Foamed and Still Extruded in One Step

Method for the Simultaneous Extrusion of Window Profiles with a Foam Core

Foamed polystyrene in window profiles and façade elements can improve their thermal insulation and therefore their environmental efficiency. Simultaneous extrusion of polyvinyl chloride profiles with a PS foam core is challenging due to the different processing conditions and has not been performed before. A trial plant for researching this process has now been set up at the SKZ.

The German energy saving regulation (EnEV) of 2014 has placed extra emphasis on the minimization of heat loss and CO_2 emissions in the construction sector [1]. Large savings in energy consumption are possible due to good thermal insulation of the building. This places particular importance on the windows. This is where the energy loss, at 47 %, is greatest in a conventional house [2].

Polyvinyl chloride (PVC) façade elements and window profiles of hollow chamber design have significantly better thermal insulation properties than solid profiles. However, heat flow still takes place within the hollow chamber. This heat exchange is based on air circulation in the hollow chamber caused by different temperatures, e.g. on the building outside and in its interior. One approach to reducing the thermal conductivity of a window frame is foaming, for example with polyurethane (PU). However, profile manufacturing and foaming are usually performed in two separate steps with a high labor, assembly work and space requirement. Alternatively, foam cores, e.g. of polystyrene (PS), can be introduced into the hollow chambers of the PVC profile at great effort. The ideal situation would be a one-step process in which the profiles are directly filled with foam during extrusion.

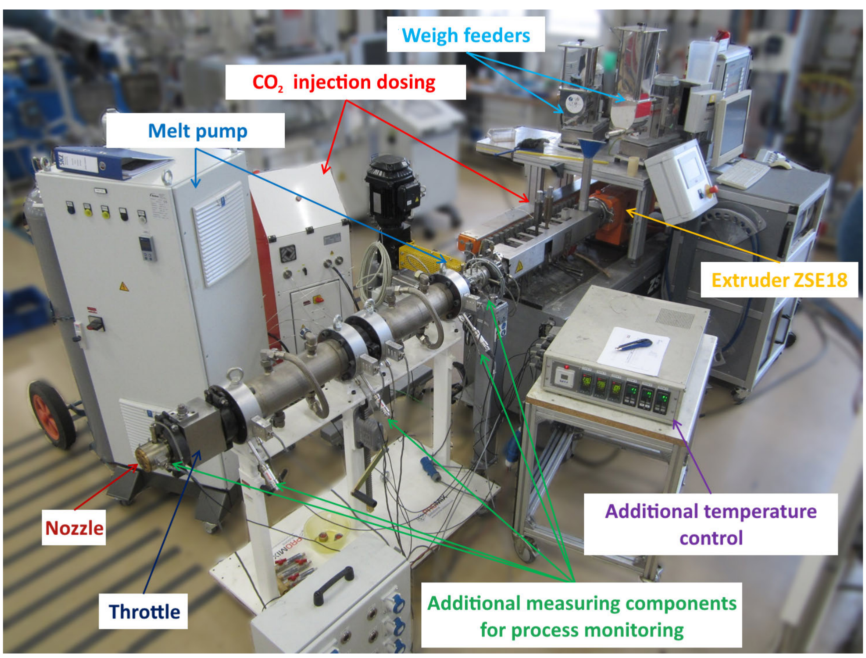

Fig. 1. The foaming of PS was investigated in a test system developed for this purpose © SKZ

One-Step Process for Foam-Filled Profiles

Therefore, the German Plastics Center SKZ investigated in a research project a process for manufacturing PVC plastic profiles with physically foamed PS core in one process step. Within the project, a suitable PS foam formulation was developed and, in parallel, a trial system for process development of foam-filled profiles was set up and tested on a pilot scale. Furthermore, the joining technology was investigated and an application-based sustainability analysis performed.

For the target application of a PS foam as insulating material in a PVC window profile, first a laboratory system for foaming PS was set up (**Fig. 1**). It consists of a type ZSE 18 HPe co-rotating twin-screw extruder from Leistritz Extrusionstechnik GmbH, Nuremberg, Germany, a type BKG BlueFlowTM GP22/22–01 gear pump from Nordson PPS GmbH, Münster, Germany, and two type P1 cooling mixers and a type Z400 gas dosing system from Promix Solutions GmbH, Wetzlar, Germany. With this system, the foaming can be investigated for different dies, such as round-hole dies with variable diameters or film dies. In addition, the pressure level in the line can be adjusted by means of a throttle positioned before the die. That is particularly helpful during start up.

On this system, foaming tests were performed while varying the material formulation and die diameter. As material, PS 153F, melt volume rate (MVR) 7.5 cm^3/ 10 min at 200 °C and 5 kg, and the PS

158N, MVR 3.3 cm³/10 min at 200 °C and 5 kg, from Ineos Styrolution, Frankfurt am Main, Germany, and combinations of these were used. As nucleation agent, talc of type Jetfine 3 C A from the Luzenac Group, Toulouse, France, was used in proportions of 1 and 10 %. To improve the thermal properties, the use of type UF1 98 C graphite from Graphit Kropfmühl GmbH, Hauzenberg, Germany, in proportions of 1 and 10 % was investigated. From the individual components, compounds were produced in a preceding step.

Foaming trials with the compounds showed that a maximum concentration of 6 % CO_2 is good enough for a good foam structure and low foam density. After the CO_2 injection, a pressure level above 80 bar must be maintained so that the CO_2 remains securely dissolved in the melt. Temperatures of 195 °C at the gear pump, 130 °C at the first cooling mixer and 120 °C at the second cooling mixer proved optimum. The nozzle temperature must be adjusted to between 140 and 160 °C to obtain a good result regarding foam quality.

Homogeneous and Fine-Celled Foam Structure

The extruded samples were characterized optically and by scanning electron microscopy. It was found that the foams have a closed-cell, very homogeneous and fine-celled structure (**Fig. 2**). In addition, the foam density was determined based on the standard EN ISO 1183–1 method A – immersion method. The studies showed that, for all material combinations, constantly extruded foams with foam densities of 0.06 g/cm³ with good cell morphology can be demonstrated.

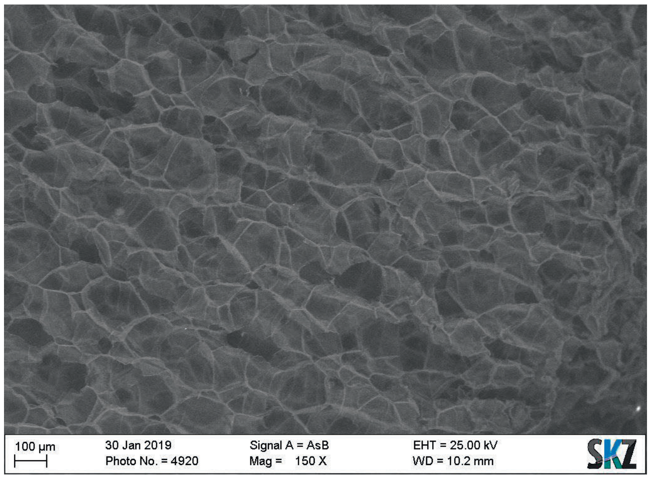

Fig. 2. SEM micrograph of a foam sample with graphite as nucleation agent with 150x magnification: the closed-cell, highly homogeneous and fine-celled structure of the foams is good to see © SKZ

To ascertain the insulating properties of the foam, the thermal conductivity was determined. This was calculated from the thermal conductivity, specific thermal capacity and foam density. To determine the thermal conductivity, a type LFA447 NanoFlash light flash apparatus from Netzsch Gerätebau GmbH, Selb, Germany, was used. The specific thermal conductivity was determined using dynamic differential calorimetry (DSC) with a type DSC 204 F1 Phoenix test unit, also from Netzsch Gerätebau. All the investigated samples showed a very low thermal conductivity in the range from 0.0175 to 0.0255 W/mK, where the formulations with the higher-viscosity PS 158N have slightly higher thermal conductivities. The nucleation agent used and the graphite introduced only have a slight influence on the thermal conductivity.

Processing in a Tandem Extrusion Line

To investigate the extrusion of PVC profiles with foamed PS core, a tandem extrusion system was designed, set up and tested in the next step (**Fig. 3**). PVC processing is performed in the system on a type KMKK40 conical counter-rotating twin-screw extruder from KraussMaffei Berstorff GmbH, Hanover, Germany. The PS is processed in the laboratory line from **Figure 1**. For the test system, a special extrusion die was designed and built, which combines PVC profile extrusion with PS foam extrusion (**Fig. 4**). The design was performed based on extensive flow simulations by Ianus Simulation GmbH, Dortmund, Germany, which could be confirmed in first test runs on the actual extruder (**Fig. 5**). A typical window profile formulation of PVC powder and different additives, such as thermal and light stabilizers, lubricants, acrylic impact modifiers and fillers, was used. »

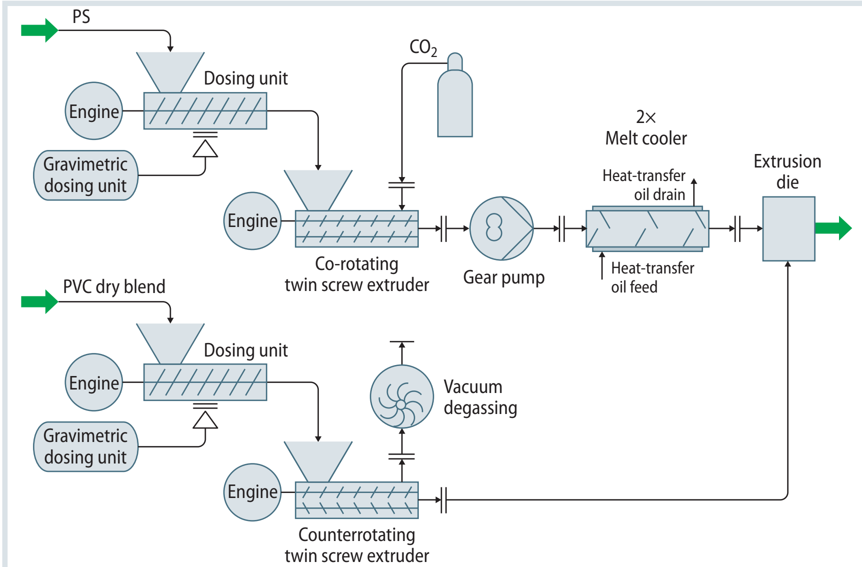

Fig. 3. The tandem extrusion system permits extrusion of PVC profiles with foamed PS core © SKZ

Problems with the Die

Both the PVC outer layer and the PS foam could be very easily extruded in the first tests in separate operations. However, since the die heated up to about 190 °C in the coextrusion process, the formation of a stable foam in the profile was hampered. The manufactured profiles were thus only partly foam-filled.

Nevertheless, the tests yielded important findings for the final process design. In the next step, the thermal separation between PS and PVC material stream was optimized and the material systems better adjusted to the temperature requirements. In addition, the manufactured foams could be used for further studies on weldability and assessment of sustainability.

Welding of Foam-filled Profiles

The welding of foam-filled profiles is an important step for transferring the new coextrusion processes into industrial practice. To generate findings for this in the early stages, profile-foam composites were manually used with box profiles and foam extrudates and subsequently used for welding tests. A type Widos 2500 S CNC servoelectric welding machine from Wilhelm Dommer Söhne GmbH, Ditzingen, Germany, was used. The welding parameters were based on the normal parameters from the welding guideline of EPPA (European Trade Association of PVC Window System Suppliers).

It was found that the PS foam in the profile core collapses locally due to the effect of heat at the heating element, and shrinks back from the direct joint zone

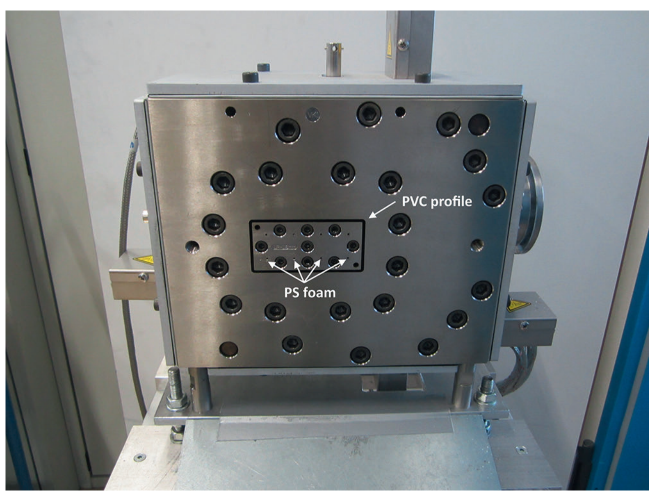

Fig. 4. Front view of the extrusion die with frame radiator: the mold combines PVC profile extrusion with PS foam extrusion © SKZ

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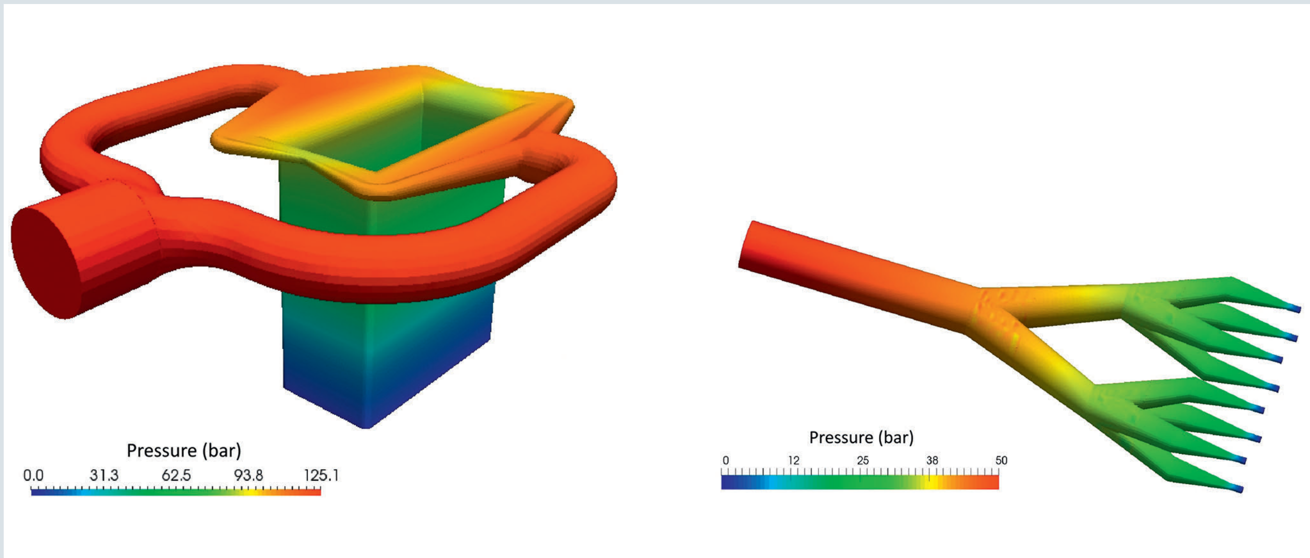

Fig. 5. Simulated pressure and viscosity profiles for the PVC flow channel of the die (left) and the PS flow channel (right) © Ianus

during heating. This is positive for subsequent applications, since it means that no PS can penetrate into the load-transmitting PVC structure. In particular, with very long-lasting construction products, such as plastic windows, possible effects on the mechanical long-term properties might not be tolerable. Furthermore, the PS foam detaches from the polytetrafluoroethylene (PTFE) coated heating element completely, so that there is no additional cleaning work.

How Sustainable Is the Process?

Considerations of sustainable are mandatory, in particular for energy-saving products. In the running process, performance measurements were performed to determine the overall energy consumption and the energy consumption of the individual components. It was possible to differentiate the profile extrusion and the consumptions of the extruder, the heater and the melt pump could be differentiated during foam extrusion as partial consumptions. A total energy consumption of 0.722 kWh can be calculated for the extrusion of a meter of foamed profile (**Fig. 6**). A total energy consumption of 1.565 kWh can be calculated for the extrusion of a meter of foamed profile. For conventional profile extrusion without foaming under industrial conditions, the average energy consumption is about 0.2 to 0.25 kWh/kg. It is thus initially distinctly higher with foamed profiles. Under industrial conditions, i.e. with an increase of the take-off velocity and energy-efficient extruders, however, it can be assumed that specific energy consumptions can be significantly reduced.

Environmental Life-cycle Analysis

In addition, a comparative environmental life-cycle analysis was performed for a PVC window with the standard dimensions 1.23 m x 1.48 m and an assumed useful life of 30 years. It was assumed that, due to the PS foam filling of a standard PVC profile produced by co-extrusion, a reduction of the total U-value (heat-transfer coefficient) of the window from 1.0 to 0.9 W/m²K can be obtained. The calculations showed that the energy savings in the use phase significantly exceed the greater outlay during manufacturing in the life-cycle balance. The calculation of the environmental effects of the thermal recovery of the PS foam was included in the substitution of thermal energy, and thereby also produced a reduction in the primary energy demand and greenhouse potential.

The aim of the research project was to develop a process technology for manufacturing highly thermally insulating PVC façade elements with a PS foam core in a single process step. The plant used can obtain a foam density of up to 0.06 g/cm³. The achieved thermal conductivity of the foam of 0.0215 W/mK represented a good thermal insulation class. Despite these positive results, the foam formation during direct foaming of the profile fell short of expectations. The temperature of the mandrel for guidance of the PS melt charged with blowing agent is increased too greatly by the PVC melt flowing around it. However, the constructed plant provides a good starting point for further development work at the SKZ pilot plant. In other projects, a direct temperature control of the tool mandrel can now be worked out and suitable material combinations sought. ■

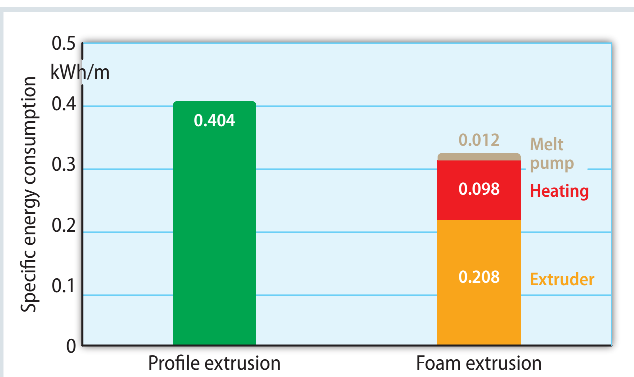

Fig. 6. Specific energy consumption of the individual components based on 1m of manufactured profile Source: SKZ; graphic: © Hanser