New Developments in Co-Rotating Twin-Screw Extrusion for Production of Long Glass Fiber Composites

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Abstract

Long fibre reinforced thermoplastics have excellent mechanical properties and stiffness-weight ratio, which is of particular interest to the automotive industry. The new Inline-Compounding processes for long fibre materials offer users more flexibility, as they are able to both compound and process such materials in accordance with their own formulation and also use ready-made compounds. The following process combinations are possible:

- E-LFT; In-Line-Compounding and Direct Extrusion to Profile or Plate
- D-LFT; In-Line-Compounding and Compression Moulding
- S-LFT; In-Line-Compounding and Injection Moulding

Background

Almost all polymers pass a compounding stage on their way from the polymerization reactor to the converting machine where the final product (film, injection molded parts, etc.) is produced. This compounding step serves several objectives:

- Incorporation of additives
- Removing of monomers or solvents
- Alloying or reactive extrusion
- Reinforcing or filling
- Production of pigment or additive concentrates
- Pelletizing for easier handling on the converting machine

Some single screws, but predominantly co-rotating twin screws are used for these demanding process tasks. (Figure 1)

Basic design of co-rotating twin screw extruders

Figure 2 shows the geometric values by which the cross-section of a fully self-wiping and sealing profile is completely described. Similar machines are defined by the number of flights and the ratio between two characteristic geometric dimensions. Erdmenger, who invented the system, chose the ratio between outer and inner diameter (D_o/D_i ratio) and described the power class by the ratio between torque and third power of another geometric value, the centerline distance. Here, the centerline distance is a useful reference value since torque is limited by the centerline distance (Md/a^3 ratio).

Today, these values are commonly accepted among experts. The diameter ratio determines free volume and average shear (which is directly linked to it), while the specific torque, determines the drive power per unit screw volume.

Different machine sizes with the same values for D_o/D_i and Md/a^3 are similar with regard to geometry and power class. This similarity is a condition for extrapolations and scale-up.

There is a correlation between the free cross-sectional area, where the compounding takes place, and the maximum permisable thickness of the drive shafts. It becomes clear that, if the free cross-sectional area is enlarged, the shaft thickness and thus the driving torque must decrease. Up to the early seventies, however, an optimization of the shaft/screw interface was possible only within certain limits since the drive power was limited by the gearbox. Md/a^3 values between 3.5 and 6 Nm/cm^3 were quite common. For these power classes, the volume of triple-flighted screw profiles with $D_o/D_i = 1.25$ was sufficient. For power transmission between the shaft/screw, simple fitting key connections were used. In the meantime, heavy-duty gearboxes with Md/a^3 values between 10 and 14 Nm/cm^3 are available. This has opened new possibilities for developments in processing.

Definition of long fibers

There are several opinions about what is a long fiber in the market. Typically a long fiber is defined as a fiber longer than the critical fiber length.

The fiber length is connected with the process of production. In the past two types of materials were available. The classical short fiber compound and the GMT. The short fiber compound is produced on a compounding machine out of raw polymer and chopped fiber strands. The typical fiber-length for PP glass fiber reinforced is about 700 µm. The GMT is produced out of a long glass fiber mat, which is impregnated which a low viscous PP in a double belt process.

In last few years a lot of new processes were developed. The obtainable fiber lengths of these processes are between the short fiber compound and the GMT.

Figure 3 gives an overview about the processes and the connected fiber length (1).

Production of long glass fibre compounds and parts

Research showed that physical properties of reinforced compounds do increase with longer glass fibres. Therefore it was a desire to adjust the compounding process that longer glass fibre lengths can be achieved in the pellet or final product.

Several processes have been presented in the last few years. In the presentation the following 3 processes will be discussed:

- E-LFT; In-Line-Compounding and Direct Extrusion to Profile or Plate
- D-LFT; In-Line-Compounding and Compression Moulding
- S-LFT; In-Line-Compounding and Injection Moulding

The principle of the process

Especially for long fibre technology, a screw configuration has been devised by which the following is ensured:

- First the matrix mix is melted.
- Then the melt is intensively mixed and homogenized, stress free.
- Finally the continuous glass filaments are automatically taken in from roving by the rotation of the screws, impregnated with the melt, cut to length and dispersed.

Upstream of the plant, a gravimetric feeder for the matrix polymer is provided and, if necessary, gravimetric feeders for additives and pigments. The components of the formulation are fed in as a continuous stream with consistent composition so that the reproducibility of the formulation is always guaranteed.

The glass fibre filaments are pulled from roving bobbins into the Twin Screw Extruder by the rotation of the screw shafts. The screw design, which has been especially matched to the viscosity of the polymer matrix and the roving features ensures uniform intake, sufficient impregnation and dispersion of the filaments as well as fibre length distribution in the plasticized material ready for moulding or extrusion.
Individual monitoring is provided for each roving bobbin, i.e. a filament rupture or a standstill is immediately observed. The roving feed system has been designed such that changing of a bobbin does not lead to a plant stop.

E-LFT

If the Twin Screw Extruder is equipped with a sheet die, sheets from long fibre reinforced can be directly extruded. To this purpose the melt is discharged through a sheet die. The sheet is gauged and cooled in a calendar roll stack and then cut to plates. These plates can be either used directly as extruded or reshaped in a thermoforming process. Profiles can also be manufactured. To this technology the Twin Screw Extruder is equipped with a downstream profile die and a gauging and cooling section. (Plant lay-out see Figure 4)

D-LFT

The D-LFT is an In-Line-Compounding and Compression Moulding Process. The Direct stands for a compounding of endless glass fibres and the polymer matrix in a twin screw extruder in front of a compressing moulding press. This press is normally a hydraulic press with a high closing and pressing speed and a very short pressure built up time.

In the automotive industry, glass-mat and glass-reinforced thermoplastics are used as a starting material for the production of multifunctional components such as front ends, noise shields or under body structures. An overview about possible parts is shown in Figure 5.

In the past GMT (glass mat thermoplast) blanks were heated up in an oven and then this material is fed to a compression moulding press. Manufacture of the multilayer semi-finish product is time-consuming and also cost intensive because of the high capital investment costs of the production plant. In semi-finished product manufacture, a glass mat and cover film are applied to each side of an extruded plastic layer. In a twin belt press, semi-finished product sheet is produced under pressure and heat. This is then cooled and cut into blanks according to specific customer requirements. These materials were in the past first choice for the manufacture of highly stressed structural components by press moulding. Increasing pressure on costs is compelling automotive suppliers to seek cheaper ways of producing technologically equivalent materials.

In developing an alternative to GMT semi-finished products, the aim was to reduce the price of the material at the press without making any concessions in term of technological properties. (Plant lay-out see Figure 6)

After compounding, the melt is extruded continuously through a slit die. A special preparation unit takes the extrudate strand and divides it up into individual blanks. The system stockpiles the blanks and keeps them at a sufficient temperature until the last individual blank has been extruded and cut. Then the unit discharges the entire set of blanks onto a feed belt. Immediately before the press molding operation, a robot fitted with needle grippers picks up the blanks and places them in the press.

By using the direct process to manufacture long-glass-fiber-reinforced thermoplastics, processors can tailor the properties of their materials to customer requirements. The flexibility of process enables the individual components of the composite material to be chosen and their ratios varied as required. (Photo of installed plant see Figure 7)

S-LFT, In-Line-Compounding and Injection Moulding

A mixture of PP and a compatibilizer are gravimetrically fed into the feeding zone of a co-rotating intermeshing twin screw extruder. Rovings are actively pulled and cut by the twin screw extruder. The melt is vented and extruded into a shooting pot until the shot volume of the part is reached. Thereafter the extruder stops plastizing and the melt is injected into a mold using injection compression. (Overview of machine concept see Figure 8)

With a twin screw extruder it is possible to use continuous rovings (made of glass, natural fibers,..) fed into a venting hole in the screw. Therefore the feeding of glass fibers is independent from the viscosity of the matrix material. When using rovings there is no limitation of the final fiber length with respect to the initial fiber length as seen with the pultruded granules.

During extrusion the molten mixture is transferred into a shooting pot. As soon as the shot volume is reached a distributor valve is changing its position so the machine is ready for injection. (Photo of installed machine see Figure 9)

To reduce fiber breakage to a minimum during injection and achieve typical wall thicknesses of 0.75 – 1 mm it is necessary to run the machine in injection compression mode. For constant wall thickness a controlled parallel movement of the clamping system is necessary. Using injection compression is resulting in lower specific clamp forces and therefore larger parts can be made on smaller machines.

The maximum available plasticizing time is the cycle time without injection and hold time. The control of the concept is simple: as soon as the extruder and the shooting pot are on process temperature, the twin screw extruder can be started. When pushing the start button the gravimetric feeding installation gets the feeding signal. It is not possible to start plasticizing before the matrix and bounder are fed into the hopper. This is to avoid that only glass fibers are fed towards the extruder. The start up from the process is very easy to control and user friendly. (Flow diagram of the process see Figure 10)

Using a discontinuous extruder operation overcomes the control problems and possible start up problems that are inherent on a system with a continuous extruder operation.

Outlook

Future developments in these In-Line-Compounding processes are in using technical polymers as matrix polymer, to obtain a higher temperature resistance.
Natural fibres will be used for ecological reasons and also carbon fibres to achieve high performance parts.
The equipment will be optimised to higher throughput rates and a faster cycle time.

With the In-Line Compounding is opened a door to a new way of material converting. Material Combination may be interesting which were not possible today because of overheating in the remelting process or dispersion problems in the converting machine.

Literature:

1.Oelgarth, A.; Dittmar, H.; Stockreiter, W.; Wald, H.: GMT oder LFT? Kunststoffe 4/1998

Honc, P.; Rodriguez, J.; Mager, M.; Scheuring, B.; Schwendemann, D.: Langglasfaser-PP compoundieren und direkt verarbeiten. Kunststoffe 8 / 1999

Billiet, J.; Leng, T.; Kapfer, K.; Schwendemann, D.: In Line Compounding / Injection Molding with a discontinuousliy operating Twin Screw Extruder. Antec 2001

Figure 1: The compounding Step in the plastic production process.

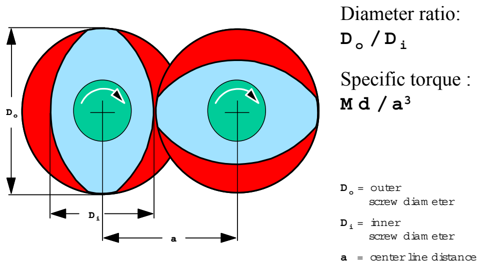

Figure 2: Characteristic Dimensions of Co-rotating Twin-Screws 2-flighted profile.

	Short fiber reinforced polymers		Long fiber reinforced polymers		
Fiber Length in the part [mm]	<1	1 – 5	5 - 25	5 – 25	> 10 - oo
Raw Material	Short Fiber compound	LFT-Pellet	LFT-Pellet	Direct -LFT	GMT
Production process	Injection Moulding		Compression Moulding		
Fiber Orientation in the part					

Figure 3: Classification of thermoplastic Fiber-Composite-Systems (1)

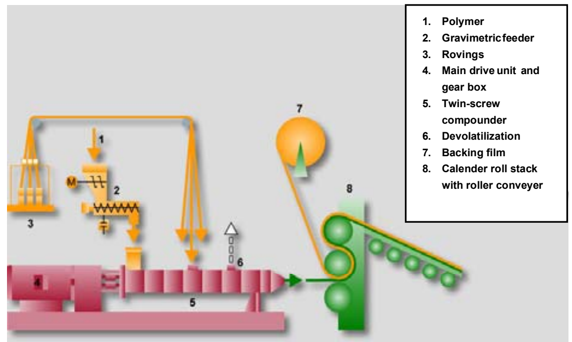

Figure 4: In-line compounding and direct processing of long-fiber reinforced thermoplastic sheets (E-LFT)

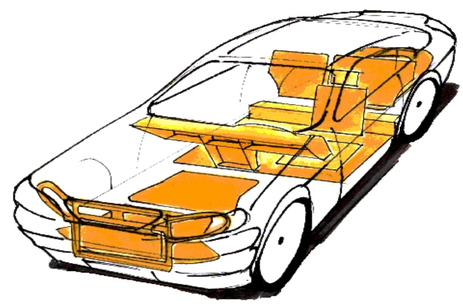

Figure 5: Possible parts in the car

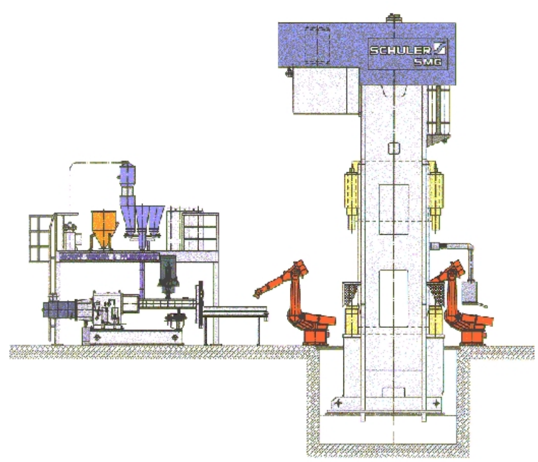

Figure 6: Integrated Production Systems for the Processing of Reinforced Plastics by Hydraulic Presses

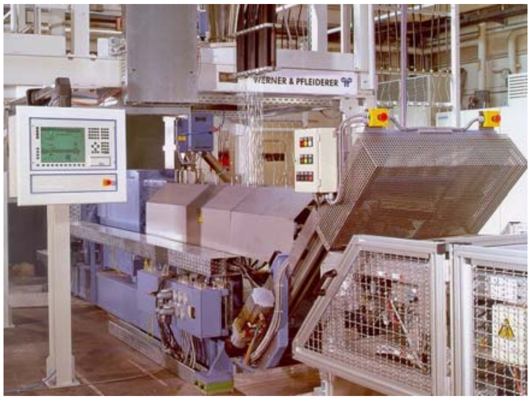

Figure 7: The glass fibers taken off roving bobbin are drawn into the barrel of the twin screw extruder

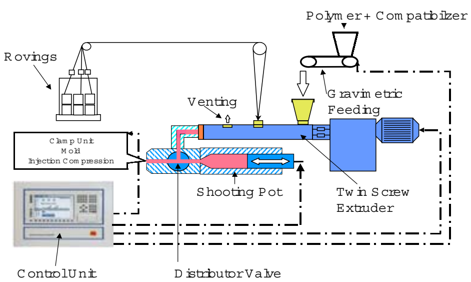

Figure 8: Overview of machine concept.

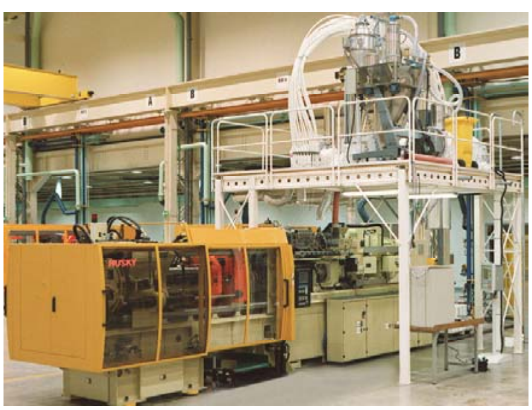

Figure 9: Picture of machine concept

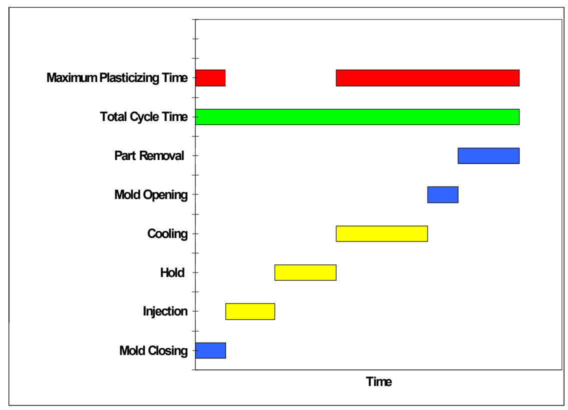

Figure 10: Flow Diagram of the process