of film yarn and strapping tape, in fact, the final cross- section is proportional to the original section: width and thickness vary approximately in the same ratio, equal to the square root of the stretch ratio p. This is not always strictly the rule. Il may thus be stated, with good approximation, that the ratios are as follows:

    $$\frac{L_p}{L_s} = \sqrt{\rho_s} \qquad \frac{S_p}{S_s} = \sqrt{\rho_s}$$

    where L and S are the original width and thickness, L, and S. are the stretched width and thickness. For example, for a stretch ratio of 9, a thickness of 120 microns will be reduced to about 40 microns and a width of 6 mm to 2 mm. This rule allows the thickness of the unstretched item to be selected (and thus die opening and width) according to the dimensions required of the stretched article. Each converter, however, must find the best possible compromise between the utilization of his equipment and the characteristics most suitable to the end use of the article.

- The temperatures of the stretching oven vary according to the dimensions of the unstretched item (particularly the thickness of the film yarn) the relative stretching speed and the oven characteristics. By way of example, it may be said that the oven should allow a continuous heat regulation at any temperature between approximately 90℃ and 200℃ so as to meet stretching requirements on both the finest and the coarsest sections and with the most diverse throughput speeds.

Stretching and tenacity
The different factors that affect the tenacity of an article at the time of stretching are as follows:

- **Stretch ratio** - Fig. 15 plots tenacity against stretch ratio p, in a product of a given melt index; it can be seen that for the given melt index the maximum of 6-7 g/denier is reached with a stretch ratio p of 10.

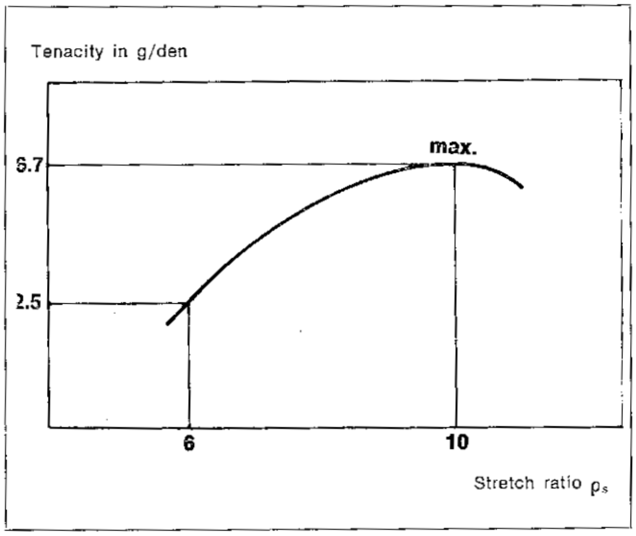

Fig. 15 - Tenacity versus stretch ratio for a product having a given melt index.

- **Melt index** - Tenacity and melt index are inversely proportional. Fig. 16 plots tenacity against stretch ratio for polypropylene grades of different melt index.

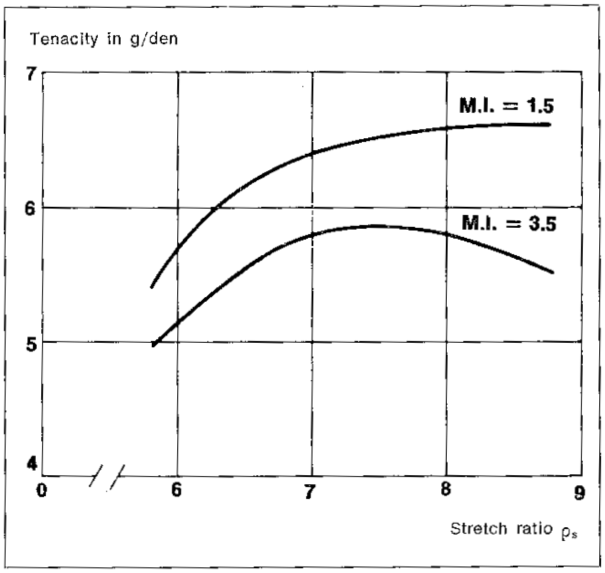

Fig. 16 - Tenacity/stretch ratio versus melt index.

- **Stretch temperature** - Temperature must be as low as possible: 10℃ higher than the yield point. Fig. 17 plots tenacity against temperature, stretch ratio being equal.

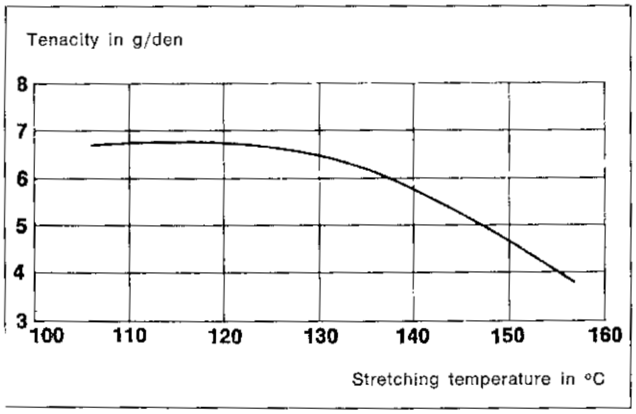

Fig. 17 - Tenacity versus stretching temperature at ρ_s = 1:7.

- **Dwell time in** the stretching oven - For equal stretch ratios, tenacity is strictly connected with stretching time which, in turn, is connected with the ratio of oven length to throughput speed. The stretching ovens should be at least 2 meters long. Fig. 18 shows how tenacity doubles by simply increasing oven length from 130 cm to 200 cm.

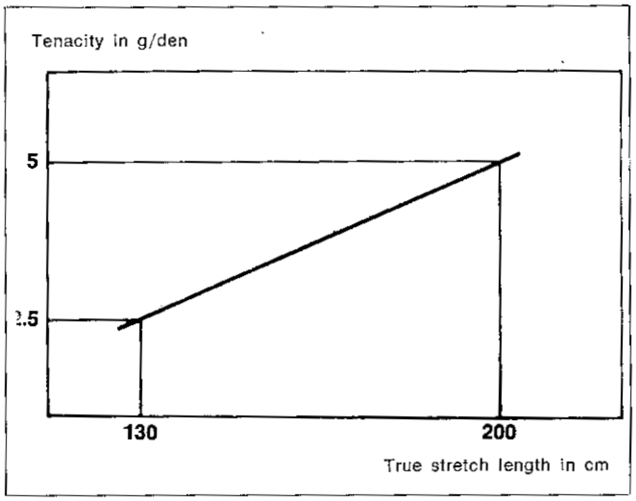

Fig. 18 - Tenacity versus streching oven length.

- **Resistance to splitting** - Resistance to longitudinal splitting is the greater the lower the melt index

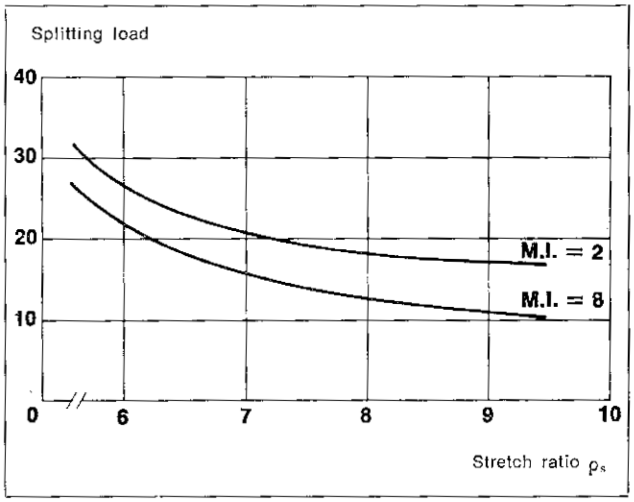

Fig. 19 - Splitting load versus stretch ratio for two polymers of different melt index.

- Figure 19 shows this property for two different melt indices, versus stretch ratio p.

- **Geometry of the untreated extrudate** - Tenacity is a function of the width/thickness ratio. This is shown in fig. 20 which plots tenacity for different width/thickness ratios and for a given polypropylene grade. It follows that the production of thin film is, within certain limits, advantageous; a compromise must be sought, since the latter objective is in opposition to a full exploitation of extruder possibilities

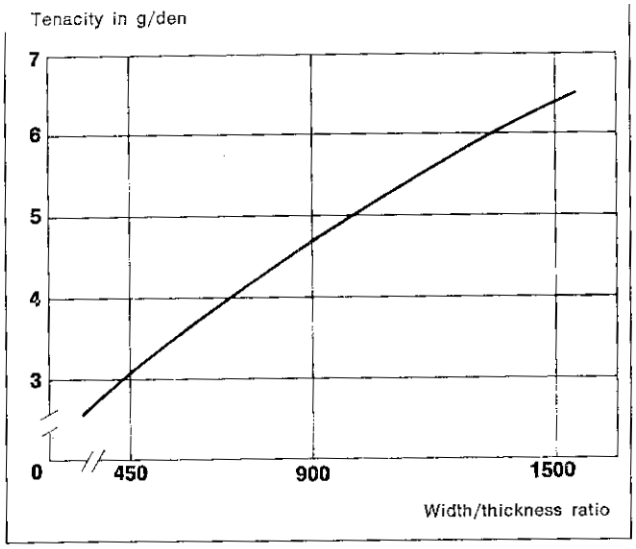

Fig. 20 - Tenacity versus width/thickness ratio of film yarn.

- **Stabilization oven**
  The stretched articles are usually conveyed through a second oven, so as to have a controlled recovery of the stressed condition. Upon leaving the oven the strips are drawn by a third group of rotating rolls at linear velocity $V_3 < V_2$, so that;

  $(V_2 - V_3)/V_2 =$ approximately 4-5%

This operation is sometimes helpful in preventing deformation of the spools during cooling, but is particularly so when the article is to be used in the weaving of carpet backing. In this end use, the shrinkage of the backing fabric must be as little as possible during cure of the rubber latex with which the fabric is coated. This second stabilization oven, capable of working at temperatures between 90 and 140℃, may also serve to remove the static electricity accumulated on the stretched item by passing it through a water- vapour saturated atmosphere.

Short stretching

Short stretching, which is of fairly recent adoption in film yarn production, is so called because the film is stretched entirely between a slow roll and a fast roll placed very close one to the other. Short stretching differs from the traditional method in that, owing to the short distance between the slow and fast rolls, the shrinkage of the film yarn is much lower. Other conditions being equal, therefore, the film yarn obtained through short stretching is wider and thinner than an article processed by the conventional method, has a higher covering power and its resistance to splitting is comparable to that of bioriented film yarn.

Wind-up
The design of the spools and wind-up method vary in all fields of application according to the use

MONOFILAMENTS

Use is made of a perforated plate die; the diameters of the holes are as follows

- 0.8 mm for a finished monofilament diameter of 0.10 mm
- 1 mm for a finished monofilament diameter of 0.20 mm
- 2 mm for a finished monofilament diameter of 0.50 mm

To prevent surface defects of the monofilament the holes should be 10 times, or more, longer than their diameter. The subsequent stretch, stabilization and wind-up operations are substantially similar to those described for film-yarn, with the exception of possible adjustments made case by case.