Chopped Fiber Processing – an Unusual Approach Leads to the Long Fiber Goal

Processing Chopped Glass Directly in the Injection Molding Process

A new screw geometry for the direct processing of chopped glass fibers significantly expands the field of application for long fiber-reinforced polypropylene. The production of such components through direct processing is significantly more economical and sustainable than with conventional long glass fiber technologies, as process steps such as compounding are no longer necessary.

Processing of chopped glass fibers on a standard injection molding machine. © KraussMaffei

Long fiber-reinforced thermoplastics are used in the automotive sector, particularly for components with increased mechanical requirements such as continuous fatigue stress. In addition, long fiber-reinforced polypropylene (PP-LGF) can achieve significant CO_2 and material cost savings when used as a substitute for polyamide (PA), for example. However, it is not only the relevance of the CO_2 footprint that has amplified, but also the increased costs for processors. As a result, existing material solutions such as PP-LGF rod pellets are often too expensive for wider applications, or process engineering solutions are too complex (such as the processing of continuous fibers in the injection molding process).

The project partners KraussMaffei Technologies GmbH and Wirthwein SE have therefore developed a new technology for the direct processing of chopped glass fibers, which reduces both component costs and the CO_2 footprint. This gives users a clear competitive advantage.

New Screw Geometry

KraussMaffei's CFP (Chopped Fiber Processing) technology is based on the familiar approach for injection molders

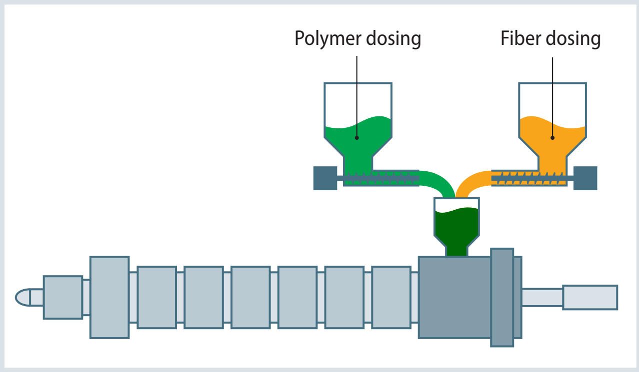

Fig. 1. Schematic representation of CFP technology (chopped fiber processing). © KraussMaffei

of adding both fibers – more precisely, chopped glass fibers – and pellets to the plasticizing feed opening (**Fig. 1**). This approach is only unusual from a process engineering point of view in that fibers are usually only added after the polymer has melted to avoid excessive shortening of the fiber length. The new processing technique uses a standard injection molding machine equipped with a novel, patented screw. A major advantage of the new geometry is that it allows the processing of chopped glass fibers and matrix material together, so that PP-LGF components can be produced very easily as described.

The special screw geometry is designed in such a way that the melting of the matrix portion of the polymer-fiber mixture is combined with gentle cutting of the chopped glass fiber bundles, without significantly shortening the fibers. This results in components with fiber lengths up to the long fiber range and great homogeneity.

Compared to continuous fibers, chopped glass fibers are coated with a much higher proportion of sizing and binder, which makes the individual fibers adhere strongly to each other. This improves the flowability of the fiber rods and simplifies the handling of the raw material. Compared to standard injection molding, only an additional dosing device is required to be able to dose the two materials (chopped glass and polymer) into the hopper in the desired ratio.

Shear Deformation without Fiber Damage

The screw geometry is based on the fact that the chopped glass fibers always undergo shear deformation regardless of the flow path length covered, without the fibers being mechanically damaged. According to Rauwendaal, shear deformation is the product of shear rate and shear time [1]. In order to maintain maximum fiber length, the shear rate should be low and the shear time correspondingly long. The shear deformation of the fiber agglomerates is therefore not predominantly dependent on the maximum shear stress but is adjusted via the shear time. This results in a disperse mixing process that is particularly gentle on the fibers and reduces fiber breakage.

Last but not least, the orientation of the fiber in the flow channel is decisive for the dissolution of fiber agglomerates. As expected, fiber agglomerates oriented perpendicular to the melt flow show better dispersion in the matrix material in tests than fiber bundles that are oriented parallel. Therefore, the new screw geometry is designed in such a way that the fiber agglomerates are reoriented accordingly and separated perpendicular to the flow direction.

The mechanical properties of the PP-LGF compound are largely determined by the fiber content, the fiber length, the fiber-matrix adhesion and the distribution of the fiber in the matrix (homogeneity) [2]. The fiber content is usually determined by the design of the component. The bonding to the matrix is mainly influenced by chemical reactions between the bonding agent and the fiber sizing and is determined by the choice of material. This means that only the resulting fiber length and the distribution of the fibers in the matrix can be influenced during the manufacturing process. The best mechanical properties are achieved at the intersection between homogeneity and fiber length (**Fig. 2**), the optimum [3].

Aim: Consistent Fiber Concentration across the Component Volume

Fiber accumulations lead to a locally disproportionate stiffening and thus to a local embrittlement of the component. Therefore, such fiber accumulations – contrary to the intention of fiber reinforcement – weaken the component. A consistent fiber concentration in all volume areas of the component is just as important for the mechanical properties as fiber content, length distribution or fiber-matrix bonding.

To evaluate the homogeneity at filament level, test plates were made from PP-LGF without coloring (**Fig. 3**). The fiber clusters (agglomerates) were then detected using common image analysis methods [4]. From this, the cluster area can be derived, which is set in relation to the total area of the sheet in order to obtain a key figure for the cluster proportion. A more homo- »

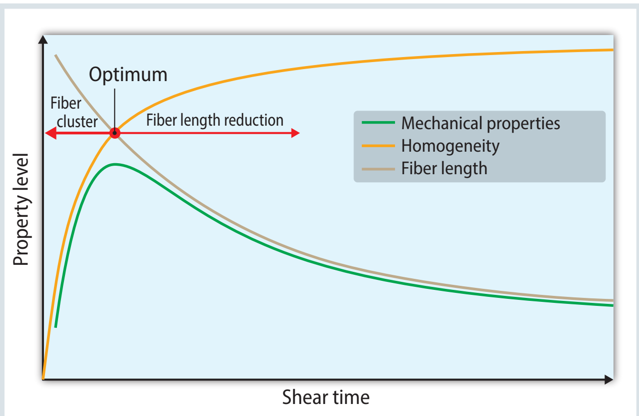

Fig. 2. The best mechanical properties are achieved at the intersection between homogeneity and fiber length. Source: [3]; graphic: © Hanser

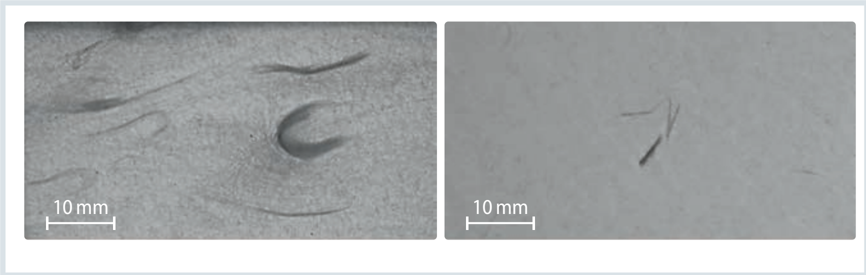

Fig. 3. Comparison of fiber clusters when using LGF pellets (left) and CFP technology (right).
Source: [4]; graphic: © Hanser

geneous fiber distribution is given if there is a lower proportion of fiber clusters, which can reduce the local embrittlement mentioned above.

The analysis of the fiber length requires a great deal of care and experience, as a component made from a short fiber-reinforced PP-GF30, for example, contains approx. 900,000 fibers per gram of component weight (filament diameter 13 µm, arithmetically averaged fiber length 1 mm, density of the glass fibers 2.6 g/cm^3). This corresponds to approx. 900 million individual filaments with a shot weight of 1 kg.

Image-based measurement methods (e.g. FiVer or FASEP), which allow the analysis of 20,000 to 150,000 individual filaments with software support, are state of the art [5]. Nevertheless, only a fraction of the existing fibers are analyzed, which is why sample selection (weld line area as well as near or far from the sprue) and sample preparation are of particular importance. The weighted mean fiber length and the weighted mean D50 quantiles are the key parameters of fiber length analysis. Fiber lengths of > 1 mm are often required for both parameters.

Dispersion of the Fibers Positively Influences the Mechanical Properties

The fiber length analyses shown (**Fig. 4**) were created for identical boundary conditions (component, position on the component, tool, machine size, fiber length analysis tool and matrix material). A comparison between injection molding machine-based continuous fiber direct processing and CFP technology shows clear differences in the weighted average fiber length and the D50 quantiles. As expected, continuous filament direct processing has higher values here by a factor of approx. 3. However, the ratio between the weighted average fiber length *LP* and the arithmetically averaged fiber length *LN* also differs, which indicates a multimodal fiber length distribution and thus suggests a reduced dispersion of the fibers in continuous fiber direct processing.

Based on these fiber length analyses, it would seem obvious that the mechanical properties of the components manufactured using the CFP process are lower in comparison. However, testing the components shows that the theory put forward at the beginning is correct: Fiber length and dispersion determine the mechanical properties. The very good dispersion of the fibers using CFP technology therefore has a positive influence on the mechanical component properties. Furthermore, compared to continuous fiber direct processing, there are hardly any fiber agglomerates, which lead to a weakening of the component as described above.

In addition, the mechanical properties and average fiber lengths of the components produced using CFP are compared with both the continuous fiber direct process and the benchmark "rod pellets" (**Fig. 5**) and different viscous matrix materials (MFR 25 to 125 g/10 min) are used in the CFP technology.

Comparison with Rod Pellets and Continuous Filament Direct Processing

The long glass fiber processing methods (rod granulate "LFTG" and continuous fiber direct processing "EFDV") achieve longer fiber lengths compared to CFP, but comparable properties. In particular, CFP shows higher characteristic values for impact strength, which was not expected. Once again, it is shown that homogeneity is just as important for the mechanical properties as fiber length. According to Thomason and Vlug [6], a tenfold increase in fiber length would be necessary for a further increase in mechanical properties. If the homogeneity of the fibers is sufficiently guaranteed, the fiber length achieved with the CFP process is therefore sufficient.

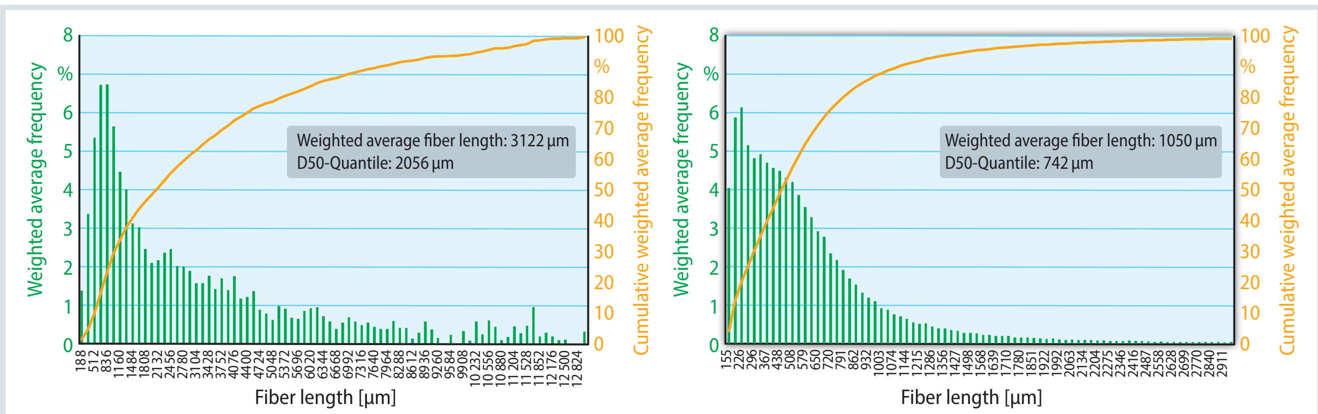

Fig. 4. Fiber length distribution for continuous fiber direct processing (EFDV, left) and CFP technology (right). Source: [7]; graphic: © Hanser

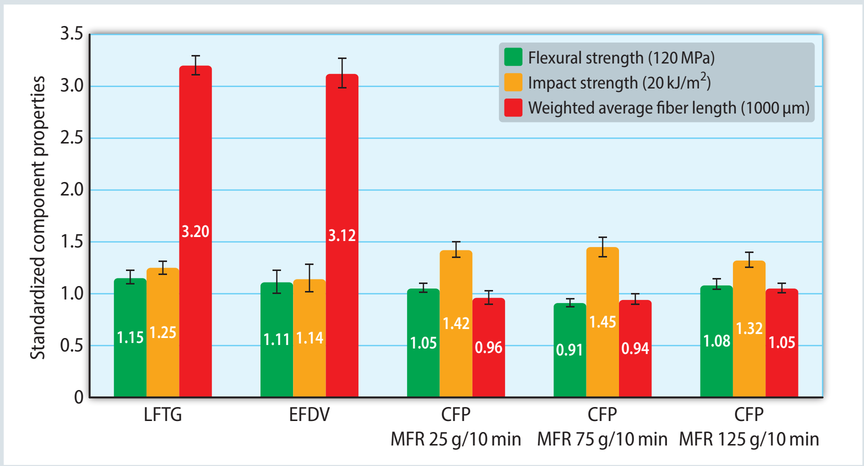

Fig. 5. Comparison of component properties and fiber lengths for LGF pellets, continuous filament direct processing (EFDV) and CFP technology. Source: KraussMaffei; graphic: © Hanser

Contrary to what is assumed, the component properties depend much less on the flow behavior of the matrix and the fiber length than on the distribution and interaction of the fiber and the base polymer used (**Fig. 6**). In comparison to the dilution systems currently used very frequently – in which a concentrate (LGF granulate) is mixed with a diluent PP (MFI > 120) in order to reduce material costs – CFP technology allows very inexpensive PP grades or PP grades with different properties (increased impact strength, UV protection, etc.) to be used in a wide viscosity range. In the future, it is conceivable that that own tailor-made formulations can be produced through the targeted use of additives (e.g. thermostabilizers).

Wirthwein SE is also currently investigating the use of recyclates (PIR and PCR) for the production of LGF components using the new CFP technology. The process offers a high degree of flexibility to produce customized PP-LGF compounds and to adapt them precisely to the respective application, both technologically and economically. Compared to conventionally produced rod pellets, costs can be significantly reduced (currently up to 30 %) and the PCF (product carbon footprint) can be lowered (by up to 10 %).

Outlook

In addition to applications in the automotive sector, the main field of application for the direct processing of chopped glass is in the energy sector, as the combination of high mechanical properties and economical manufacturing processes meets current requirements. In the future, there are plans to replace existing LGF material systems with direct processing of chopped glass in order to generate ecological and economic benefits.

The new processing technology will solve the existing dilemma of achieving either long fibers or a homogeneous mixture. The components produced using the CFP process exhibit properties comparable to rod granulate at significantly reduced costs and a lower CO_2 footprint, as there is no compounding step. ■

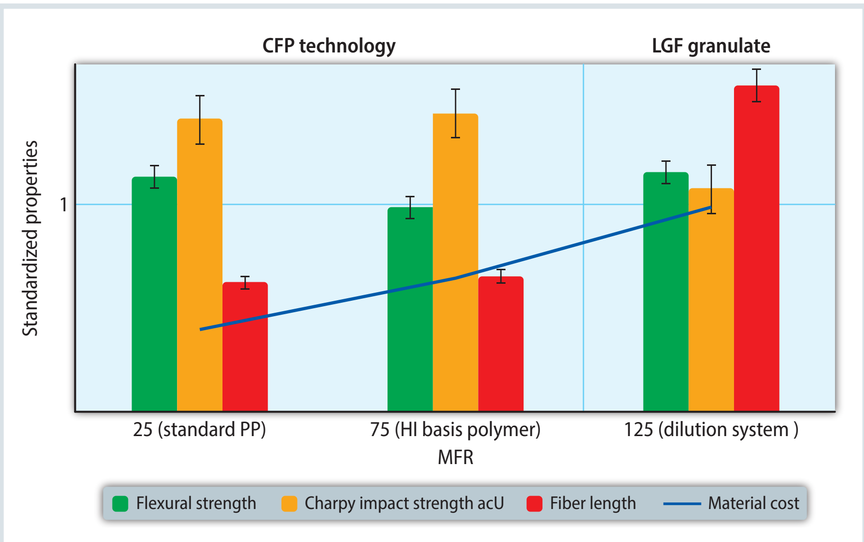

Fig. 6. Standardized comparison of the mechanical properties and material costs of CFP technology with a dilution system. Source: Wirthwein; graphic: © Hanser

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Information on the project partners:
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References

You can find the list of references at
www.plasticsinsights.com/archive