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PROCESS EFFECTS ON THE PROPERTIES OF A SANDWICH PART MANUFACTURED BY PARTICLE FOAM INJECTION MOLDING

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1. INTRODUCTION

Particle foams are shaped parts made from thermoplastic foam beads. Particle foams are characterized by very low densities in the range from 15 to 80 kg/m^3 [1] as well as good dynamic properties, static shock resistance and an acoustic and heat-insulating effect [2,3]. With a tensile strength of up to 500 kPa, the tensile strength is far below that of solid plastics [4]. Basically the foaming of polyolefins (PP, PE) and polystyrene (PS) is based on the expansion process of foam particles. The foamed particles are further processed in a molding process. They are passed through with superheated steam and thus interact with each other resulting in a sintered particle foam part [5]. Injection molding is the preferred method for processing thermoplastics to molded parts. The injection molding process is characterized by a high degree of integratability of process sequence steps, whereby a wide variety of process combinations are possible. In this regard, particle foam composite injection molding (PVSG) was developed by Ruch Novaplast GmbH + Co. KG together with Arburg GmbH + Co KG and the Krallmann Group Kunststoffverarbeitung GmbH [6]. In this process, a substance-to-substance bond is formed between a particle foam inlay and a plastic component. For this purpose, the pre-foamed inlay is inserted into the injection molding machine. Due to the temperature of the melt, the surface of the particle foam is permanently bonded to the solid material during a subsequent injection molding step [7]. The combination of two plastic components with different properties creates a composite component that achieves high stiffness combined with low weight per unit volume [2].

In principle, the production of sandwich components using this process is also conceivable. However, some research questions have to be solved: The foam insert has to be fixed in the mold. The injection pressure used in injection molding must not cause the foam to collapse. The bond between the particle foam and the surface layers must be able to transfer loads under bending, for example. In this contribution, the process-impact on the properties of a particle foam injection molded sandwich part is investigated by means of mechanical tests.

2. EXPERIMENTAL

Manufacturing of Foam Inlays and Injection Molding of Sandwich Parts

The mold plates for the foam inserts were produced on an automatic molding machine from Erlenbach GmbH. The expanded polypropylene originated from the company JSP of the material types Arpro 1133 Dragonfruit and Arpro 5195, with bulk densities of 35 kg/m³ and 90 kg/m³. The slabs have a size of 500 × 500 × 50 mm³. After the plates were ejected from the molding machines, they were tempered at 80 °C for 4 hours. The slabs with a bulk density of 35 kg/m³ had a molded part density of 50 kg/m³. In the foam plates with a bulk density of 90 kg/m³, the mold was slightly overfilled during the filling process of the molded part, thus achieving a molding density of 100 kg/m³. The boards were then cut to the required insert size of 200×60×20 mm³ using a band saw.

In order to reduce the pressure in the cavity and hence preventing the foam from collapsing during injection molding, a groove with 2 mm in depth was subsequently inserted into the foam insert over the sprue width. With the help of this flow aid, the inlay of both high and low density was overflowed and the cavity was completely filled. The schematic geometry of the mold cavity including the gating is shown in Fig. 1. Polypropylene with an MFI 120 was chosen as the matrix material. Table 1 shows the respective process parameters for the different inlay foam densities.

Table 1: Process parameters for the particle foam injection molding.

Foam density	Mass temperature	Injection speed
50 kg/m³	180 °C and 200 °C	10 and 20 cm³/s
100 kg/m³	180 °C and 200 °C	10 and 30 cm³/s

The second stage of the injection speed corresponded to the maximum achievable speed, depending on foam density, without the insert being overmolded. For the foam density of 50 kg/m³ a speed of 20 cm³/s was chosen, for the foam density of 100 kg/m³ a speed of 30 cm³/s was chosen.

Mechanical and Microstructure Characterization

The samples were stored under standard climatic conditions for at least 48 hours prior to testing. In both cases the sample as a whole was tested. The sample dimensions are presented in Fig. 1.

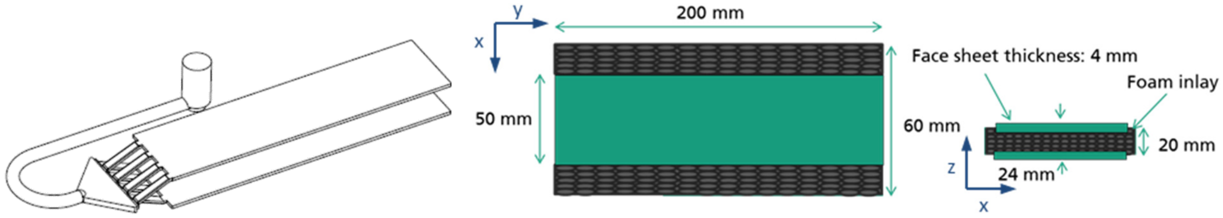


Fig. 1: Schematic drawing of the mold cavity (left), final specimen geometry (right).

The characterization of the interlaminar strength in the DCB test was carried out in the x-y-plane (c.f. Fig.1) of the sandwiches on the basis of ASTM D5528 which is a standardized testing procedure for composites. The load was applied in z direction. The procedure can also be used for sandwich structures [8] and was carried out on a universal testing machine with a constant crosshead velocity of 2 mm/min. The foam inserts were prepared prior to the injection molding process for the DCB test. At the end of the flow path, a 10 mm wide strip of polyimide adhesive tape covered the entire width of the inserts. Thus, it was ensured that a crack occurring during the test was introduced into the interface in a targeted manner. To clamp and test the specimen, two aluminum lids were glued on the PP surface using a two-component epoxy resin adhesive. The adhesive was cured according to the data sheet at 65 °C for 60 min.

Due to the specimen dimensions, three-point bending test could only be carried out in accordance with DIN EN ISO 178 at a constant test speed of 10 mm/min. The load was applied in z direction. The support diameters were 10 mm and the lower support distance 140 mm. The test was aborted when a failure of the surface layer or core occurred or when the travel of the testing machine had reached its maximum.

In order to analyze potential air inclusions in the samples, the distribution was investigated at a total of five points per sample. The sample was cut using a band saw. The surface layers of the samples were then sanded with 220 grit sandpaper and subsequently a 800 grit. The occurrence and the percentage volume distribution of the air inclusions were determined according to the line intersection method.

3. RESULTS

Mechanical Characterization

Due to the different sample height of the two foam densities and the associated change in the moment of inertia of the area the results of the 3-point bending test can only be compared qualitatively with each other. For each parameter combination, an example of a bending test specimen was selected that represents the average course of each parameter combination. Fig. 2 shows the bending curves of the two foam densities of 50 and 100 kg/m³.

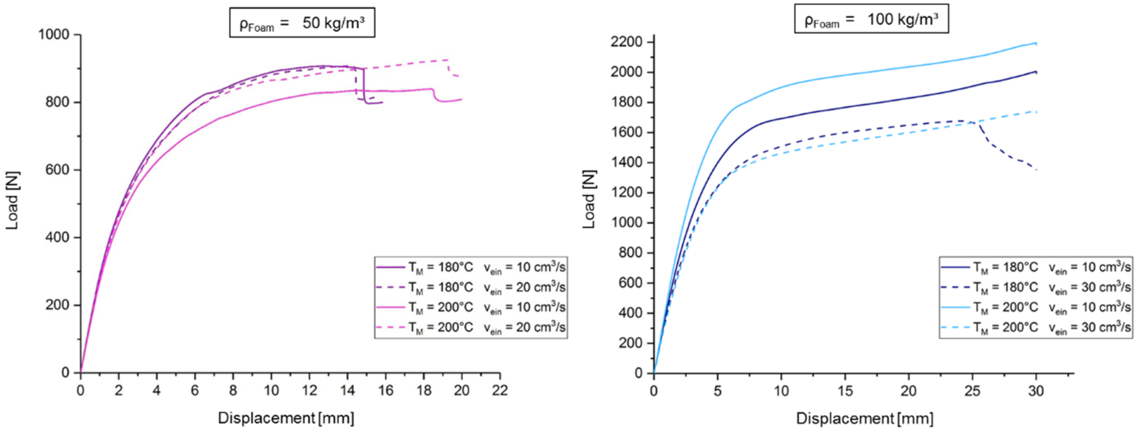
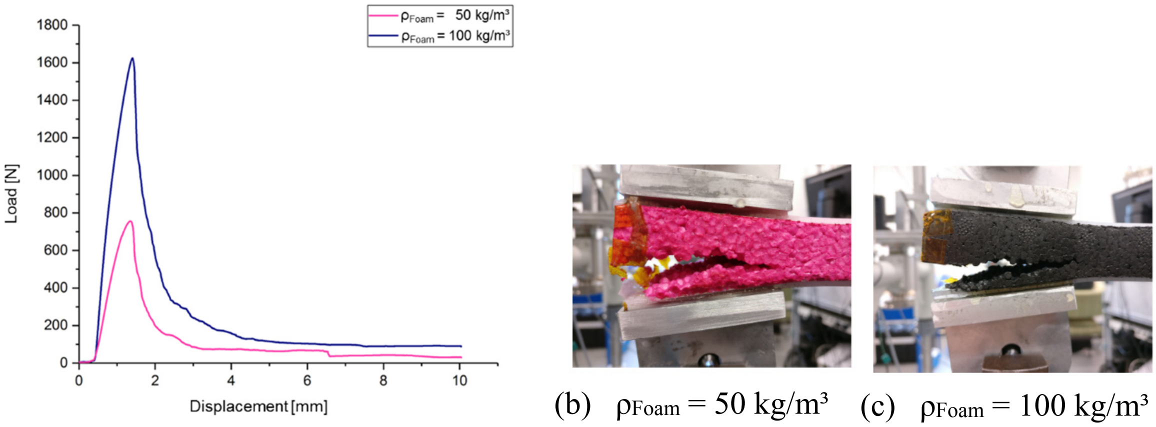


Fig. 2: Results from the 3-point bending tests for both foam inlay densities at different injection speeds (v_{ein}).

Comparing the curves of low density with each other, a similar curve can be observed for all of them. With a deflection of approx. 7 mm a short time force plateau is visible, followed by a further increase in force. All configurations suffer from surface layer failure. It should also be noted that the composites of low melt temperature (180 °C) have potentially a higher maximum force than those of the higher temperature. However, the tests with sandwiches manufactured at 200 °C reveal a higher deflection. Additionally, for the foam featuring the higher density, an impact of injection speed (v_{ein}) is visible.

The DCB test was used to investigate the interface between foam and injection molding material. Fig. 3 shows an example of the curves for the test results. In all samples, the crack has spread directly into the foam core after insertion of the defect. The force-displacement curves for the individual foam densities therefore characterize the strength of the particle foam. As a result, the interfacial strength is higher than that of the foam core.



(a) (b) $\rho_{Foam} = 50\ kg/m^3$ (c) $\rho_{Foam} = 100\ kg/m^3$

Fig. 3: Results from DCB tests (a) including the crack propagation observations (b,c).

Microstructure Characterization

Fig. 4 shows representative cross-sections for sandwiches with different foam densities at otherwise comparable process parameters. It can be seen that the low foam density results in a much higher share of air bubbles within the interlayer between foam inlay and face sheet. This suggests that, due to the higher compressibility of the foam, it is possible to increase the capacity of the foam to expand the escaping air from the molten particles. This allows the formation of larger air inclusions

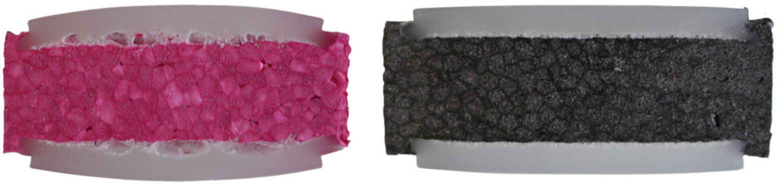


Fig. 4: Cross-sections (x-z-plane) for particle foamed injection molded sandwiches ($T = 180$ °C, $v = 10\ cm^3/s$) for the different inlay densities 50 kg/m^3 (left) and 100 kg/m^3 (right), dimensions c.f. Fig. 1.

4. SUMMARY

The production of a sandwich component by combining a particle foam as core material and an injection-molded top layer has shown to be feasible using a specially design injection molding tool. The bending properties of the particle foam can be significantly enhanced by the bonded compact surface layers. The connection between the foam insert and the top layer is not a weak point, but a low foam density leads to the formation of entrapped air bubbles at the interface between the inlay and top layer.

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