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The examination of weld line properties in injection molded PP composites

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Abstract. This paper focuses on the effect of different fiber content on the mechanical properties of specimens with and without weld lines. The effect of three different melt temperatures and holding pressures were also investigated. For the experiments dumbbell shaped standard tensile specimens with and without weld lines were injection molded from PP (TVK's H116F homopolymer) and short glass fiber (0, 10, 20, 30, 40 wt%). The mechanical properties of these composites were determined by quasi-static (standard tensile testing) and dynamic (Charpy impact test) testing methods and the corresponding weld line factors were calculated. The fracture surfaces were analyzed with the help of scanning electron microscopy (SEM). From the results of the tensile and Charpy-impact tests, it was ascertained that the temperatures and the holding pressures during injection molding did not affect the tensile and impact properties, but fiber length had a major impact on the mechanical properties of this specific composite. By increasing the fiber content, the tensile strength increased until a peak and declined after. Whereas the impact resistance decreased by the increasing fiber content in the whole examination window. Comparing the weld lined and weld line free specimens, it was concluded that weld lines did significantly decrease the tensile strength and impact properties due to the unfavorable fiber orientation beside the weld line which was visualized by scanning electron microscopy.

Introduction

The interest in weld line analysis of injection-molded parts has increased greatly in the past few years mainly because of the ever-increasing requirements on the performance of injection-molded parts. Weld lines are formed during mold filling whenever two separated melt streams recombine and often result in reduced mechanical strengths and/or poor optical surface appearance. Whereas the total elimination of weld lines is not always possible without modifying the part geometry, their negative influence on part performance and appearance can be minimized. This can be done by trial and error experiments or by model prediction. The cost and time efficiency of the latter makes it a preferred route for weld lines analysis. Computer simulation packages of injection molding are capable of telling the weld lines' location exactly, but none of the current ones can predict the weld lines' properties quantitatively. Several researchers [1-4] used the weld line factor (WL-factor), defined as: strength of specimens with weld line divided by the strength of specimens without weld line, to evaluate their experiments. Highest WL-factors were obtained for unfilled materials and using high melt temperature, high holding pressure, and low mold temperature.

Experimental

The effect of processing conditions and fiber content on the mechanical properties of injection molded dumbbell shaped tensile specimens with and without weld lines were investigated. The examined processing conditions were the following: melt temperature (T_{melt} [ºC]) and the extent of holding pressure; the materials used for the investigation were TVK's PP (Tipplen H116F) with different short glass fiber (SGF) contents described in Table 1. The so-called pressure ratio

(P_{ratio} [%]) was used to describe the ratio of the holding pressure correlated with the injection pressure.

Table 1. Injection molding parameters

Injection molding parameters		
Fiber content [wt%]	Melt temperature [°C]	Pressure ratio [%]
0	200	40
10	230	60
20	260	80
30		
40		

PP-SGF granulates with different fiber content were produced on a Brabender twin screw extruder with the parameters given in Table 2. From these materials according to the standard MSZ EN ISO-3167-2003 dumbbell shaped specimens were produced on an ARBURG 420 A 800-250 injection molding machine. The tensile strength of the specimens were determined at room temperature (23 ºC) on a Zwick Z020 universal testing machine driven at a constant crosshead displacement rate of 5 mm•min^{-1} and 10 mm•min^{-1} according to the standard MSZ EN ISO-527-1. The Charpy impact strengths of the specimens were measured on a Charpy impact tester according to the standard MSZ EN ISO 179-1. The load displacement curves were recorded with a computer data logger in both cases. The fracture surfaces of the tensile specimens were investigated by scanning electron microscopy on a JEOL JSM-638OLA SEM machine.

Table 2. Extrusion parameters

Extrusion parameters				
Feeding zone [°C]	Compression zone [°C]		Metering zone [°C]	Revolution of the screw [1/min]
1st zone	2nd zone	3rd zone	4th zone	
185	190	195	200	10

Results and discussion

At first the effect of the processing parameters and fiber content on fiber breakage were investigated. The revolution of the screw on the extruder was raised from 2 1/min to 30 1/min in 7 steps to examine its effect on the fiber breakage during the extrusion process. As it can be seen on Figure 1. (left) the increase in screw revolution (n_{screw} [1/min]) caused a linearly proportional decrease in fiber length until reaching 20 1/min. After this rpm limit the decrease in the fiber length is negligible. The following equation describes the relation between the revolution of the screw and the fiber length (Eq. 1):

$$\text{If } n_{screw} \leq n_l \text{ than } l_{fiber} = l_0 - m \cdot n_{screw}, \qquad (1)$$

where l_{fiber} [μm] is the fiber length after the extrusion, l_0 [μm] is the fiber length before the extrusion, n_{screw} [1/min] is the rpm of the screw, n_l [1/min] is the maximum rpm where the equation is valid and m is a material and extruder dependent constant. For the given material and extruder the value of m is approximately ~29, l_0 ~660,4 μm and n_l is about 20 1/min. Above its limit the l_{fiber} is constant which is about 100 μm.

Next the effect of fiber content on fiber length was investigated. Our experiments indicate that by increasing the fiber content the fiber length after the extrusion and the injection molding process was decreased respectively. By reaching fiber content 40 wt% injection molding (as the second processing procedure) hasn't changed the fiber length compared to the length experienced after extrusion (Fig. 2).

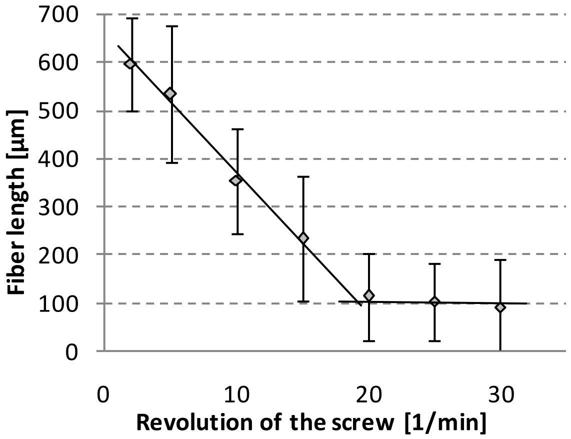

Figure 1. Effect of the revolution of the screw on the breakage of fibers during extrusion, PP+30 [wt%] SGF

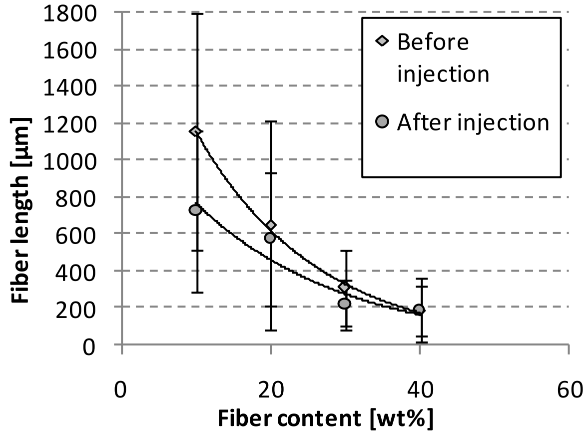

Figure 2. Effect of the different processing steps on the length of fibers (n_{screw}=10 [1/min] ; T_{melt}=230 [ºC], P_{ratio}=60 [%])

An ideal value for the revolution of the screw (n_{screw}=10 1/min) which produced fiber lengths around 400 μm was selected. Further experiments were carried out wherever the mechanical properties of the produced specimens were investigated. The effect of fiber reinforcement can be seen on Figure 3. There are two effects that have influence on the corresponding mechanical property: the effect of the increasing fiber content which raises the tensile strength; and the effect of the decreasing fiber length which lowers it. In our case the first effect is dominant until a critical fiber content/fiber length where the second effect takes its place. In case of weld lined specimens is however a noticeable monotonic decreasing trend in tensile strength due to the perpendicular fiber orientation to the load direction at the weld plane caused by the fountain flow of the polymer melt. The dynamic properties of the specimens were also tested where the increase in fiber content decreased the impact strength in both cases but for the weld lined specimens this decrease was major. At 40 wt% fiber content the starting ~130 kJ/m^2 impact strength difference between the values for specimens with and without weld lines cut down to ~10 kJ/m^2 (Fig. 4).

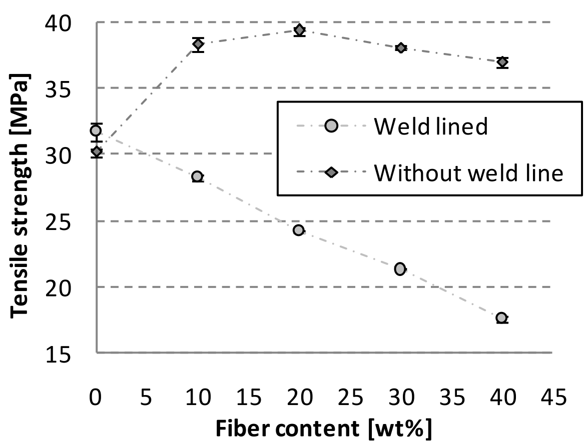

Figure 3. The effect of fiber content on tensile strength (n_{screw}=10 [1/min], T_{melt}=230 [ºC], P_{ratio}=60 [%])

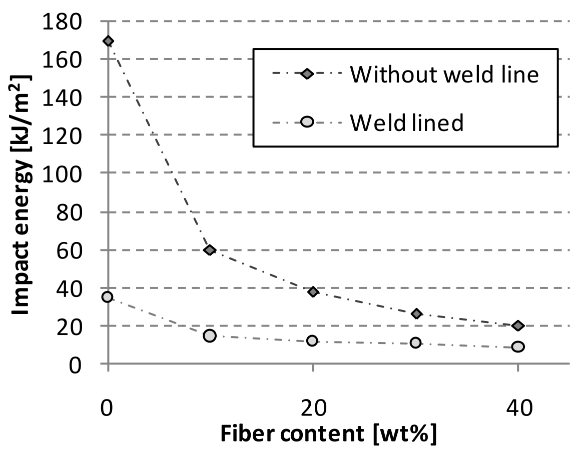

Figure 4. The effect of fiber content on impact energy (n_{screw}=10 [1/min], T_{melt}=230 [ºC], P_{ratio}=60 [%])

SEM shots were taken of the fracture surfaces to investigate the fiber orientation. On weld lined specimens it was found to be parallel to the weld plane and so perpendicular to the direction of the load (Fig. 5, left). On several images voids were found at the weld surface that further deteriorate the mechanical properties of the specimens and are caused by the shrinkage of the matrix [6] (Fig. 5, right).

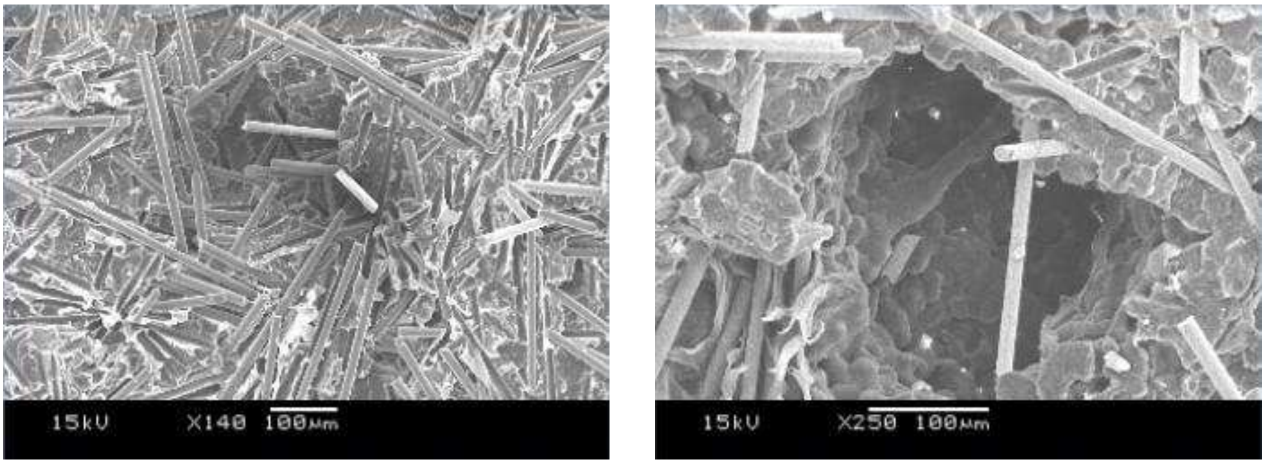

Figure 5. SEM shot of the fracture surface of a weld lined tensile specimen (parallel to the fracture surface/welding plane), fiber orientation (left) and a void at the weld plane (right)

Figure 6. shows the so-called V-notch that is generated usually at the edges of the weld plane on the surface of the specimen. It can be seen that near the edges of the specimen the notch starts to vanish because of the better venting conditions. The notch deepens towards the middle of the specimen's width reaching its peek at the middle. This can be explained by the mentioned venting.

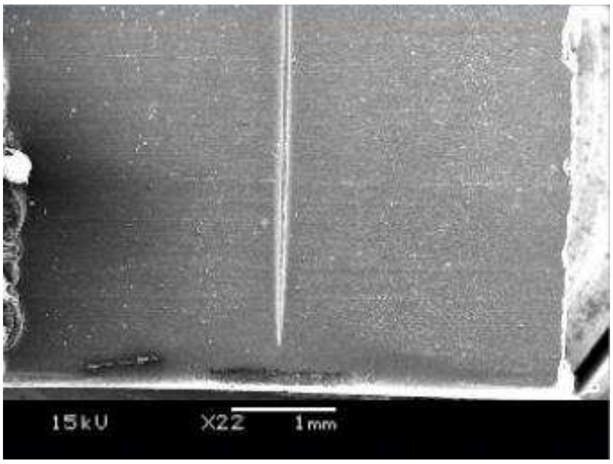

Figure 6. SEM shot of the v-notch on the specimen surface

Summary

In our work, the effect of different evolution of the extruder screw and fiber content were investigated on the fiber length of extruded and injection molded standard dumbbell shaped specimens. It was found that the increasing revolution lead to a linearly proportional decrease of fiber length until a critical fiber length is reached. Furthermore, at 40 wt% a secondary processing technology, injection molding, could not further deteriorate the fiber length.

Additional experiments were taken to show the effect of melt temperature, pressure ratio and fiber content on the tensile- and impact strength of the investigated specimens. It was found that melt temperature and pressure ratio had no effect on the examined properties. However the fiber content decreased both mechanical properties except the tensile strength of the weld line free specimens. It was shown by SEM images of the fracture surfaces that the fibers were oriented parallel to the weld plane/fracture surface on weld lined specimens and several voids were found.

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