Versatile tool for researching structural and functional polymers

In order to ensure the rapid and effective transfer of a newly developed process from the laboratory to production, new parameters must be explored with the widest possible range using the same state-of-the-art components that occur in the production plant. As far as melt spinning is concerned this includes the extruder, the spinning head, quench, finish application, drawing with or without relaxation, intermingling by air jet and winding. Such a versatile spinning machine for thermoplastic and other melt spun fibers has been installed in the Thuringian Institute of Textile and Plastics Research (TITK) in Rudolstadt/Germany by Fibre Extrusion Technology(FET) Ltd., Leeds/UK. The purpose of the project is to support the strategic research fields of the Institute, especially in the fields of structural and functional polymers.

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Work at the TITK extends from the characterization of native polymers to the development of functional materials with specific properties such as conductivity. The latter requires the application of additives to polymers prior to melt spinning. Another requirement is the ability to look at bicomponent structures, which can range from nanofilaments to a core/sheath structure with the core providing the physical properties of the composite yarn and the sheath providing the required surface structure and properties.

There is a whole array of new products to be explored. Bicomponent yarns have been available for many years but some of the new products that are now achievable make further development once again commercially interesting.

Melt spinning to make filament yarns at one time encompassed 3 or 4 fiber materials, namely PA 6 and 66, PET and PP. The list of polymers is now greater than 40 and still growing. Finer filaments have been a target for many years but now it is even possible to contemplate nanofilaments using bicomponent spinning technology. This opens up huge areas for exploitation including filtration and fiber surface activation.

Filaments with cross sections other than round are common but new structures have led to items of clothing with improved wear properties, for example in socks for hill walking and other active sports.

The capability (competency) of FET is to apply a technology and plant that incorporates key components to enable new products to be researched, developed and launched using a single versatile spinning machine. This requires not only the selection of the appropriate proven components but also their application and control.

Starting point

The starting point however is to know the process required to make the new products under development and to be capable of specifying the plant accordingly without compromise or unnecessary resort to home made solutions.

A state-of-the-art spin-draw machine is both compact and versatile. It lends itself to a modular approach since the process comprises clearly definable stages:

- Extrusion – melting, mixing and forwarding molten polymer
- Spinning head – distribution to the spin pack by means of polymer metering pumps
- Spin packs – filtration, distribution and conversion to filaments at the spinneret face
- Quenching – cooling and solidification of the filaments appropriate to the polymer
- Pre-treatment – application of finish together with yarn compaction
- Drawing – in controlled stages with the application of heat where appropriate

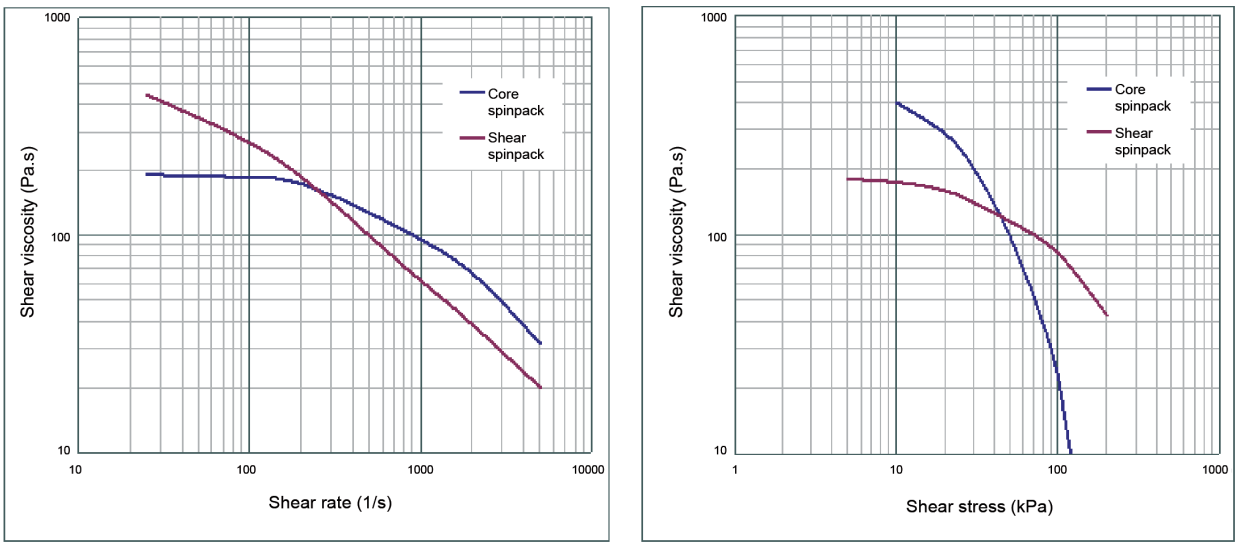


Fig. 1
Coinciding melt viscosities

- Interlacing – use of air jets for locking filaments together to aid further processing
- Winding – of up to four ends and more if very fine yarns are being wound.

It is impossible to put together a specification for a spin-draw machine without considerable knowledge of the process. This does not mean that every detail of the process has to be defined in advance. It is often the purpose of operating such a machine to refine the process. Alternatively it may be to prove the concept of a new process.

For example, polymers behave differently during and after melting and this has a large influence on the design of the extruder and especially of the screw. Polymers that degrade quickly should be treated at the lowest temperature possible and also the time that the molten polymer resides in the extruder screw must be kept to a minimum.

Polymers that contain additives require special treatment, both before and during melting. Compounding using twin screws before the actual spinning can be followed by an extruder screw that includes a special section for mixing. This technique is especially important for the dispersion of additives.

Problem solving

Spinning 2 mismatched polymers in a bicomponent spinning machine can cause problems such as a distorted filament cross section, variable sheath thickness and even fragmentation of one polymer within the other.

Solution

The melt viscosity of the two polymers should converge at the point of extrusion. To achieve this, the melt viscosity of each polymer is measured at different conditions of temperature and shear rate using rheology testing methods.

Using a rheometer it is possible to produce graphs for each polymer at a given temperature which show the melt viscosity for different rates of shear and stress (Fig. 1). By superimposing the curves for each polymer it can be seen whether they coincide at a realistic shear rate. If not, then additional curves should be produced at higher and/or lower temperatures.

If the polymers come from the same 'family' e.g. biodegradable aliphatic polyester polymers such as PGA and PLA then the chances are good that such a point can be found. Other workable combinations include PP with high or low density PE, both polyolefins of course.

The melt viscosity of a single polymer within a spin pack is determined by the temperature of the polymer, the spin pack design and the flow rate of the polymer through each spinneret hole.

Testing the 2 polymers by rheology is necessary in order to evaluate the spinning conditions of each polymer so that the polymers can be conditioned to have similar melt viscosities at the point of extrusion. In some cases it is essential to supply the two polymers at different temperatures to the spin pack.

The spin pack may appear at first sight to be nothing more than a filter and distribution system from filter to each hole in the spinneret. However, the properties of the freshly spun filaments emerging from the spinneret are influenced strongly by the shear rate, which is a measure of the work being done on the polymer. The formulae used to calculate the shear rate and stress are based on a melt flow or rheology testing instrument where the polymer is charged in a heated cylinder and the polymer flow measured under conditions of a given orifice and a constant force provided by a piston (Fig. 2) [1]. The spinning head can be considered as a crude equivalent of the test instrument, at least when comparing rates of shear through the same orifice or spinneret capillary. From the formulae in Fig. 2 it can be seen that the shear rate is proportional to the 4th power of the spinneret orifice diameter D as well as polymer flow rate Q. Also the shear stress depends inversely on the length of the capillary L. The apparent viscosity η depends on the pressure P at the orifice. This shows how the capillary dimensions and polymer pressure are important factors in determining the flow of polymer and the resulting properties of the newly formed filaments.

Fig. 2
Calculation of apparent shear rate Y and shear stress

The CFT-500D and CFT-100D measure sample viscosities using the flow resistance of the sample melt as it flows through the die orifice. The construction of the cylinder unit at thje core of the testing machine is shown below. The sample is charged in the heated cylinder to melt.

After a specified time the sample melt is extruded with a constant force by the piston, through the die orifice. The flow rate is obtained from the speed of extrusion; and the plasticity (viscosity of the sample melt) is calculated from the formula below:

(1) Flow rate Q

$$Q = A \cdot \frac{S_2 - S_1}{10 \cdot \Delta t} \ (cm^3/s)$$

A : Piston cross sectional area (cm^2)
S_1: Calculation start point (mm)
S_2: Calculation end point
Δt: Piston travel time from S_1 to S_2

(2) Apparent shear rate γ

$$\gamma = \frac{32\,Q}{\pi D^3} \cdot 10^3 \ (s^{-1})$$

A : Die orifice diameter (mm)

(3) Apparent shear stress τ

$$T = \frac{P\,D}{4\,L} \ (Pa)$$

P: Test pressure (Pa)
D: Die orifice diameter (mm)
L: Die length (mm)

(4) Apparent Viscosity η

$$\eta = \frac{T}{\gamma} = \frac{\pi D^4 P}{128\,L\,Q} \times 10^3 \ (Pa.s)$$

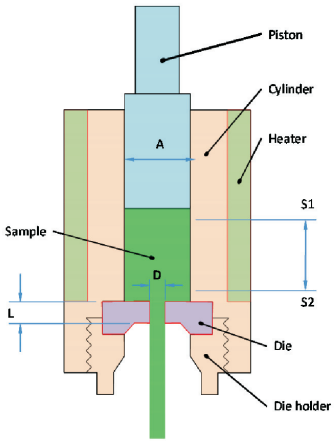
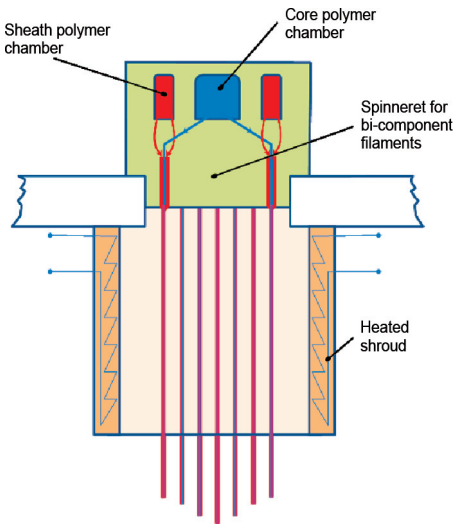


Fig. 3
Heated shroud fitted below spin pack



Post spinneret

Quenching, finish application and heated godet pairs or duos are quite versatile components which are incorporated in spin-draw plant without exception. On the other hand, the fitting of a heated shroud before quenching is a part of the machine specification that depends on the polymer and process. The heated shroud (Fig. 3) has been used for many years, especially for spinning polyesters with a high melt viscosity of 0.8-1.0 IV with the aim of achieving high strength yarns and plies for tire cords. The heated shroud serves the dual purpose of maintaining a higher

Fig. 4
View of spin draw lab machine at ground floor level

face temperature at the spinneret, which lowers the spinning melt pressure and it also allows crystallization to proceed further than without a shroud, since crystallization ceases almost as soon as the cooling quench air comes into contact with the filaments.

The properties of as-spun polyester yarns are greatly influenced by the flow drawing that takes place between the spinneret holes and the first draw roll. At a time in the past when this yarn was stored before drawing in a separate process, the shelf life of the as-spun yarn was fairly short. High speed spinning with haul off speeds of > 3,500 m/min enables a much more stable precursor yarn to be produced. This made possible the commercial success of the simultaneous draw-texturing process, often in plants located some distance from the spinning plant.

In the case of the spin-draw process, shelf life is not an issue but the structure of a polyester yarn is still greatly influenced by the interaction of flow drawing and the drawing stages that follow using heated godet rolls. Neither high speed spinning to make POY nor the spin-draw process to make FOY were achievable commercially until the advent of the high speed multi-threadline in-line winder, which enables winding at up to 6,000 m/min. The machine at the TITK has this capability (Fig. 4).

There are, however, many products where winding at such high speeds is unrealistic and undesirable, since it requires an extruder and spinning head having equally high capacities (kg/h). With many niche products, where high added value polymers are the essential raw material, such high throughput rates would be counter-productive especially in a pilot plant.

Process expertise

Quite clearly, it requires a considerable amount of process expertise together with practical experience of the performance and capability of the key components, in order to supply a small-scale laboratory spin-draw unit that will fully meet the objectives of the customer. In addition these components should have specifications that are as close as possible to those that will be used in a future production plant.

Reference

[1] www.shimadzu.eu/brochure/CFT-D.pdf