Influence of talc in polypropylene foam cores of sandwich structures with skins made of thermoplastic prepregs

N Loypetch1,*, J Tröltzsch2, D Nestler1 and L Kroll1
1 Institute of Lightweight Structures, Technische Universität Chemnitz, Chemnitz, Germany
2 Karl Mayer Technische Textilien GmbH, Chemnitz, Germany
* e-mail: nalin.loypetch@mb.tu-chemnitz.de

Abstract. Properties of sandwich structures with a core of thermoplastic foam depends on cell size and cell density (cell number). Nucleating agents have a benefit to generate cell nucleation, which affects an increase in the cell density. In this study, sandwich structures composed of a polypropylene (PP) foam core and organic sheet skins in-situ produced by injection moulding process. A chemical blowing agent was employed to generate cellular structure in the core. The influence of the varying nucleating agent content with the same chemical blowing agent content on density, cellular structure and mechanical properties of the sandwich structures were investigated. The talc contents had a slight influence on the density of the sandwich structures. Moreover, flexural modulus and flexural strength of the sandwich structures consisting of the foam core with 4 wt% of talc were higher than the foam core without talc. However, the utilization of these talc contents with PP and the chemical blowing agent had no significant effect on the reduction of the cell size and the increase of the cell density.

1. Introduction and motivation
Sandwich structures consist of a light core material locating between two highly-stiff skin layers [1]. It is a composite material which has been commonly used in many applications such as automobile, aerospace and building [2]. One of the advantages of the sandwich structures is the combination of different materials of which dominant properties are different. Consequently, this combination can lead to desire properties. Sandwich structures components can be made of various kinds of material such as polymer and metal. In addition, they can be produced in form of a hybrid material which is composed of different kinds of material [1]. The structure of core materials can be found in many forms such as honeycombs and foam structures [2]. In case of the skin layers, they can be made of metal alloys or fibre composites [2].

Thermoplastic is one of the materials used for sandwich structure manufacturing due to high recyclability [4,5]. Moreover, the use of same kind of thermoplastic for the skin layers and the core material can achieve the skin and core adhesion without the use of adhesive layer between these two layers studied by Mechraoui et al. [6], Menrath et al. [7] and Tröltzsch et al. [8]. In these three studies, PP was used as the core material and the matrix of the composite skin layers.

Thermoplastic foams can be produced using a blowing agent to generate cell structures in injection mould parts. Due to the generation of the cell structures, the material content can be reduced, which leads to the reduction of material cost. The blowing agent can be divided into chemical blowing agent (CBA) and physical blowing agent (PBA) [9,10]. The advantage of CBA over PBA is that it can be...
employed directly with a conventional injection machine. Conversely, the PBA requires the additional equipment as can be found in MuCell® technology [11,12].

Due to the mechanism of CBA, cell nucleation, gas diffusion and cell growth occurs [13], which affects the cell size and cell density in thermoplastic foams. The cell size and cell density have an influence on the mechanical properties of foam structures [14]. The effective mechanical properties of the sandwich structures can be achieved if their core layer consists of the low cell size and the high cell density. Large cells can lead to a defect which can cause the failure of the sandwich structure’s core.

The generating of cell nucleation controlling a quantity of cells depends not only on homogeneous nucleation (self-nucleation) but also heterogeneous nucleation which is generated by a nucleating agent [11]. Moreover, the gas diffusion from the polymer matrix into the nucleated cells causes the cell growth. This should be controlled - otherwise, it will affect large cell size or cell coalescence. Talc is one of the widely-used nucleating agents to increase the cell density in the thermoplastic foams either amorphous [15] or semi-crystalline [16].

The effect of talc on the microstructure has been investigated. Talc particles influence the prevention of the cell growth in PP and increase the nucleation site [17]. This cause the increase in cell number and cell density. In the study of Ruiz et al. [18], the microstructure of the foam depends not only on the kind of CBA but also fillers. In comparison between neat PP and PP with 7 wt% talc, the cell density in PP with 7 wt% talc was higher than neat PP, when the CBA was sodium bicarbonate. However, the cell density in both PPs was nearly the same when the CBA was the mixing between citric acid and sodium bicarbonate. The final density of all specimens was approximately 0.6 g/cm³ in every case. The relation between amount of blowing agent and the effect of talc was also studied by Kim et al [19]. They found that talc had a significant effect on the increase of cell density in PP at the N₂ of 0.4 wt%. The influence of adding talc content did not affect the cell size and cell density at some amount of blowing agent. It is, for instance, 5 wt% of talc in the study of Kaewmesri et al. [20]. The addition of talc was effective when the CO₂ was low (about 1-3 wt%). This study also found that at 5 wt% of CO₂ and 0.8 wt% of talc, the desirable properties could be achieved. Wong and Park studied the cell nucleation in polystyrene (PS) by using talc as a nucleation agent [21]. The result suggests that the cell nucleation can be improved by using large talc particle. When the talc content was between 2 to 5 wt%, this effect was reduced. However, even small talc content (0.2–2.4 wt%) led to increase of cell content in PP foams produced by extrusion process [22].

Moreover, talc has also an effect on the mechanical properties of thermoplastic. The increase of talc content affected the improvement of tensile modulus [23–25]. However, it affects also the decrease of ductility, which can be found by the reduction of elongation at break. These have the same result as the talc micro-composite from the study of Wang et al. [26]. However, the results from the study of Palutkiewicz and Postawa were different [27]. PP with talc as well as PP with talc and CBA had a lower tensile strength than compact PP. Moreover, the weight of PP with talc and CBA was the lowest. Talc has also the influence on the increase of flexural strength and flexural modulus, especially when the talc content was 30-50 wt%, good stiffness in PP occurred [28]. The increase of tensile and bending properties of PP was found in the work of Lapečik et al. However, the ductility decreased which can be seen in the reduction of fracture toughness [29].

A pre-impregnated fibre layer in thermoplastic is called prepreg [30]. It is a composite material which consists of many stacking layers. The prepreg can be divided into unidirectional continuous fibre prepreg and bi-directional fabric prepreg. The use of continuous fibre lamination leads to the higher modulus and strength than discontinuous fibre [30]. An organic sheet in form of the thermoplastic prepreg composed of continuous glass fibres and PP matrix can improve bending performance of sandwich structure when it is used for the skin layer. However, the presence of the skin layers affects the limitation of heat transfer. This leads to more time for cell growth, which increases the possibility of cell coalescence.

The influence of talc has been mostly investigated in case of the nucleating agent in thermoplastic foams as well as the filler in compact thermoplastics produced by many processing techniques.
Nevertheless, a study of nucleating effect from talc on foam core morphology of the sandwich structures produced by injection moulding is not widely performed. Therefore, the aim of this study is to investigate the influence the talc content on the density, microstructure and bending properties of the sandwich structures.

2. Experiments and materials

2.1. Materials

2.1.1 Core material. PP (Moplen 501H) used to produce the core material of the sandwich structures was supplied by LyondellBasell. The melt flow rate measured according to ISO 1133 was 2.1 g/10 min. The talc masterbatch was produced by a twin screw co-rotational extruder (Noris Plastic ZSC 25/40D). The masterbatch was composed of 80 wt% of Moplen 501H and 20 wt% of talc (UM-A1) supplied by Universal Mills GmbH. The median and top cut particle size were less than 1.2 and 5.0 µm respectively. Endothermic CBA (Cell.mixa072) supplied by KCD Kunststoffe, Additive und Beratung GmbH was used to generate cell structure in the core material of the sandwich structures. The CBA masterbatch consisted of 17 % of carbonate, which generate CO₂ at decomposition temperature approximately 175 °C.

2.1.2. Skin material. Glass fibre reinforced PP prepregs were used for the skin layers of the sandwich structures. The unidirectional glass fibre reinforced layer was applied in each layer. The components and the fibre orientation in each layer of the prepregs are shown in Figure 1. They were produced by applying OLU-Preg® technology. The density of the prepregs determined according to DIN EN ISO 1183 was approximately 1.53 g/cm³. The fibre volume fraction was approximately 38 %. The thickness of the prepreg was approximately 0.8 mm. Tensile modulus and tensile strength of the prepregs according to DIN EN ISO 527-5 were 15.1 GPa and 299 MPa respectively. The components of the sandwich structures are shown in Figure 2.

| Melt blown S2963 PP (50 g/m²) |
|-------------------------------|
| Roving GF 300 tex 14 µm (200 g/m²) 0° |
| Melt blown Neenah S2817 PP (100 g/m²) |
| Roving GF 300 tex 14 µm (200 g/m²) 90° |
| Melt blown Neenah S2817 PP (100 g/m²) |
| Roving GF 300 tex 14 µm (200 g/m²) 0° |
| Melt blown Neenah S2817 PP (100 g/m²) |
| Roving GF 300 tex 14 µm (200 g/m²) 90° |
| Needle punched PP (75 g/m²) |

Figure 1. Components and fibre orientation in each layer of the unidirectional glass fibre reinforced PP Prepregs.
2.2. Experiments
2.2.1 Production of sandwich structures. Injection foaming with low-pressure moulding technique was applied to produce the core material of the sandwich structures by using conventional injection moulding machine (KraussMaffei, KM-C80-380CX). A bolt-on plasticising unit of which the diameter of injection screw was 40 mm as shown in Figure 2. PP pellets were mixed with the CBA masterbatch of 4 wt% and the talc masterbatch at the content of 5, 10 and 20 wt% respectively so that the mixture with talc content of 1, 2 and 4 wt% can be achieved. The mixture was then introduced into a hopper. The height and width of the mould cavity were 100 and 250 mm respectively. The thickness of the injection-moulded specimens was adjusted at 4 mm. The continuous glass fibre reinforced PP prepregs were used as the skin layers of the sandwich structures. They were pre-heated in a vacuum oven (Heraeus Vacutherm) supplied by Thermo Scientific. The temperature was set at 140 °C for 2 minutes. The prepregs were applied on the mould surface with an adhesive tape as shown in Figure 3. The prepreg which was on the surface of moving-mould had a hole. The molten plastic can be injected pass through this hole into the mould cavity. The cylinder temperatures from the hopper to the nozzle were 50, 140, 160, 180, 195, 200, 205 and 210 °C respectively. The temperature of the hot runner was set between 200 and 210 °C. The injection speed was set at 110 cm³/s. The mould temperature was set at 130 °C. After the molten plastic was injected into the mould cavity, the mould temperature was reduced to 70 °C. The list of the sandwich specimens is shown in Table 1.
Figure 3. Injection mould machine component and position of the prepreg on the mould surface.

Table 1. List of the sandwich specimens.

| Specimen name | CBA (wt%) | Talc (wt%) | Skin layers                                  |
|---------------|-----------|------------|----------------------------------------------|
| SW_F          | 4         | 0          | Continuous glass fibre reinforced PP prepreg |
| SW_F_T-1      | 4         | 1          | Continuous glass fibre reinforced PP prepreg |
| SW_F_T-2      | 4         | 2          | Continuous glass fibre reinforced PP prepreg |
| SW_F_T-4      | 4         | 4          | Continuous glass fibre reinforced PP prepreg |

2.2.2 Microscopy. A specimen per kind of Sandwich structures were polished by a grinding-polishing machine (STRUERS TegraPol-15) and mounted by cold mounting technique. The height and width of the specimens were 10 mm. The microstructure was investigated by a light microscope (Axio Scope.A1) which supplied by Zeiss in panorama mode.

2.2.3 Density measurement. Five specimens of the sandwich structures were prepared for density measurement according to DIN EN ISO 1183. The specimens were weighed in air and in liquid which was alcohol with the density of 0.79 g/cm³, respectively. The experiment was conducted by using a density test equipment and an analytical balance (KERN, ALS 220-4N).
2.2.4 Bending test. Three-point bending of ten sandwich structure specimens was performed according to DIN EN ISO 178. This test was performed by using a compression testing machine (Zwick/Roell Z5.0 TN). The applied preload was 2 N. The testing speed was 2 mm/min. The support span distance was 64 mm. The support span and the anvil had the radius of 5 mm.

3. Results and discussion

3.1. Microscopy
The microstructures of the sandwich structures are shown in Figure 4 (a)-(d). These microstructures suggest that the continuous glass fibre reinforced PP prepreg (the skin layers) and the PP foam core (core material) can achieve good consolidation after the foam injection moulding, which also occurred in the work of Menrath et al. [7] and Tröltzsch et al. [8]. The SW_F had only the skin layers and the foam layers as shown in Figure 4 (a). In contrast, the sandwich structures with talc had the skin layers, compact layers and the foam layer as shown in Figure 4 (b)-(d). The connection of the cell structures in the middle of the sandwich structures occurred. It can be described that the lower temperature reduction rate at the middle area is due to distance to mould wall and the presence of the skin layers. Therefore, the cell structures in the middle area have more time to expand than the area near the mould wall.

Cell density in the foam core material of the sandwich structure with talc tended to increase with the increase of talc content from 1 wt% to 4 wt% as depicted in Figure 4 (b)-(d). However, the cell size in the PP foam core of the sandwich structures was observed without significant difference. The cell density of SW_F_T-1 and SW_F_T-2 was lower than SW_F. Nevertheless, SW_F_T-4 exhibited the cell density as nearly to same amount as SW_F. The reason of the variation in the cell size and the cell density may be described by the relationship between talc and blowing content [20].
Figure 4. Microstructures of the sandwich structures  
(a) foam core without talc (b) foam core with 1 wt% of talc  
(c) foam core with 2 wt% of talc (d) foam core with 4 wt% of talc.

3.2. Density
The result of the density measurement which is presented in Figure 5 reveals that the increase of talc content had slight effect on the reduction of the sandwich structure’s density. SW_F_T-1 and SW_F_T-2 had a higher density than SW_F. In contrast, the density of SW_F_T-4 was lower than SW_F. The reduction of the density, when the core material of the sandwich structures was PP foam with talc, is consistent with the result of the part weight from the study of Palutkiewicz and Postawa [27].
3.3. Bending properties

The bending properties of the sandwich structures were demonstrated in Figure 6-8. Figure 6 indicates that the flexural modulus decreased when the sandwich structures consisted of 1 and 2 wt% of talc. However, the flexural modulus was slightly higher than SW_F when the content of talc was 4 wt%. Figure 7 demonstrates that the flexural strength significantly decreased when the content of talc in the sandwich structure was 1 wt%. Nevertheless, it increased when the talc content was 2 wt%. Moreover, the flexural strength led the higher value than SW_F if the talc content was 4 wt%. The increase of the flexural modulus and flexural strength of SW_F_T-4 was consistent with the study of Kant et al. [28] and Lapcik et al. [29]. In addition, when compared SW_F and SW_F_T-4, the compact layers which occurred in SW_F_T-4 had a positive improvement of the flexural modulus and the flexural strength. The flexural elongation at break presented in Figure 8 had the same tendency to the flexural strength. However, SW_F_T-4 could maintain the flexural elongation at break at nearly the same level as SW_F. This suggests that the presence of 4 wt% of talc in the foam core of the sandwich structures had no adverse effect from brittleness.
4. Conclusions
In this study, the sandwich structures composed of PP foam core, generated using CBA, and continuous glass fibre reinforced PP skin layers in the form of prepreg were investigated the influence of talc on their properties. The result of microscopy suggests that the presence of talc had no significant effect on the cell size and cell density of the cell structures in the core of the sandwich structures. However, talc affected the presence of compact layers in the sandwich structures. This may be caused by the cell growth prevention, which leads to the reduction of cell expansion under the skin layers. The slight reduction of the density of the sandwich structure occurred when the talc content was 4 wt%. In contrast, the density of SW_F_T-1 and SW_F_T-2 was higher than SW_F. In comparison between SW_F and SW_F_T-4, the slight increase of flexural modulus and flexural strength of the sandwich structures could be achieved by applying CBA and 4 wt% of talc in the core of the sandwich structure. Moreover, the flexural strain at break of SW_F_T-4 maintained nearly the same value as SW_F.

The use of the PBA to generate the cell structures is interesting to be conducted as a further study in order to compare the influence of PBA on the cell size and the cell density with that of CBA.

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