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INFLUENCE OF FIBER LENGTH IN BASALT FIBER FILLED THERMOPLASTICS ON MECHANICAL PROPERTIES

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ABSTRACT

This investigation focuses on fiber damage during processing and the effect of fiber length and fiber content of basalt fiber compounds on mechanical properties. A composite of basalt fibers (BaF) and Polypropylene (PP) is compounded with a twin-screw-extruder and specimens are fabricated via injection molding. Fiber contents and process parameters are varied in extrusion and injection molding processes. Fiber lengths and contents in specimens are determined and correlated with tensile strength, tensile modulus, impact strength and elongation at break. The investigation of the processes regarding fiber damage is necessary for determining achievable fiber length in moldings and resulting mechanical properties.

1. INTRODUCTION

Fiber reinforced thermoplastics are used in various fields of applications because of the improvement of mechanical properties such as tensile strength and tensile modulus [3,4,8,9]. Most common fibers for reinforcing thermoplastics are glass fibers (GlF).
Processing of fiber reinforced thermoplastic compounds can result in significantly reduced fiber length. Reinforcing effect of glass fibers is investigated by various authors [1 – 10]. As reinforcing element, basalt fibers are valid alternatives to glass fibers. BaF have mechanical and thermal properties similar to GlF and are produced in a similar manufacturing process, but with less energy consumption [1,10]. Furthermore, BaFs are free of health hazards and ecologically harmless [12]. In this study PP is compounded with BaF via twin-screw extrusion and processed to specimens by injection molding (Figure 1).

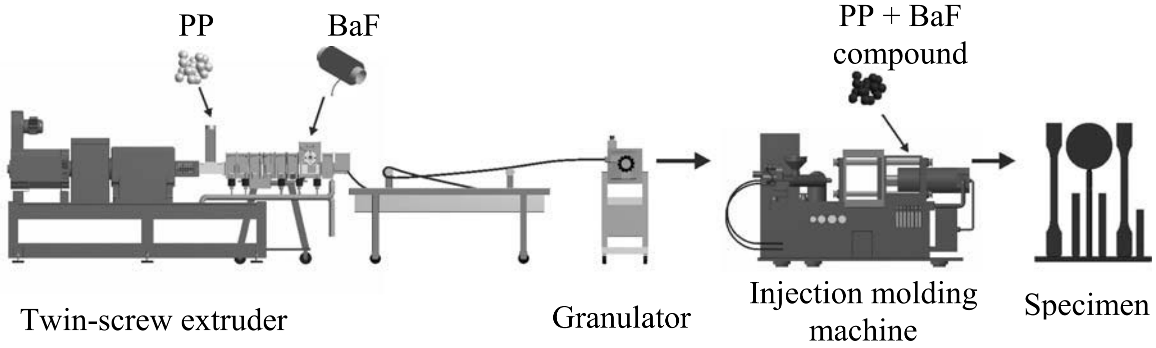

Figure 1: Examined manufacturing processes

Fiber length and content have major influence on mechanical properties of the reinforced composite. For determining achievable mechanical properties, it is essential to investigate the fiber damage in processes and resulting fiber length. The processes are analyzed regarding fiber damage as a function of process parameters. Influences of fiber lengths and contents on mechanical properties, such as tensile modulus, tensile strength, charpy impact resistance and elongation at break are investigated.

2. EXPERIMENTAL

Processing of thermoplastics in twin-screw extruders and injection molding machines induces shear stresses into the melt. For fiber reinforced compounds these shear stresses can result in fiber length reduction. Therefore this study investigates processing parameters which affect shear stresses. The experiments are based on Design of Experiments (DoE). Process parameters are varied in a full factorial design with additional levels to determine non-linear effects on fiber length (Figure 2). [13]

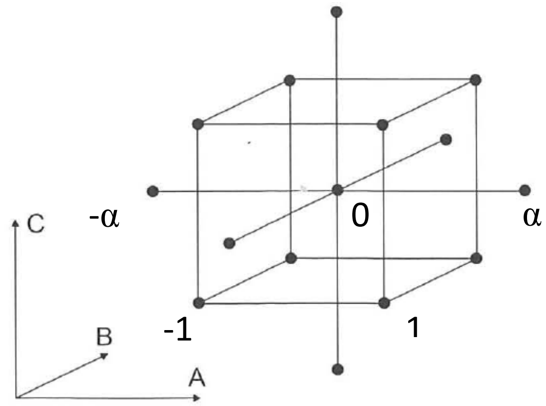

Figure 2: Full factorial design with additional levels (α) for non-linear effects

Additionally, linear interactions of two or more input values can be identified. The resin used for the experiments is a Polypropylene resin (Borealis BC612WG). The PP resin is an injection molding grade with a melt flow rate (MFR) of 5 g/10min (230 °C; 2.16 kg) and a density of 0.9 g/cm³.
Regarding the compounding process, endless basalt fiber rovings with 1200 and 2400 tex are used. The rovings have 13 µm of filament diameter and a density of 2.68 g/cm³.

2.1 Compounding

A DoE study for compounding basalt fibers with polypropylene examines the influence of screw speed, throughput and melt temperature on fiber length. Compounding was executed with a co-rotating twin-screw extruder with a diameter of 40 mm and a length-to-diameter (L/D) ratio of 38. The screw design in Figure 3 provides a homogenous distribution of fibers and matrix.

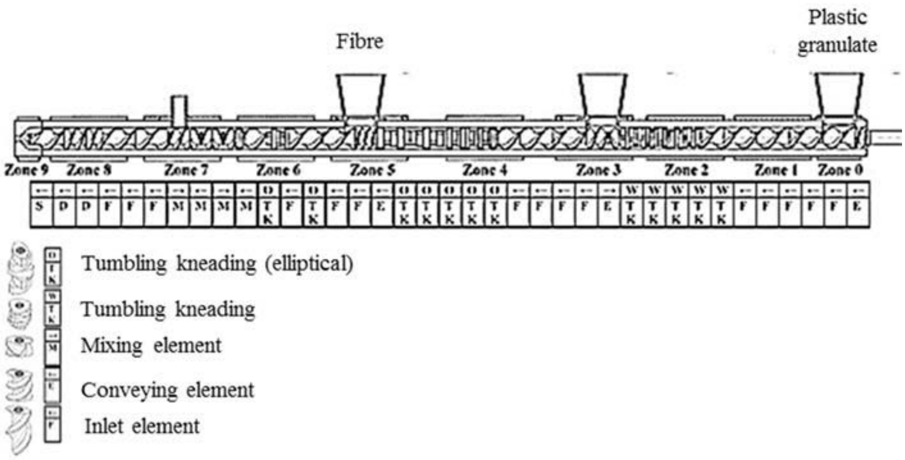

Figure 3: Screw design of the twin screw extruder used for the study

Shear rate and residence time are identified as primary influences on fiber degradation, distribution and orientation. Investigated main process parameters, which affect shear rate and residence time are screw speed, throughput and melt temperature. Shear rate is directly proportional to screw speed. Throughput and screw speed control the median filling grade of the extruder and therefore influence residence time. Melt temperature affects melt density and viscosity. Pretests are used to determine a process window for the main experiment. The throughput is limited by torque rates at 250 g/min and by screw speeds of 50 rpm. Screw speeds over 150 rpm reduce fiber lengths to a minimum, thus increased speeds over 150 rpm do not further affect fiber lengths. Thus the screw speed maximum is limited to 150 rpm. To avoid decomposition of the used material, temperature range is set from 200 to 260 °C according to fabricators data.

2.2 Injection molding

For injection molding the examined parameters are injection volume flow, back pressure, screw speed and melt temperature. The used material for the experiments is compounded under best parameter set for longest fiber according to the results of the compounding experiments.
An injection molding machine with a screw diameter of 35 mm, a standardized screw and a clamp force of 80 tons is used. The DoE is equal to the design of the compounding study. Fiber length reductions due to injection molding is analyzed with the four parameters.
The back pressure influences the material compression and the region of the melt bed along the screw. This affects the residence time of molten compounds. Melt temperatures and screw speed dependencies are mentioned in the compounding process description. Flow rate influences both shear rate and residence time while injecting the molten compound into cavity. Because of the compounding process results and pretests of injection molding, screw speed variation is set to a maximum of 150 rpm. Back pressure is limited to 100 bar pressure due to pretests and volume flow rate is varied up to the maximum ranges of the machine. Melt temperature ranges are chosen according to manufacturer's data to avoid decompositions.

2.3 Measuring method

Fiber content is measured by calcination methods in accordance with DIN 53568. Consequently, fibers are measured using a light microscope with a camera and the number average length can be calculated according to the following equation.

$$L_n = \frac{\sum N_i L_i}{\sum N_i}$$

While summations of the equation should be carried over the whole population of basalt fibers, in practice only a representative population of fibers are measured, to determine the average fiber length. In this study roughly 300 fibers are measured for each calculation. Figure 4 shows a typical distribution of fiber length in compounds and in specimens.

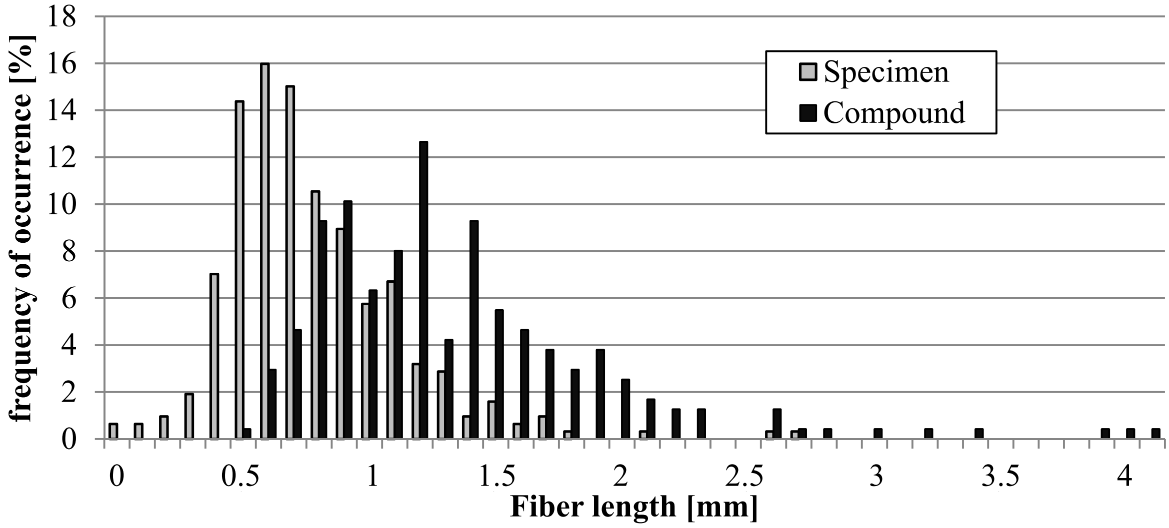

Figure 4: Distribution of fiber length in compound and specimen

Mechanical properties are tested at room temperature (23 °C) and 50 % relative humidity. Tensile strength, tensile modulus and elongation at break are determined in accordance with the procedures in DIN EN ISO 527. Charpy impact properties testing is performed in accordance with DIN 179.

3. RESULTS

3.1 Influence of Processing on fiber length

The DoE results for extrusion displayed in Figure 5 show, that the average fiber length can be described in a linear function of screw speed and melt temperature and a quadratic function of the throughput.

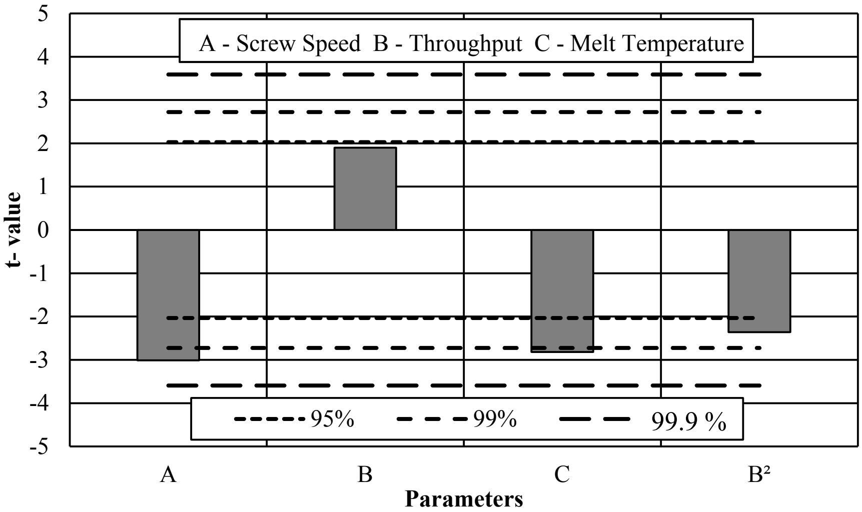

Figure 5: Influence of Process parameters on fiber length in extrusion

The DoE shows that increases in screw speed and melt temperature fiber length decreases linearly. Higher screw speed leads to higher shear rates, which favor interactions between fibers and machine parts as well as fibers among themselves. Increasing throughput up to 160 g/min reduces residence times and preserves longer fibers. Furthermore, fiber to machine interactions are reduced because of the increasing filling level in each spiral of the extruder. Thus, fiber lengths are preserved at higher throughputs up to a peak. Increasing throughput beyond that peak increase the pressure at and in front of filled elements to a point, where the higher shear rates outweigh the decreased residence time and fiber to machine interactions. Thus, further increases of throughput shortens fibers. Based on the results of the DoE, fiber lengths in compounds can be adjusted. Using the machines, compounds can be produced with average fiber lengths from a range of 300 µm up to 2100 µm. A Compound with optimized process parameters regarding fiber length is processed for the further investigation of injection molding process.

The DoE results displayed in Figure 6 show, that the average fiber length is affected significantly by volume flow at injection, screw speed and melt temperature. The DoE identifies a significant interaction of back pressure and melt temperature, that’s why these parameters must be examined together.

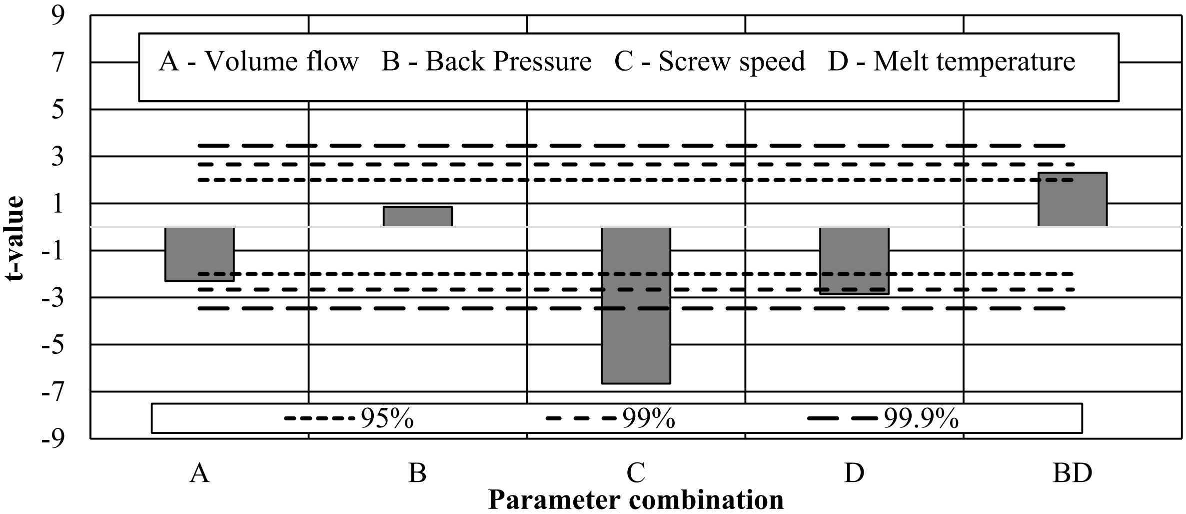

Figure 6: Influence of significant process parameters on Fiber length in Injection molding

Increase of injection volume flow and screw speed has linear and negative influences on fiber lengths. Low screw speeds and injection velocities create low shear rates, which decreases the potential of fiber breaking through shear stress, and therefore result in longer fibers. Increasing melt temperature at low back pressure decreases the viscosity of melt in the compound and a low compression. With well distributed fibers, fiber to fiber interactions cannot occur because of the melt surrounding them. Thus, increasing melt temperature preserves the fiber lengths in injection molding processes. Increasing back pressure leads to longer plasticizing times at higher compression, which increases residence time at high shear rates. As a result of high melt temperature, melt viscosity decreases but is outweighed by the effect of high residence time and compression. Therefore, high injection pressures and melt temperatures shorten fibers.
For injection molding, variations of examined process parameters result in average fiber lengths from 200 µm up to 1300 µm. Results of the DoE enable adjustment of fiber length in specimen via a variation of process parameters. Specimens with different fiber length from the investigations of processes are submitted to mechanical test mentioned in chapter 2.3.

3.2 Influence of fiber length on mechanical properties

Figure 7 represents mechanical properties of BaF/PP composites in dependence of the basalt fiber content and length. As shown in Figure 7, the basalt fiber content has a major influence on the mechanical properties of the composites.

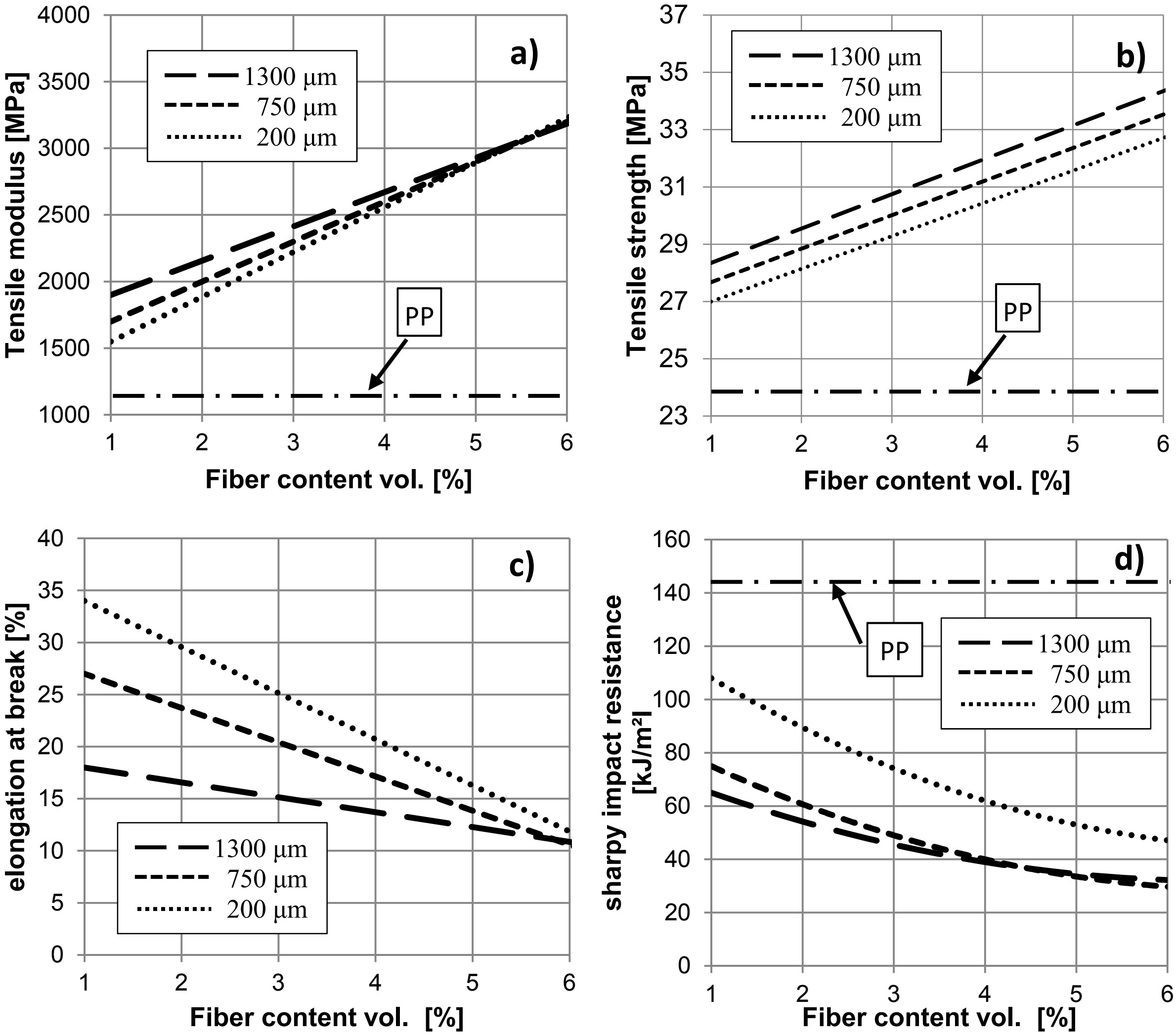

Figure 7: Influence of fiber content and length on mechanical properties of BaF/PP composites

The addition of 6 vol.-% of fibers results in a significant increases of the tensile modulus up to 300 %. The same trends are also found in the tensile strength of the composites. But from Figure 7 (c) and (d), it can be seen that elongation at break and charpy impact resistance decreases when fibers are added.

Fiber reinforced composites absorb impact energy via three major mechanisms: fiber breakage, fiber pullout, and matrix crack propagation. Each fiber is weakening point for the matrix material and promotes crack propagation. Composites with short fibers can have areas where the matrix isn't completely weakened by fibers as it is with long fiber reinforced composites at same fiber content. This can be observed in Figure 7 (d), where the charpy impact resistance decreases with increasing fiber length and content. But increase of fiber length corresponds to an increased surface area, which can provide better transmission of force and therefore higher pullout forces. Hence longer fibers lead to increased tensile modulus and tensile strength.

Composites with long fibers can withstand higher tension. Failure of Matrix to fiber adhesion (pullout) leads to high tensions in matrix material. With higher abruptly loaded tension the elongation at break of the composite decreases. Same effect occurs when fiber content is increased.

4. CONCLUSION

Variation of investigated process parameters in extrusion and injection molding can be used to manipulate fiber lengths of compounds and thereby mechanical properties. The properties can be fitted to the application purpose. The injection molded specimens show mechanical properties which vary according to the fiber length. Increasing the fiber length from 200 µm to 1300 µm increases tensile modulus and tensile strength by 3 – 15 %. On the other hand it results in a decrease of elongation at break and impact strength by up to 50 %.

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