Injection moulding of long glass fibre reinforced polypropylene

E. Burkle, M. Sieverding and J. Mitzler*
*Kraus Maffei GmbH, Munich, Germany

Selected from International Polymer Science and Technology, 30, No. 11, 2003, reference MG 03/09/308; transl. serial no. 15063

Translation submitted by E.A. Inglis

1. INTRODUCTION

Some components used in the automotive industry, such as housings and floor elements are mainly made from glass reinforced polypropylene. PP is currently displacing engineering plastics and metals in these applications because of its lightness and cheapness and by virtue of its recyclability. The mechanical requirements can only be met by PP, however, if it is reinforced with glass fibre to improve its elastic modulus and impact resistance.

During the manufacture of components glass fibre reinforced PP is injection-moulded or compression-moulded. During compression moulding, glass mat reinforced thermoplastic (GMT) PP is used as the starting material. Classical GMT compression moulding results in a component with excellent mechanical properties because of the length and isotropy of the fibres. Since GMT production is very expensive, the semi-finished slabs are expensive. The most recent developments allow compounding of the PP and glass fibre during a single production run, which permits direct processing in a single press. Despite the developments in pressing technology the process has some serious disadvantages as compared with injection moulding. The finished components require further processing most cases. Apertures can be made in most pressed components only by subsequently cutting them out. The resulting waste also gives rise to further costs.

For injection-moulding of components made from PP reinforced with long glass fibres the glass fibre granulate is processed by a modified injection unit. Krauss-Maffei have marketed a new machine known as an injection moulding compounding, IMC, as an alternative to granulate processing. With this machine it is possible to manufacture injection-moulded products directly from the starting materials (PP and glass fibre) in a single step. The injection moulding compounding consists of a twin-screw extruder and an injection machine. Melting of the PP and mixing with the glass fibres take place in the extruder. The melt goes via an intermediate buffer into a so-called shot pot injection unit, and from there it is injected into the mould.

In the following report we shall compare the injection moulding machine and the injection moulding compounding from technical and economic perspectives, i.e. we shall supply key assistance to the processor to decide which process best solves the manufacturing problem.

2. BEHAVIOUR OF FIBRE-REINFORCED THERMOPLASTICS

Good fibre/matrix adhesion is crucial to the mechanical properties of the moulded component. Thermoplastics reinforced with glass mats possess higher strength and impact resistance than materials processed directly or with long fibres (Figure 1).

The intertwined weave structure has advantages because of the physical entanglement of the fibres and fibre segments and because of the very good distribution, but when compared with injection-moulded materials, starting directly with long fibre granulate, these advantages are reduced during pressing in the case of longer flow paths. Using the better possibilities of fibre orientation in the component provided by injection moulding the
disadvantage of physical entanglement can be compensated partly by load-dependent design.

Defects in the fibre structure allow conclusions to be drawn regarding the process in question. We have to differentiate between fibre breaking, debonding and fibre pull-out.

In order to make best use of the strength of the fibres their length should be greater than what is known as the critical fibre length \( L_c \). In the literature the value of \( L_c \) is given as between 1.3 and 3.1 mm for composites of PP and glass fibre/matrix. With special auxiliary adhesion agents values of 0.9 mm can be achieved.

We can judge the strength of adhesion between the fibre and the matrix from the relation of the actual fibre length to the critical value. If the actual fibre length of the component is greater than the critical value, i.e. greater than \( L_c \), we can expect fibre breaking. If the fibres are shorter than the critical fibre length, then the danger arises of fibre pull-out (the region below the critical value). Below this we expect mainly separation between the fibre and the matrix in the boundary, as can frequently happen with short-fibre compounds with fibres from 0.2 to 0.6 mm.

The length of the reinforcing fibres remaining in the component is in fact not a relevant unit with regard to the construction. Much more important in the design of the mouldings are the mechanical factors such as the strength, rigidity and impact strength. Of course these are dependent on the fibre length, but the relationship is extremely complex. Simple measurement of the fibre length is therefore suitable only between certain limits but can be useful for indications of the tendencies. Fig. 1 shows the relationship between change in rigidity, strength and impact resistance vs fibre length.

3. FIBRE LENGTH IN THE PRODUCT

During processing of long fibre-reinforced PP the long fibres should be incorporated in the moulded component as far as is possible, since this gives the best mechanical properties. In pre-processing and injection moulding, however, breaking and hence shortening of the fibres is inevitable under the mechanical effect. The fibres are damaged most seriously when the fibre-containing melt is poured into the mould (Figure 2). Fibre shortening can be reduced by the correct choice of mould. The melting process also has a considerable effect on the fibre length. Significant differences are found in this respect between the injection moulding machine and the injection moulding compounding.

With an injection moulding machine the initial fibre length is limited in account of the length of the granulate (basically from 10 to 25 mm). Manufacturers of granulates reinforced with long glass fibres offer coated and pultruded systems (Figure 3). In the case of pultrusion the fibres are first of all meshed with the matrix in a melt bath, than bound together to form bundles. The advantage of this is that the individual fibres are uniformly impregnated with the matrix material. In the case of the coated granulate the fibres are coextruded together with the matrix material. Here during
the process of melting that occurs in the injection moulding machine, firstly the fibre bundles separate, then following this the fibres are coated with the matrix material.

The fibres are damaged less during melt formation in the injection moulding machine if the flow resistance is lower. Flow channels with larger cross-sections have a gentler effect on the fibre. During processing of long glass fibre granulates, therefore, the screw geometry and backflow inhibitors must be suitably modified.

During processing of the granulate pass through the injection moulding machine in the complete melting process. The period during which the fibres are under a mechanical load is therefore fairly long. Apart from this the fibres achieve a relatively high reinforcing effect at the beginning of the plasticising process, since the matrix material is still not fully melted. Some of the fibres get stuck and hence are subjected to high shear forces.

In addition to this the fibre crumbling occurring in the screw is affected by the screw size and stroke available (feed distance). Comparison of Figures 2 and 4 shows that the larger screw (D = 165 mm) grinds the fibres much smaller than the smaller screw (D = 90 mm).

Figure 4 shows the negative effect of a longer feed distance (S/D = 1.5 and 2.5) on the residual fibre length. The dispersion areas have an effect on the structure of the long-fibre granulate (pultruded or coating).

In the injection moulding compounding, by contrast, the pure matrix material is melted without the fibres. The fibres are only added later to the melt, and so are subjected to much less mechanical force. (Figure 5).

This technique is gentler on the fibres than the melting process that takes place in the injection moulding machine, and results in a longer average fibre length. The injection moulding compounding offers the possibility of introducing a continuous roving into the melt rather than a chopped glass fibre. The fibre rovings are also broken into smaller pieces as a result of the screw movement. But the average fibre length is still fairly high (Figure 3).

4. ECONOMIC CONSIDERATIONS

An important economic factor in the manufacture of fibre-reinforced polypropylene is the cost of the initial materials. The long glass fibre granulates are cheaper than the semi-finished GMT products, but the processor still has to pay more for the granulates than when purchasing the components separately, namely the non-reinforced polypropylene and glass fibre. It is here that the injection moulding compounding shows a major advantage: the starting materials are cheaper for the processor than the long fibre granulate, and the cost of the materials is reduced as part of the total production cost of the component.

An advantage when processing from the long glass fibre reinforced PP granulate as compared with the use of the injection moulding compounding is that the investment costs are lower. It is sometimes possible to alter or modify the plasticising unit of an existing injection moulding machine so that it can process long glass fibre granulate. If it is not possible to modify it in this way and a new machine has to be introduced, the investment cost for the injection moulding process is lower. The installation of an injection moulding compounding is made considerably more expensive by the incorporation of a twin-screw extruder.

Thus, in addition to the advantages mentioned above in the fibre length distribution of the product, the injection moulding compounding also offers the possibility of a saving in base materials, which the manufacturer can only achieve however by higher investment costs. Therefore important criteria when choosing between the injection moulding machine and the injection moulding compounding are the bulk and quantity of the product being made. With high bulk products the installation of an injection moulding compounding is more advantageous, since an economy can be achieved when purchasing the starting materials which rapidly overtakes the high investment cost so that the investment is recovered over a short period. With
lower bulk products or smaller runs, on the other hand, processing long glass fibre granulates in an injection moulding machine offers a better alternative on account of the lower investment costs.

The injection moulding compounder offers the manufacturer greater flexibility, so that he can tailor his material consumption to his own particular requirements. The consumer can consciously influence the system consisting of a matrix, fibres and other materials, e.g. he can adjust the fibre content in the product to meet technical requirements. This is possible only under certain conditions when processing granulates, since the manufacturers supply granulates with a given fibre ratio. Using the classical injection moulding technique the fibre content can only be modified by mixing the long glass fibre granulate with non-reinforced polypropylene, a process that has to be carried out by machine and a material conveyor system.

The degree of freedom which the injection moulding compounder gives to the processor in material selection allows does however increase risks with the product and his product liability. Quality assurance and those guarantees which up to now the granulate manufacturers took upon themselves in connection with composition must now be borne by the processor. It is here where the chances reside, however, with regard to future prospects: the IMC process will powerfully increase the processor’s value formation, and hence his own added value.

5. CONCLUSIONS

Products made from polypropylene reinforced with long glass fibres can be manufactured using an injection moulding compounder or a modified injection moulding machine. Which process is more economic can only be judged by consideration of other boundary conditions. The advantages of the injection moulding compounder – savings in material costs, preservation of the fibre and the long fibre dimensions – are primarily effective for processing large amounts of material and in cases where the products have to meet high mechanical requirements. In the case of smaller products and smaller amounts of material a better option for the plastics processor on account of the lower investment costs may be to process long glass fibre granulates in a conventional injection moulding machine.

(No date given)