LFT-D-ILC - Innovative Process Technology Decreases the Costs of Large-Scale Production of Long-Fiber-Reinforced Thermoplastic Components

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Abstract

Long-fiber-reinforced thermoplastics (LFT) have gained an increasing market share in the European automotive industry. In some large-scale applications the processing of semi-finished products such as LFT-GMT (glass-mat reinforced thermoplastic sheets) and LFT-G (long-fiber-reinforced thermoplastic granulate) is already known.

The LFT-D process, in which continuous rovings are fed directly into the polymer melt, differs fundamentally from the LFT-GMT and LFT-Pellet-Process.

High economic efficiency is achieved when the cost intensive production of semi-finished products as well as the subsequent logistic costs are avoided. Thermal stress of the compound is minimized. Excellent flow properties as well as consistent glass fiber content are obtained.

The degree of freedom regarding the use of new polymer blends and different types of fibers, for example natural fibers, enables an individual matching of the compound according to the specific needs of the application. In addition the glass fiber content can be adjusted as needed.

The solution presented in this paper is based on the Dieffenbacher Direct Process (LFT-D-ILC). This development is responding to the technical requirements of automotive parts for large-scale production.

As the leading manufacturer of presses and fully automated press lines for the production of components of fiber-reinforced materials such as SMC, BMC, LFT-GMT, LFT-P and LFT-D-ILC, Dieffenbacher offers complete technical solutions to suppliers and the automotive industry.

Introduction

There is a need for establishing new direct processes in order to meet the demands of the automotive industry with regard to cost reduction and improvement in environmental protection. Dieffenbacher developed the LFT-D-Process approximately five years ago [1] and introduces now the LFT-D-ILC Process to the market. The major difference is the separation of the matrix compounding step from the incorporation of fibers in a second twin-screw-device. Usually thermoplastic polymers do not fulfill the requirements of a technical application and therefore need to be stabilized and modified. This separation allows an optimized compounding of the matrix polymer with simultaneously increased output rate of the compounding unit. High shear strength has to be introduced into the molten mixture of polymer and additives to optimize the compounding. This can be realized by a common compounding unit. High shear strength causes at the same time fiber damage which has to be avoided to achieve a long fiber reinforced polymer melt. Thus the incorporation takes place in a separate twin-screw-device with a matched screw design that avoids fiber breakage. This one-step process prevents the granulation step of the matrix and with it polymer degradation.

In addition the decoupling enables the economic production of small amounts of a customized material for small volume production whereas the producer of semi finished products will not be able to provide the material because of economical reasons.

Beside all the mentioned advantages the manufacturer of automotive components has to keep in mind the necessary increased knowledge and process effort.

The In-Line Compounding LFT-D Process

In-Line compounding systems are integrated with the molding process to deliver homogeneous long fiber reinforced compound performs at molding temperature, in complete synchronization with the demand established by a cycle time of less than 30 s. In-Line compounding systems currently in use are capable of providing five hundred kilogram per hour at a screw speed of about 500 1/min.

Figure 1 shows a schematic drawing of the in-line compounding system. Matrix granulates and additives are delivered to a combination of gravimetric dosing units, see Figure 2, which guarantee a suitable mixing in respect of the mechanical requirements of the component. Usually colorants, antioxidants, heat stabilisers and coupling agents enable a suitable recipe for automotive applications. The molten compound exits the twin screw extruder through a film die right into the
opening of the twin-screw-device. This is the location where the glass rovings are added.

**Twin Screw Extruder Leistritz ZSE 60/GL**

The compounder is a co-rotating, closely intermeshing and self-cleaning Leistritz ZSE 60/GL unit with a L/D ratio of 32. The degassing takes place at 26 D, vacuum assisted or at atmospheric pressure. The underfed partly filled cylinder guarantees a large surface and with it a sufficient venting of the plasticised matrix. Depending on the chosen Polymer the possibility of adding special additives is given by a side feeding unit at 14 D. The melt pressure at the die is about 40-60 bar depending on the MFI of the polymer.

**Provision of Rovings**

To reduce the interaction of rovings the bobbins are placed in a special designed roving rack, see Figure 3. Each roving is guided separately through a special plastic tube to avoid friction and static charge.

Depending on the glass fiber content of the component, rovings with 2400 or 4800 tex are used. It was found that direct rovings show a better spreading of the filaments and therefore a better wetting. However mechanical properties show hardly a difference compared to assembled rovings. Each roving is monitored by a special sensor which controls its presence.

The rovings are fed through the tubes to a preheating device as shown in Figure 4. The rovings are spread on five iron bars which are heated up to 220°C. The temperature should not be elevated further to avoid the damage of the sizing. Compared to competing technologies a pre-impregnation of the fibers with polymer is not needed. Through a special designed interface the fibers are introduced straight on top of the polymer film as it enters the twin-screw-device.

**Twin-Screw-Device (ZSG)**

The twin-screw-extruder has an effective cylinder length of about 8 D. The completely fed cylinder cuts the fibers by a defined cylinder geometry to obtain an average fiber length of about 40 mm. The average fiber length can be adjusted by the chosen screw design.

The ZSG continuously provides the plasticised material which enables the process to generate a compound with approximately 1 % of glass fiber deviation. A slit die vacates the bulk molding preform at molding temperature on a fully automated belt. To raise productivity and output a two conveyer belt comes into operation. The conveyer belt is covered by a heat tunnel to prevent temperature decrease at the surface of the extrudate. When the extrudate is gripped by a handling robot, the heat tunnel opens. The ZSG length of 8 D combined with the design of the feed section avoids a separate degassing of the extrudate. The obtained extrudate shows a uniform geometry which is suitable for either manual or robotical handling, see Figure 5.

**Design of a Modern LFT-Press**

In a high volume production a modern hydraulic LFT-press with a clamping force in the range of 15.000 up to 40.000 kN is recommended. Usually a press table with 3.600 to 2.400 mm in dimension is used. Speed of press closing movement can be raised up to 800 mm/s. The maximum forming speed is 80 mm/s. The characteristic value for pressure built-up time is 0,5 s.

The described press is suitable for two-cavity molds in which two parts can be molded during a cycle time of just 25 s. This includes the closing of the press inclusive control of working stroke and pressure built-up (4-5 s), cooling time (approx. 8 s), opening of the press inclusive pressure reduction and the control of the opening movement (4-5 s) as well as the loading and unloading of the press (approx. 8 s). The consistent mold closing movement is supported by an active parallelism control.

Dieffenbacher is the only supplier manufacturing and offering the complete process equipment (extruder-, press- and automation technology) for LFT materials worldwide. One of several advantages of this fact beside for example service is the quality control by extended diagnostic facilities.

**Quality Control by extended diagnostic facilities**

The centralized PC-production-line control unit enables the fast, exact and concise control of all process components as shown in Figure 6. from one single, centralized terminal.

As a result of the described LFT-direct process and the implementation of plants for production of automotive components, the manufacturer of LFT plants has to meet higher requirements in order to guarantee a process for safe part production including an acquisition and evaluation system of process data (SPC). The possibility of process data storage for each individual part has been taken into account as well.

According to these requirements a complete controlling concept (SPC) has been developed including the administration of all components within a LFT-D-ILC plant. The evaluation of process parameters is based on a user-friendly data analysis system which is the basis for the statistical evaluation of the process parameters (SPC). It also observes the long-term behavior of the production process by determination of process performance parameters. The following parameters are important for a statistical quality control:

- batch constancy
- reproducibility of process
- part weight
- part geometry
The determination of the essential process parameters take place at each different process unit which influences the material properties. Registered parameters are:

- material provision (gravimetric)
- roving monitoring
- temperatures of material (while extrusion and compression molding)
- melt pressure
- screw speed
- screw torque
- speed of the conveyer belt
- length of the extrudate
- position of the extrudate
- time for robot handling (loading and unloading of the press)
- cycle time of compression molding
- closing speed of press
- force progression and pressure built-up
- change-over point to force control
- distance of the male mold to the female mold
- final part thickness

Flow characteristics and information about viscosity as well as uniformity of part thickness, zone of extrudate positioning and amount of material can be determined or calculated with these parameters. Reproducibility can be controlled by free programmable positions of the male mold during one forming process.

The result of the comprehensive parameter evaluation and recording is the providing of an in-line equipment with high reproducibility.

**Long-Fiber-Properties**

*Figure 7* provides a property data comparison of an in-line compounded front-end module and a module manufactured with LFT-GMT. Both materials show a glass fiber content of 40 weight-%. *Figure 8* provides a property data comparison of a 20 weight-% glassfiber reinforced underbody cover and the delivery standard. The test values of the considered materials were generated from test specimens which were cut out of the components.

The property profile of the in-line compounded material compares favorably with the LFT industry standard; i.e. the LFT-GMT material. Impact-, flexural strength and E-Module are superior to the industry standard. Therefore LFT-D and LFT-D-ILC are replacing LFT-GMT and LFT-P in many applications. Especially the energy absorbing properties like impact resistance are noticeably higher than comparable long and short fiber reinforced injection molded parts. This helps to explain the success of long fiber compositions in semistructural and structural applications.

**Advantages of the LFT-D-ILC Process**

*Figure 9* shows the advantages of the LFT-D-ILC Process compared to LFT-GMT and LFT-Pellets [2].

The most compelling advantage consists in the cost savings by avoiding the step of manufacturing a semi-finished product like pellets or plates. The economic advantage is derived from the efficiency of the process, its reliability and from the use of raw materials such as plastic pellets, reinforcing fibers and additives. Maintaining inventories of multiple grades of pre-compounded pellets or LFT-GMT-plates are not necessary and save logistics cost. Thermoplastic glass fiber reinforced extrudate is just-in-time produced on demand.

Unlike precompounded pellets or plates, thermoplastic polymers entering the in-line-system have undergone a single heat history. The reduced exposure to thermal degradation leads to improved initial and long-term properties for molded composite components produced with the LFT-D-ILC process.

The expenditure for total energy consumption to produce a composite component is significantly less compared to the alternative processes. In the direct process energy which is spent transforming raw materials into LFT-pellets or GMT-plates, tansporting the pellets or plates to the component manufacturer and subsequent reheating of the pellet or plate feedstock prior to compression or injection molding, are completely eliminated.

Separation of compounding thermoplastic polymers prior to the incorporation of fibers reduces screw wear significantly and extends the useful lifetime of compounding feed screws. Fibers are not present at the solid/melt interface compared to processing LFT-pellets.

LFT-D-ILC is perfectly suited to match the material formulation to the requirements of the application. The selection of materials is not constricted by the efficiency of a semi-finished material supplier’s production. The glass fiber content and the composition of the molding material can be adjusted like required. This is realized by computer controlled gravimetric feeders and screw speed or by the number of rovings fed into the ZSG. This enables the use of individual color matching. Color concentrates as well as liquid colorants delivered to the polymer of the ZSE 60/GL are uniformly dispersed in the polymer of the composites. To eliminate the need of custom compounded precolored pellet feed stocks, custom colors are prepared in-line as needed. The first visible application is already in development.
Recycling

The LFT-D-ILC process offers a further economical and environmental advantage referring to the direct reprocessing of recycled LFT materials. Usually production waste comes into operation. Components after life cycle can be utilized as well. After the shredding metal parts or particles have to be removed. Single screw shredders with a sieve aperture diameter of maximum 50 mm are most suitable to generate a particle size suitable to be added to the virgin material. Figure 10 illustrates the two possibilities for a closed loop concept.

Shredded particles in the range of 8-12 mm are mainly used to improve mechanical stiffness and are added to the compounding. An additional feeding and dosing unit is required. Large particles up to 50 mm in diameter require a specific extruder with a screw design which is preserving fiber-length. The plasticized recycled material is side fed into the twin-screw-device.

Future Technologies

The LFT-D process is an extraordinary versatile process. Material use, defined by the requirements of the molded part, can be molded directly from raw material blends defined in-line prior to compression molding. Carbon, aramid or natural fibers such as hemp, flax, sisal or wood fibers can be compounded with a variety of thermoplastic polymers such as polyolefins, polyesters and nylon [3]. Different fillers like for example talc, calcium carbonate or chalk can be added to for example influence cost and flow properties.

The combination of impregnated textile reinforcements like woven fabrics with long fiber reinforced material increases the mechanical properties - especially impact properties - significantly. The Fraunhofer ICT together with Dieffenbacher and other industrial partners recently won the European innovation JEC Award 2001 for the Direct-Forming-Process which enables the production of thermoplastic sandwich structures in one step [4].
Fig. 2: Gravimetric Dosing Units for In-Line Material Matching

Fig. 3: Preparation of Glass Rovings

Fig. 4: Preheating of Rovings

Fig. 5: LFT-D-ILC Extrudate on Conveyer Belt – Heat-Tunnel Opened
1) LFT-D-ILC Line
2) Conveyor Belt
3) Roving Rack
4) Loading Robot
5) Quenching Bassin
6) Press Type DYU
7) Unloading Robot
8) Mold Change
9) Outfeed Conveyor

Fig. 6: Production Line Layout

Front-end assembly carrier (glass-fiber content 40 weight-%)

- Tensile Strength: LFT-D/GF 60 (MPa), GMT 65 (MPa)
- Impact Strength: LFT-D/GF 60 (KJ/m²), GMT 75 (KJ/m²)
- Flexural Strength: LFT-D/GF 110 (MPa), GMT 110 (MPa)
- Modulus of Elasticity: LFT-D/GF 7200 (MPa), GMT 6100 (MPa)

*including 30% of recycled LFT material

Fig. 7: Front-end Assembly Carrier - Material Properties

Underbody cover (glass-fiber content 20 weight-%)

- Tensile Strength: DBL 35 (MPa), LFT-D/GF 35 (MPa)
- Impact Strength: DBL 15 (KJ/m²), LFT-D/GF 35 (KJ/m²)
- Flexural Strength: DBL 50 (MPa), LFT-D/GF 70 (MPa)
- Modulus of Elasticity: DBL 2300 (MPa), LFT-D/GF 3670 (MPa)

Fig. 8: Underbody Cover – Material properties

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<th>LFT-D-ILC</th>
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Fig. 9: Comparison of LFT-D-ILC Technologies
**Fig. 7: Closing the Materials Loop**

**Literature:**


**Keywords:**

Direct Process
Long Fiber Reinforced Thermoplastics LFT
Direct Forming Process
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In-Line-Compounding
Thermoplastic Composites