Thermoplastic Foam Injection Molding with Post-Consumer Recyclate

Saving CO_2 Twice Over

Foam injection molding already saves material. But what about using post-consumer recyclate instead of virgin material to reduce the carbon footprint even further? KraussMaffei, together with the University of Schmalkalden, Germany, has investigated this question particularly with respect to what it means for the mechanical part properties.

Double benefit: Reducing part weight and processing recyclate by the MuCell process. Source: KraussMaffei; collage: © Hanser

The carbon footprint should be low – almost every customer makes this demand on his plastics processor. Consequently certain process technologies for lightweight design processes are coming under the spotlight again, for example thermoplastic foam injection molding (TFIM), in particular the MuCell process (licensor: Trexel). Investigations by KraussMaffei and the University of Schmalkalden now show the positive effects of combining thermoplastic foam injection molding with the use of post-consumer recyclate.

The test set-up was extremely difficult to implement, since the foamed part should weigh 12% less than the non-foamed part, and be made of 100% recycled pellets. The latter comes from treated post-consumer resin (PCR), and is thus significantly more contaminated and less homogeneous in terms of its material characteristics than homogeneous recyclates from post-industrial resin (PIR). The key question that was researched at KraussMaffei as part of a master thesis at the University of Schmalkalden was how do the mechanical properties of parts change when the TFIM process is performed using such a recyclate? Both of these factors often have a negative effect on the mechanical properties.

In the case of the MuCell process, this is already obvious by virtue of the basic technology: here, a physical blowing agent (often nitrogen) is added to the thermoplastic melt, resulting in a part structure with a solid outer layer and a foamed core layer. Consequently, different mechanical characteristics will be established compared to non-foamed injection molded plastic parts. In other respects, however, the process offers technical advantages, since the low viscosity of the gas-charged melt improves the filling behavior; sink marks and warpage are reduced by the gas pressure in the cavity, and lower clamping forces and shorter cycle times often result as welcome side effects.

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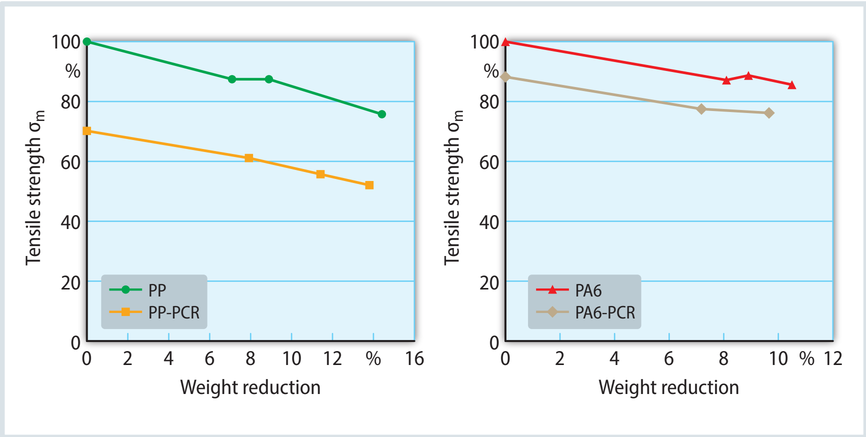

Fig. 1. Tensile strengths for PP-GF and PA6-GF, comparing virgin material with recyclate in each case. The values of all the studies are shown as percentages (virgin material, non-foamed = 100 %).

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Are the Negative Influences Cumulative?

Recycled material from post-consumer waste, in turn, has often undergone a stressful compounding process, in which it was melted in the extruder; these shear forces and thermal stressing always affect the plastic. For such recycled material to be used in the MuCell process, it was therefore necessary to clarify whether the two effects are cumulative as feared. In addition, the electrical properties of the parts should be analyzed in cooperation with an industrial partner.

Lightweight construction processes, such as TFIM and the use of recyclates, particularly from post-consumer waste, are gaining in importance for almost all industries. The combination of the two can save twice as much CO_2: The foaming reduces the part weights, and the raw material used additionally has a lower carbon footprint. There were fascinating questions as to whether the PCR material would have an effect on the foam structure, how much the carbon footprint would be improved and how the overall economy would be influenced.

The test specimens were classical standardized tensile rods and square disks for the electrical tests. As defined by the industrial partner, the materials

- PP and PCR-PP, as well as
- PA6 and PCR-PA6,

were used, each reinforced with 30 % glass fibers. The PP recyclate consisted of about 68 % PCR. An even higher quota, 100 %, was shown by the recycled PA6. The PA6 recyclate was a relatively new material type, which was not yet available in large quantities at the time of the work, and a mold with a smaller shot weight than for PP was therefore used for the production of the PA test specimens.

This resulted in tensile rods produced by non-foamed injection molding and – as a result of the gradually increased addition of nitrogen – with weight reductions of about 8, 10 and, in the case of PP, even 12 % (the actual values deviate somewhat from those sought). Since, in practice, setters often add somewhat more blowing agent than necessary to the melt, further tensile rods were additionally produced with a degree of foaming of 12 % with 50 % excess gas to determine whether the higher amount of gas influences the strength.

Determination of Tensile Strength

With test specimens that were freshly molded or conditioned according to the standard, it was then possible to perform the tests, and there were already interesting findings with the first series of measurements. Although – as expected according to information from the manufacturer – it was found, in the case of PP, that the non-foamed parts of recycled material only had 70 % of the tensile strength according to the standard for articles from virgin material, the gap hardly increased when PP and PCR-PP were additionally foamed. The loss of tensile strength as a result of foaming was linear and almost parallel over the reduction steps 8, 10 and 12 %, which were sought according to the experimental plan (**Fig. 1**). In the case of the modulus of elasticity, a similar picture emerged: PP recyclate started at about 85 % of virgin material and, like virgin PP, declined almost linearly with increasing degree of foaming.

While, in the case of polypropylene, the virgin material and the chosen PCR differ significantly from one another as regards the tensile strength, the difference for polyamide is significantly smaller. The analyzed glass fiber-reinforced polyamide recyclate pellets reached 88 % of the virgin value. However, these grades are often used, for example, in automotive applications, where high mechanical properties of a part are essential. 12 % less strength can be crucial here. It was all the more »

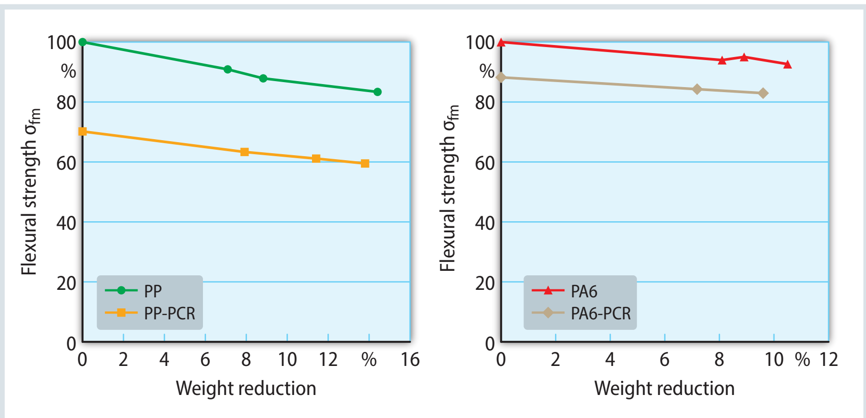

Fig. 2. Flexural strengths for PP-GF and PA6-G, comparing virgin material with recyclate in each case. The values of all the studies are shown as percentages (virgin material, non-foamed = 100 %).

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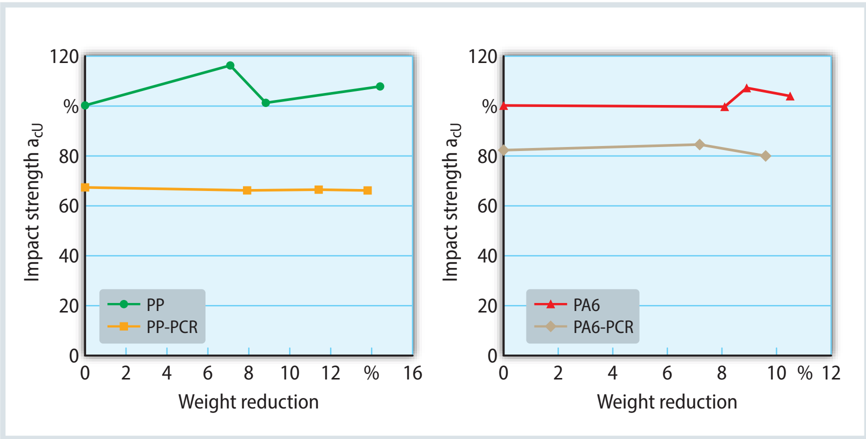

Fig. 3. Impact strengths for PP-GF and PA6-GF, comparing virgin material with recyclate in each case. The values of all the studies are shown as percentages (virgin material, non-foamed = 100 %).

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important to ask what would happen if foaming is performed as well. As with PP, the additional waste was approximately linear via the MuCell reduction steps (**Fig. 1**).

The tensile strength tests led to similar findings to those for the flexural strength (**Fig. 2**). According to the standard, PCR-PP started at about 70 % of virgin material and fell linearly over the reduction steps. It was found that foamed virgin material loses more flexural strength than the recycled material.

Determination of Flexural Strength and Impact Strength

The investigated PA6 recyclate had 11 % less flexural strength than PA6 virgin material, which (as with the tensile strength) was reduced linearly but less significantly by the reduction steps. The modulus of elasticity of the two material types was at a similar level and remained relatively constant even during foaming without showing a significant reduction.

The difference between virgin material and recycled material in the Charpy impact strength according to the standard had the most significant effect – the factor of foaming had virtually no effect here (**Fig. 3**). It was tested on non-notched parts sawn from tensile rods, with the chosen PP recyclate having about 65 % of the impact strength of the non-recycled polymer and being hardly any less foamed. Recycled PA was 82 % of the tested virgin material. The reason for the finding that the TFIM had hardly any effect here is probably that the non-foamed outer layer of the samples had a greater influence than expected, even because of the absence of a notch during testing.

All three analyses (tensile properties, flexural properties, impact strength) showed that the MuCell process does not have a greater effect on post-consumer recyclates than virgin material. The original fear that the two factors may be cumulative and the mechanical properties would be exponentially worse has not been confirmed. What also had no effect was the charging of the melt with 50 % more blowing agent. That means that the process window is not restricted in this respect.

Investigation of the Electrical Properties

As explained above, the electrical properties of the test specimens were also investigated – in the form of the comparative tracking index (CTI) and the surface resistance. The comparative tracking index represents the insulation capability of a substance and is high when high voltages occur to generate measurable currents on the surface of the specimen. At PP, both values remained almost constant (600 V and approx. $1.2 \cdot 10^{10}\,\Omega$). There was no apparent difference between virgin and recycled material and non-foamed and foamed parts.

In the case of PA6, no difference in surface resistance between PCR and virgin material, or non-foamed and foamed material, could be demonstrated. On the other hand, there was a difference in the comparative tracking index of the foamed sheets. This fell from about 500 V (for compact) to 375 V for both PCR and virgin material, probably because of pronounced

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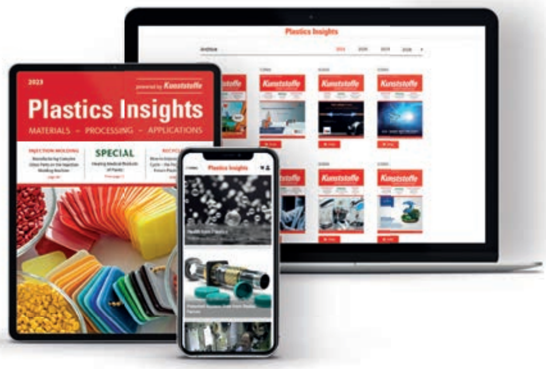

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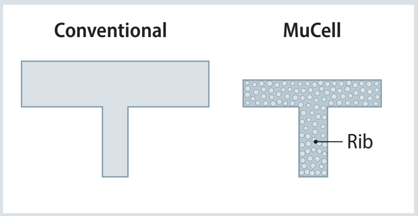

Fig. 4. Foam-compatible part optimization by local structural wall-thickness adjustment.
Source: KraussMaffei/Trexel; graphic: © Hanser

streaks on the surface, which influence the test results.

PIR versus PCR – Specific Advantages and Disadvantages

Anyone using recycled goods generally prefers recyclate from post-industrial resin (PIR), i.e. material that, for example, occur as sprues or reject parts in the factory and is added, often directly, proportionately in the processing shop, and thereby reclaimed. This material is homogeneous and less contaminated. However, it is therefore usually not available on the market in the required volumes. Higher recyclate proportions and therefore better CO_2 balances can thus only result from the post-consumer area.

In the Yellow Bag (a German collection system for recycling) , a large number of different plastics are collected, including food or pigment residues, labels – and odors. Despite complicated compounding, tiny foreign particles sometimes remain in the recyclate melt – in the case of the MuCell process, they can even be helpful. Occasionally, fillers are used as nucleation agents in TFIM to achieve a finer foam structure. The working hypothesis was therefore that the distribution of the gas bubbles in the recyclates of PP and PA6 would be more uniform and more fine-pored. In fact, this effect can be seen subjectively with enlarged sectional views.

The physical properties of plastic parts form the technical basis of a decision for or against recyclates – but the balance is tipped by the carbon footprint and the price. To define how much carbon dioxide can be saved by using the recyclate types, KraussMaffei makes use of the manufacturer's information relating to production, compounding and treatment. The outlays for logistics, which should be almost the same irrespective of the pellet type, are not taken into account. According to this, PP is 2.1 kg CO_2-eq/kg, but the compared PCR-PP is only 1.2 kg CO_2-eq/kg. In the case of PA6, the ratio is similar: 5.1 to 3.85 kg CO_2-eq/kg according to the manufacturer. In terms of magnitude, the differences in injection molding are hardly significant.

The Question Remains: When Is It Worth Changing Over?

Based on these CO_2-advantages of recyclate, the combination with the TFIM opens up further possible savings. The part weight is reduced by foaming, and the clamping force requirement is often reduced, so that less energy is consumed. This is particularly successful in conjunction with foam-compatible part optimization (**Fig. 4**), which, particularly for PCR, makes use of the potential for achieving higher strength by locally adjusting the wall thickness. This only reinforces the article areas in which mechanical strength is required, and reduces all the others in volume as far as possible. In this way, the maximum saving potential can be achieved. In non-foamed injection molding, on the other hand, flow paths often have to be made unnecessarily thick to produce the part at all.

The price for plastics is always volatile, which has made recycling efforts difficult for many years. If – as at the time of the investigation – recycled PP is more expensive than virgin PP, there is no economic incentive to switch over. With PA6 recyclate, it was at least a little worthwhile. It was about 11 % less expensive.

Summary

What is the conclusion for the combination of the MuCell process and post-consumer recyclate? As always, the application is crucial. Because PCR usually has worse mechanical properties, the most important criterion for the particular project is the customer's strength specifications. The studies carried out by KraussMaffei can now be used to precisely compare the behavior of virgin and recycled material via the weight reduction steps.

A balance then has to be struck by weighing up all the relevant factors. For example, it can be decided to use foamed recompounds, but to change the dimensions of the part appropriate to foaming in order to obtain higher strength values. Or to foam virgin material and only use recyclates for non-foamed parts. With these analyses, KraussMaffei can competently advise interested parties on which route would be most appropriate.

Overall, there are therefore possibilities for selectively and appropriately using recyclates in physical foam injection molding in order to double the carbon footprint of parts. ■

Info

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KraussMaffei at Fakuma

In keeping with this topic, KraussMaffei is presenting a MuCell application at this year's Fakuma. The all-electric PX 321 injection molding machine is fitted with the new HPS-physical foaming screw for MuCell applications.
Hall A7, booth 7303

References

The new MuCell screw is universally applicable and ensures a 30 % higher plasticizing rate (see also ***Kunststoffe international*** 5/2023**,** p. 48–51).
plasticsinsights.com/a/article-4930718

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