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INFLUENCES WITH REGARD TO THE PROCESSING OF CONDUCTIVE POLYMERS

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ABSTRACT

Technical plastics products offer a high potential for light-weight construction techniques. The research activities for functionalized plastics components increasingly become focused. In complex plastics parts, the integration of materials with different properties plays a key role. Especially, conductive polymers offer the possibility to produce low cost complex plastic components in injection molding processes. Beside the functionalization of parts, conductive polymers are also interesting for the housing of electromagnetic compliance (EMC) devices. The conductivity of these plastics components strongly depends on its processing conditions. On consideration of each step of processing, such as the compounding of the plastic with fibers and a subsequent injection-molding, the main influences on the conductivity are carved out.

1. INTRODUCTION

For reducing part weight and manufacturing complexity, functionalized parts become more important. Beside other molding technologies, especially the film back molding allows the assembly of complex plastics components. In the production of plastic parts with integrated electronic applications, the inset of inserts, such as conductors or sensors is necessary. The integration of these inserts leads to intricate process conditions with high wastrel rate. The replacement of the inserts by plastics materials such as conductive polymers leads to a simplified production process. The plastic and the electronic components such as conductors or control elements can be moulded together on nK-injection molding machines.

To produce conductive polymers, fillers are added into the insulating resin. With this intermixture, the plastic is made conductive and capable of transmitting electric current. Though, the conductivity of the plastics material cannot reach the metallic conductivity [2]. By the combination of different fillers, higher conductivity can be reached [1]. For simple electrical applications the conductivity of the material is sufficiently to transmit small currents [6].

This work analyses the main influencing parameters on the conductivity during processing conductive polymers. The conductivity of the plastics components is basically influenced by the conductivity of fillers, filler content and processing parameters. In the context of this work, the processing of carbon fiber is analyzed. Starting with the incorporation of fiber in the compounding process up to finished plastics components from the injection-molding process, the main influences on the conductivity are determined.

2. MECHANISM OF CONDUCTIVITY

On principle, conductivity describes the property of a material to conduct thermal or electrical energy. In regard of the electrical characteristics of a material, the conductivity is declared as reciprocal value of specific resistivity.

The insulating property of polymers can be changed by the incorporation of conductive fillers. In dependence of filler and filler content, different conductivities can be reached. In relation with the electrical current flow through the fibers, the created network is called percolation network.

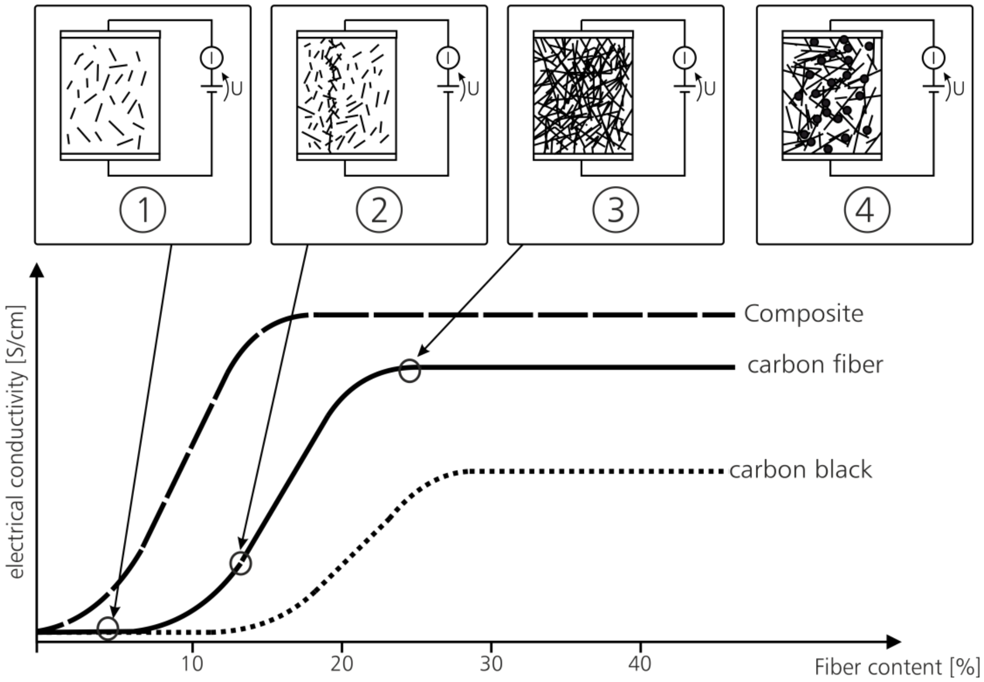

Figure 2.1: percolation at conductive polymers [2][1][7]

In Figure 2.1 the conductivity mechanism of filled conductive polymers is shown using the example of carbon fiber. At low fiber content, the insulating base material dominates the electrical properties. By increasing the fiber content (2), conductive paths are created and small currents can flow. The result is an improvement of the conductivity. At high fiber content (3), a percolation network is generated and high conductivity in the range of 0.01 up to 100 S/cm can be achieved [1] [2]. The combination of two different conductive fillers (4) leads to higher conductivity at lower filler content.

The percolation threshold, which describes the transition between isolation and conductivity, is influenced by the following factors:

2.1 Electrical conductivity of the filler

In dependence of the filler material, different conductivities are reachable. Organic compounds and hydrocarbons have the lowest conductivity. Metallic fillers such as silver fibers possess higher conductivity [2].

2.2 Chemical reactions in the melt

Chemical reactions are based on molecular decomposition caused by thermal effects or hydrolysis. By executing of material pre-treatment, these factors can be influenced [3] [4].

2.3 Mechanical exposure of the melt

The mechanical exposure depends on the shear strain of the melt. Therefore processing parameters such as screw geometry, screw velocity and tool geometry have a high influence [5]. Additionally, filler form, size and content influences the shear strain of the material [3].

2.4 Filler-melt interdependency respectively Filler-Filler interdependency

Interdependencies between filler and filler or filler and melt depend on the polarity of the individual materials. The surface-volume relations, which depend on the size of the filler has a high influence [3]. Finally, the surface energy of the individual components takes effect on the embedding of the filler in the matrix [4].

Some of these factors can be influenced by processing parameters or by choice of material. Generally, there are two suppositions in relation with the processing of fibers: Longer fibers can conduct electrical current over longer distances. There is a probable contact between the fibers. Due to the fact, that the longer fibers are less flexible, they orientate in flow direction. This deteriorates the forming of a percolation network. The advantage of shorter fibers is, that they are disordered in the molten plastic and so they can form a dense network. For the shorter fibers a good mixing of the melt is very important.

3. ANALYSE OF THE PROCESSES

The general processing of filled polymers is divided in compounding process and processing on injection molding machine.

First, the compounding process is analyzed. The experimental extruder is a twin-screw-extruder ZSK40 (Figure 3.1) with screw-diameter of 40mm and L/D-ratio of 38. The extruder has three feeding zones for polymer (1), short fibers and fillers (2) and continuous filament (3). In the following, the particular influencing parameters are explained.

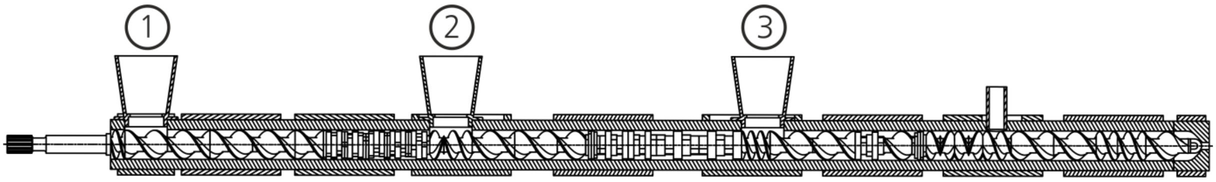

Figure 3.1: Twin screw extruder ZSK40 with L/D-ratio of 38

3.1 Screw geometry

The screw geometries are shown in Figure 3.2. Beside a standard screw with two shear- and mixing zones, a conveying screw is deployed. By using the conveying screw, the mechanical stress of the melt should be very small. Longer fibers follow from the lower shear strain of the melt [5].

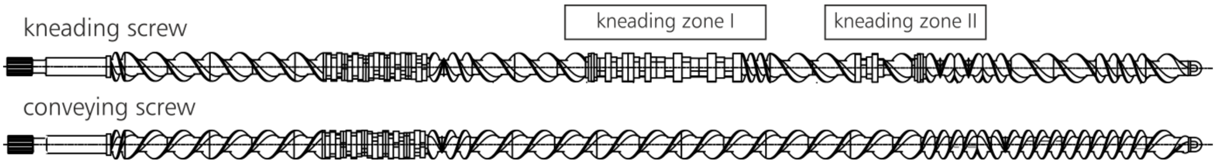

Figure 3.2: Screw geometry

3.2 Screw rotation speed

As the screw geometry, the rotational speed of the screw influences the shear strain of the melt and the included fibers. Therefore, the influences of rotational speeds of 100, 200 and 300 U/min are analyzed [5].

3.3 Temperature control

The melt can be heated up by 10 zones. With temperature sensors, the temperature of the cylinder wall is determined. For identification the influence of the temperature on the conductivity, the material is processed 30K over respectively under the recommended processing temperature of 210°C.

3.4 Tool injector

The Influence of the tool injector of the extruder is tested using a single-hole-nozzle with diameter of 5mm and a multiple-hole-nozzle with diameter of 4mm.

3.5 Fiber length and Material

The used fiber is a STS40 24K and 1600tex. This fiber is incorporated in a thermoplastic matrix of PP Addilene HNR012 PV24. For the incorporation of the fibers in the matrix, the fiber feeding (3) is used. The fibers have different initial lengths. Continuous filament from the Roving is compared with long fiber (50mm) and short fiber (5mm). The melt is charged with fiber by the feeding screw.

The conductivity of the produced compound is tested. Afterwards, test specimens are produced on a 600 kN injection molding machine with screw diameter of 35 mm. During the molding process, the process parameters kept constantly for better comparison of the pre-treatment. The mold generates specimen according to the standard of DIN ISO 527-1. With the test specimen, the influence of injection tool geometry such as edges, corners and changes in wall thickness can be analyzed.

4. MEASUREMENT CONDUCTIVITY OF STRAND AND TEST SPECIMEN

First of all, the electric conductivity of the strand is analyzed. The conductivity in direction of flow as in the perpendicular direction is tested. By using the dimensioning equation for resistance and Ohm's law, the specific resistivity can be calculated.

$$R = \frac{U}{I} = \rho \cdot \frac{l}{A} \tag{1}$$

The geometric sizes diameter d and length of the test specimen l can be measured with a caliper. With an ohmmeter, the volume resistance of the test specimen can be detected. By knowing these values, the conductivity can be calculated with (Equation 2).

$$\gamma = \frac{1}{R} \cdot \frac{l}{\pi d^2} \tag{2}$$

For preparation, electrodes, coated with conductive silver lacquer, are put on the surface of the test specimen. In preliminary tests it was declared that the surface conductivity is negligible. The test setup is shown in Figure 4.1.

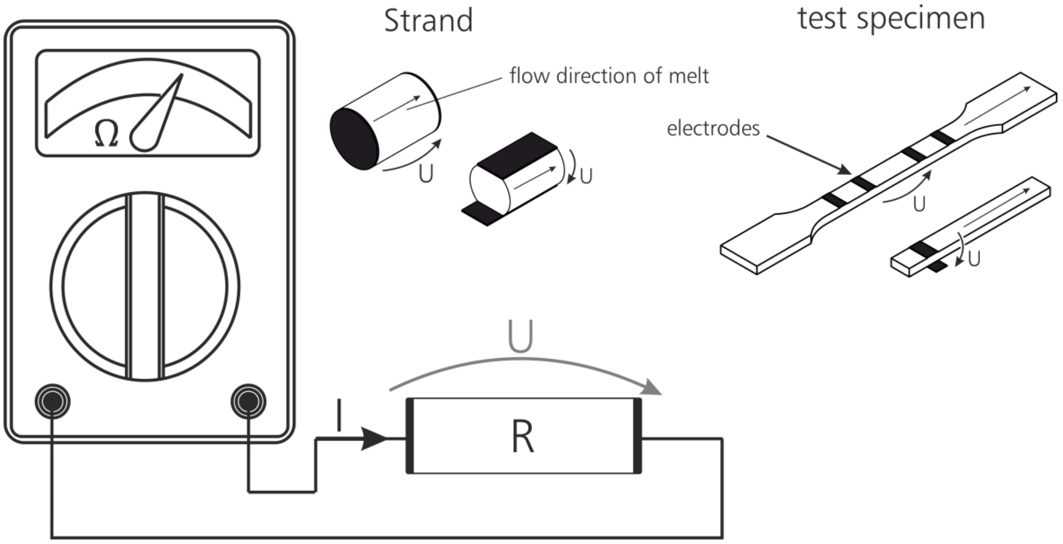

Figure 4.1: Test setup for the measurement of test specimen

Especially at low fiber content, the adhesion of the electrode on the surface of the test specimen is very low, so the contacting of the fiber cannot be ensured.

For determining the fiber content of the individual test specimen, three different measurements were applied. In the Thermographical Analyses (TGA), the temperature is increased until the plastic material evaporates. The difference of weight equates the fiber content of the sample. Another possibility is the Thermal Analysis (TA). As in the TGA, the synthetic part of the sample evaporates and the carbon fiber remains. In difference to TGA, bigger samples can be analyzed, which compensates local differences of fiber content. Another possibility to determine the fiber content of the test specimen is measurement of the density.

5. RESULTS

5.1 Conductivity in strand

The characteristic dependence of fiber content and conductivity can be approved. It appears that the fiber content diversifies along the strand and therefore, a prediction of the conductivity is not possible. In comparison of the screw geometry, a lower shear strain of the fibers leads to higher conductivity.

5.2 Conductivity test specimen

The measurement of conductivity of the test specimens clarifies a difference to the conductivity of the strand. On the one hand, the screw of the injection-molding machine affects a mixing of fibers and homogenizing of the melt. This effect improves the generation of the percolation network. The better mixing of the melt with shorter fibers can be preferred to a lower mixing with longer fibers. In Figure 5.1 the results of the measurement of the test specimen in and perpendicular to flow direction are illustrated.

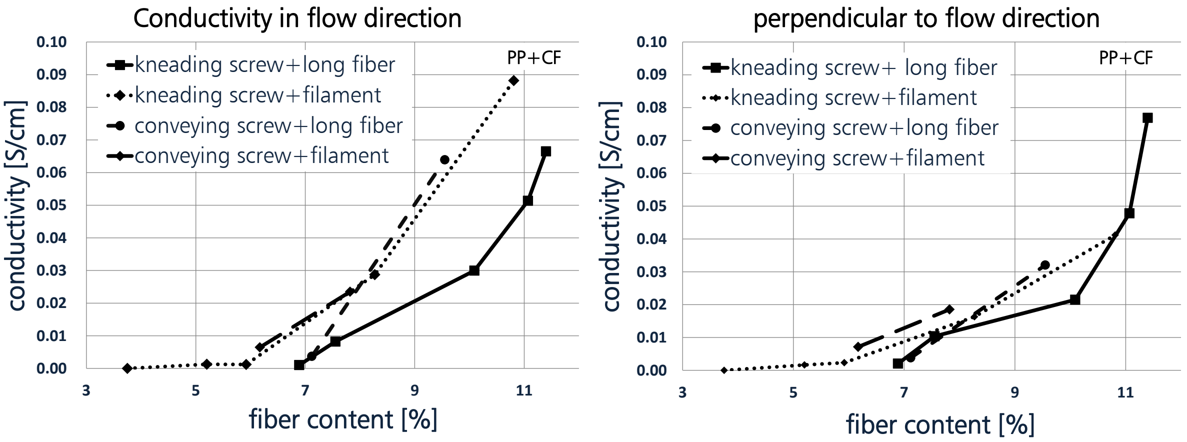

Figure 5.1: Conductivity of test specimens

Processing the material with the kneading respectively conveying screw in connection with different initial fiber lengths leads to different conductivities. Especially at lower fiber contents (<10%), higher conductivity can be achieved by feeding with continuous filament.

When comparing the conductivity in respectively perpendicular to the flow direction, higher conductivities can be detected in flow direction. This is due to the fact that the fibers are orientated during injection molding process and a better conduct of the electric current occurs [3].

5.3 Fiber length und Fiber orientation

With the shear strain of the fiber by processing on twin-screw extruder maximal fiber length between 300 and 400 µm were achieved. In comparison to the fiber length, the orientation of the fibers has a higher influence. For determining the orientation of the fibers, the test specimens are analyzed by using the scanning electron micrograph.

6. CONCLUSION

In context of the work, the influencing factors on the conductivity during processing were examined. For this purpose the extrusion of the fibers as well as the processing with injection molding machines were analyzed.

The conductivity of the test specimens after injection molding process is higher than directly after extrusion process. This implies that for the creation of a dense percolation network the mixing of the melt can be preferred to processing with low shear strain. The achieved conductivities alternate in dependency of fiber content between 0.01 and 0.07 S/cm.

In a subsequent step, the percolation network will be improved by adding additional fillers with different surface-volume relation. These fillers improve the contact between the fibers and intensify the percolation network. Finally, the composites can be established as conductor in functionalized assemblies.

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