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THERMOPLASTIC FOAM INJECTION MOULDING OF ULTRALIGHT STRUCTURAL COMPONENTS WITH HIGHLY REINFORCED EDGE LAYER

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Abstract

The trend toward lightweight construction continues unabated across all industries. Due to their low density, plastics play an important role here and are increasingly replacing metals. Possibilities for implementing a lightweight construction strategy range from the use of continuous fibre-reinforced thermosets to short fibre-reinforced thermoplastic components. By combining thermoplastic foam moulding (TFM) and back injection of continuous fibre-reinforced tapes, such lightweight structural components can be realized economically in high volumes.

Introduction

Structural lightweight design with plastics will continue to gain in importance as weight is to be saved in many industries, but especially in all areas of transportation. Lighter vehicles not only consume less fuel, but they also emit less CO_2. Plastic components in themselves already bring considerable weight reductions. The use of foamed components can make an additional contribution here. Of course, the weight savings also mean lower consumption of raw materials.

The aim is to produce integral skin foams from thermoplastics which, thanks to their sandwich-like structure, offer very high lightweight potential combined with very high flexural rigidity. Integral foams are foam structures with a compact outer skin and a porous core. In this process, the density decreases continuously toward the centre of the component. An important process to produce so-called integral skin foams is thermoplastic foam moulding (TFM). The foam structure can be achieved by chemical and physical blowing agents. A combination of the two process variants is also possible, whereby particularly high weight reductions can be achieved. The advantages of these injection moulded components are their low density combined with good mechanical properties, the functional and process integration possibilities, and the design freedom they offer.

Preliminary study

In a preliminary study, the influences of process parameters and foaming technologies (chemical, physical) on the weight and flexural modulus were investigated on a Wittmann-Battenfeld Smartpower 60/130 using a simple test component (plate: 150 x 40 x 5 mm^3).

In various experimental test series, integral foams were produced both by physical foaming or by adding chemical blowing agents in the injection moulding process. The respective weight savings, microstructures and flexural elastic moduli were determined and compared. The flexural modulus of elasticity was determined in a 3-point flexural test according to DIN EN ISO 178. Polyamide was selected as a potential material for the planned series component.

As an example, some results for a polyamide Grilon TS from EMS-Grivory are presented below. Test series were run with minimum (V1) and maximum (V2) blowing agent metering and an optimization test series was run (V3) to achieve a finer and more homogeneous foam structure. For this purpose, the injection volume was increased, and a lower weight reduction was accepted.

Fig. 1. Component weight and flexural modulus as a function of the blowing agent used (see below)

Fig. 1 shows the weight and bending modulus for the test settings compared to the compact component. As expected, the flexural modulus decreases with increasing weight savings. Thus, at the maximum weight savings of 43 % the flexural modulus reaches only 69 % of the compact part. Based on the specific bending modulus of V2 and V3, it can be seen that the specific bending modulus does not increase identically to the weight reduction. It would therefore be interesting to investigate the flexural modulus even more closely at smaller jumps in weight savings to achieve the highest possible specific flexural modulus.

In a subsequent series of tests, trials were carried out with different melt metering volumes since the weight reduction is directly influenced by the metering volume. Thus, the optimum ratio between weight and bending modulus can be determined. It is important to note that the flexural moduli of the individual test series cannot be compared with each other, as they could not be tested at the same time interval after processing.

Fig. 2: Component weight and flexural modulus as a function of dosing volume for an endothermic chemical blowing agent. (see below)

Fig. 2 shows the dependence of the component weight and the flexural modulus on the metered melt volume for an endothermically acting chemical blowing agent. In each case, a pair of bars represents a metered volume. Thus, as the metering volume decreases, the mold is filled less and can thus foam more. For the endothermic blowing agent, the best combination between weight and flexural modulus would be a weight saving of 34 %, i.e. a metering volume of 66%. In subsequent trials with physical blowing agents, greater weight savings were achieved, but with larger cell sizes, which had a negative effect on the flexural modulus. Further trials with nucleating agents will follow here to achieve better foam distribution.

Public founded project with industry

In a partly publicly funded project by Innosuisse, Swiss Innovation Agency, and two industry partners the potential of TFM for various materials and blowing agents (chemical as well as physical) was being investigated. Various process variants are being used to produce integral foams that are as rigid as possible. Process variants that were being investigated in detail include standard TFM with one material (like in the preliminary study), sandwich moulding with two different materials and back-foaming of continuous fibre-reinforced tapes. The back-foaming of continuous fibre-reinforced tapes allows particularly rigid components to be realized and therefore offers a great potential (Fig. 3). Goal of the project was to realize stiff and lightweight parts for different applications.

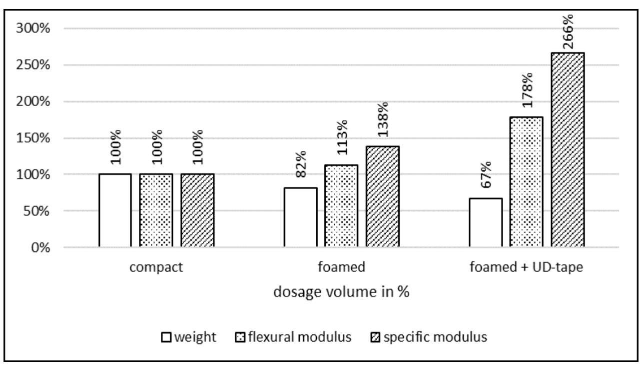

Fig. 3: Achievable weight reductions and flexural moduli with the TFM process (material: PPGF20, blowing agent: Luvobatch)

One possible cause of failure of such sandwich structures is a lack of adhesion between the face sheets and the foamed core, i.e. delamination. To prevent such a failure, the bond adhesion should be optimized as far as possible. The bond strength can be quantitatively determined by peel tests on a tensile testing machine (Fig. 4).

A component specially designed for this test serves as the test specimen. In the injection moulding process, a continuous fibre-reinforced tape is back injection moulded from two sides so that the tape remains exposed in the centre of the component. The exposed tape allows clean peeling.

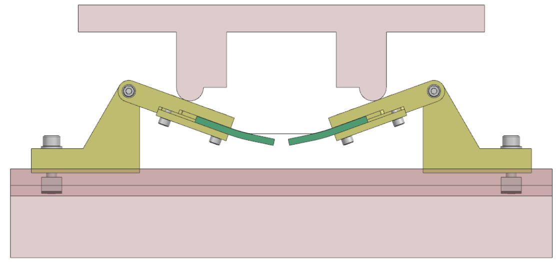

Fig. 4: Device for characterizing composite adhesion

Investigations showed that the following variables have a positive influence on the bond strength:

- A high pre-heating temperature of the tape semi-finished products (> melting temperature of the tape matrix) and a high melt temperature favour the adhesion properties, primarily due to the higher mobility of the molecular chains.

- Due to a low mould temperature, the components exhibit a compact boundary layer. This has a positive effect on the boundary layer and the bond adhesion.

- For low-filled materials, a low injection speed is recommended. For highly filled materials, the injection speed has no significant influence.

Application surf fin

One potential application of the back foaming of continuous fibre-reinforced tapes is the surf fin, which is currently being produced by KWB, Buchs, Switzerland. It is the first high-end surf fin produced by injection moulding and meets all technical requirements.

In surfing, the characteristics of the fin are of immense importance; its behaviour in the water influences the overall handling of the surfboard. The most important characteristic value is the so-called flex (bending stiffness) of the surfing fin. Also very important is the total weight of the surfboard and therefore of the individual components. For professional surf boards in general three surf fins are normally attached to the board. To meet these two requirements for a surf fin, conventional surf fins are produced using infusion or RTM processes with thermoset resin systems, among other things, but this is correspondingly costly and time-consuming.

By integrating unidirectional thermoplastic carbon tapes into the injection moulding process, similar properties can be achieved with a much more efficient manufacturing process. The carbon tapes are inserted into the injection mould and back-injected. Under a bending load, the tapes on the outer sides form a compression and tension band (sandwich component). The properties can be fine-tuned by aligning the fibres and the cut-out geometry (Fig. 5). Thanks to the lower density of the plastic core, the weight of the fin remains low.

Fig. 5: Different types of surf fins and three-pack as sold

For measuring the local fin's stiffness it is fixed on one side and a force of 75 N is pushed on 5 definite points. The deflection is measured at each point (Fig. 6).

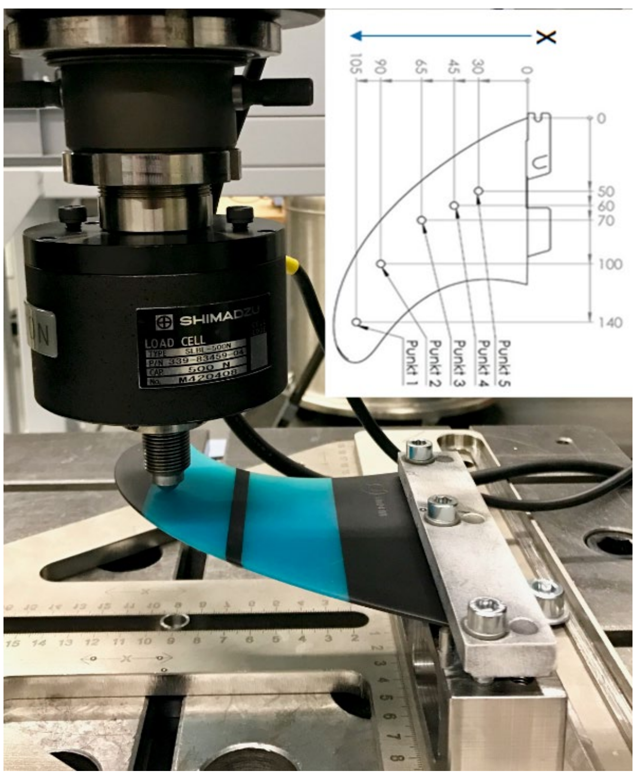

Fig. 6: Set-up for local stiffness measurement

The next optimization step is to further reduce the weight of the fin. This can be achieved by minimizing the density of the core component. There are two ways of doing this while keeping the geometry the same: Either a material change to a material with a lower density is carried out - however, this material must ensure the same connection (adhesion) to the tapes as the previous material, or, as a second option is to foam the current material (TSM). This allows the amount of material and thus the weight to be reduced without changing the structural mechanics of the surf fin. The tension and compression bands remain in place, thus generating the excellent properties of the surf fin. First trials with Polyamide (not allowed to tell details) leads to a weight reduction of app. 10 %. These foamed surf fins also show comparable results concerning the local stiffness to the current compact one (Fig. 7).

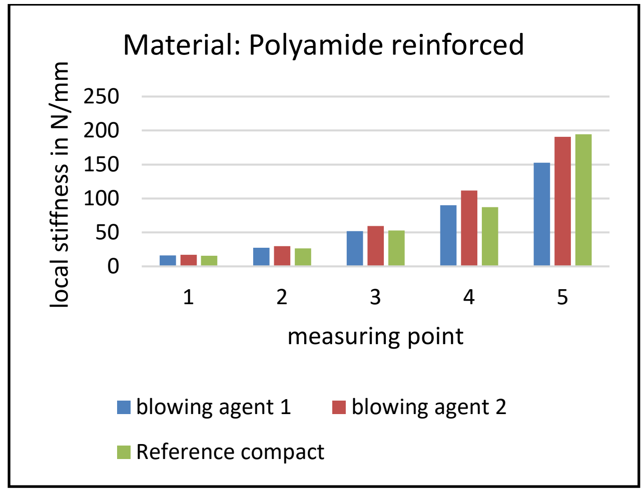

Fig. 7: Local stiffness of compact and foamed surf fins

Conclusions

The thermoplastic foam injection moulding of structural components with highly reinforced edge layers offers great potential for lightweight components with very good mechanical properties. The application oriented design of such parts need know-how in structural analysis and thermoplastic foam processing. Particular attention must be paid to the adhesion of the structural layer to the core material. A special test equipment was developed for characterizing the bonding.

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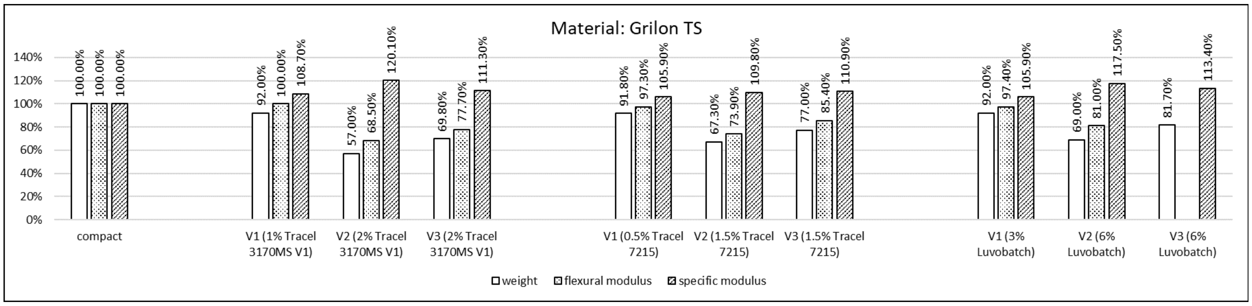

Fig. 1. Component weight and flexural modulus as a function of the blowing agent used

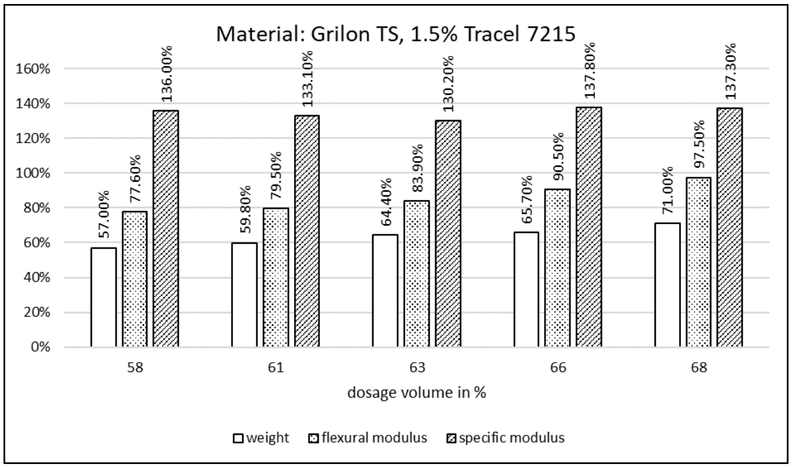

Fig. 2 shows the influence of dosage volume