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Development of Bicomponent Fibre to Combat Insects

M. Bischoff, F. Schmidt, J. Herrmann, J. Mattheß, G. Seide, T. Gries

***Abstract*—**Crop yields have not increased as dramatically as the demand for food. One method to counteract this is to use pesticides to keep away predators, e.g. several forms of insecticide are available to fight insects. These insecticides and pesticides are both controversial as their application and their residue in the food product can also harm humans. In this study an alternative method to combat insects is studied. A physical insect-killing effect of SiO_2 particles is used. The particles are applied on fibres to avoid erosion in the fields, which would occur when applied separately. The development of such SiO_2 functionalized PP fibres is shown.

***Keywords*—**Agriculture, environment, insects, protection, silica, textile.

I. Introduction

IN recent years, a global rise in the population has produced a common practice of using harmful pesticides on all manner of crops to increase yields and cater to the rising demand for food. While the use of pesticides is effective against insects, their harmful side effects also negatively impact the people who treat and eat these crops, as well as the environment. The development of resistance against classical chemical pesticides has also given rise to the introduction of more aggressive and harmful pesticides, rendering these more dangerous to society and sustainable farming. A more ecological and sustainable alternative has been found in the use of silica (SiO_2) nano- and microscale particles [1]. A solution proposed by and researched at the Institut für Textiltechnik (ITA) of the RWTH Aachen University and Wesom Textil GmbH aims to improve pest control on commercial crops by creating a silica-enhanced fibre for agricultural use.

The market for agricultural textiles has been growing rapidly, doubling in Germany in the last 15 years. In 2010, 2 million tons of agrotextiles were produced [2]. The same trends can be seen in other countries worldwide. Applications have included sun, wind, frost and passive insect protection [3]. It can also be applied for water storage [3]. The structure in these textiles is flexible; knitted, woven, and non-woven textiles which can be used in these applications. The ability to tailor the textiles for specific needs through material selection and structure makes these agrotextiles very versatile. In order to enhance this textile technology, an analysis of the current use of silica particles for pest control is carried out. Silica particles work through the adsorption of the protective wax layer on the chitin shell of the insect [4]. It is used in the form of a fine powder, with a grain size in the micrometer scale. The dehydration induced through the adsorption is lethal, rendering the whole process strictly physical rather than chemical [5]. This is significant because there are no harmful side effects for humans and the environment in contrast to classical chemical pesticides. Silica is one of the most abundant materials on the planet, usually occurring naturally in its amorphous state. The investigated pure SiO_2 particles are also 100% lethal for insects within six hours. Therefore, the process is quite effective. Silica particles are so far rarely used in open land agriculture because of the problems associated with administering them to crops; additionally, wind and rain quickly erode away the small particles. This reduces the effectiveness drastically over a short time period, lowering the cost-benefit-ratio so application is not worthwhile. The solution to this problem is adding some sort of structure, for example, embedding the particles in the surface of a polymer matrix. At ITA, coextruded polypropylene (PP) fibres with a silica-enhanced sheath were created for the application in an anti-insect agrotextile. Here the combination of both anti-insect and additional properties (e.g. anti-sun) can be combined, giving a more promising agrotextile with a high cost-benefit ratio.

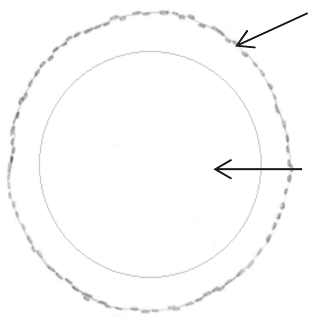

Fig. 1 Concept of a bicomponent fibre with virgin polypropylene core and functionalized sheath

II. The Process

Two methods of fibre production were carried out and will be introduced below.

Small scale experiments were conducted on a lab size micro compounder by Xplore Instruments located in Geleen, Netherlands. The compounds were spun into fibres with a

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silica concentration of 5% and 10% at 10 rpm (without filtration). Several types of silica were investigated:

- Kostropur 020508, Chemiewerk Bad Köstritz GmbH, Bad Köstritz, Germany
- Kostropur 050818, Chemiewerk Bad Köstritz GmbH, Bad Köstritz, Germany
- Aerosil R812, Evonik, Hanau, Germany
- Sipernat 22S, Evonik, Hanau, Germany
- Sipernat 500LS, Evonik, Hanau, Germany
- Sipernat D17, Evonik, Hanau, Germany
- Sylobloc S200, Grace, Columbia, USA
- Syloid 244, Grace, Columbia, USA

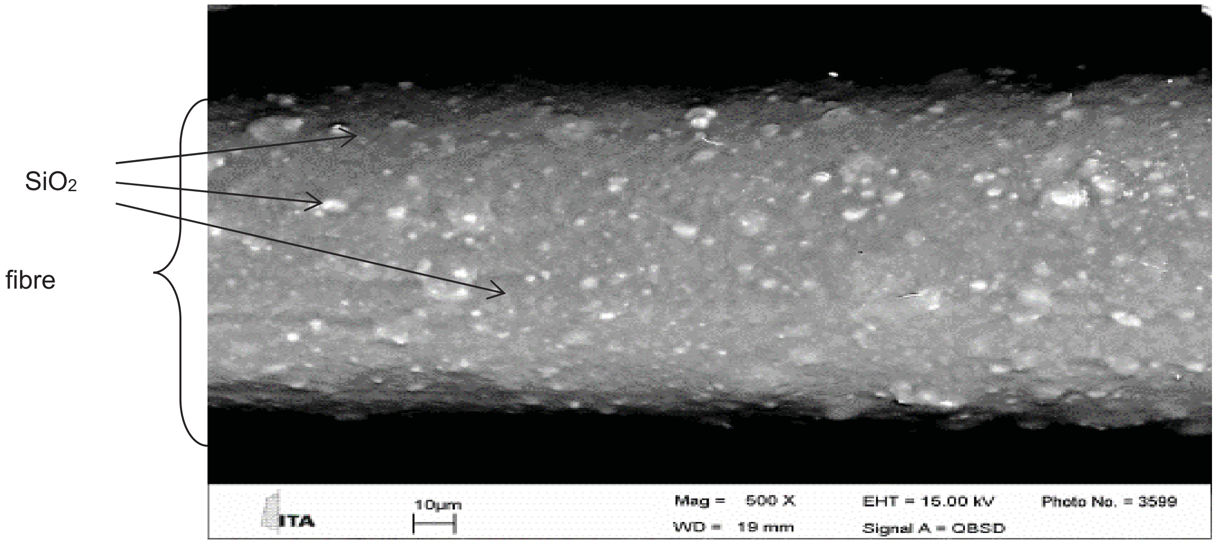


Fig. 2 Silica applied PP-fibre in SEM produced on a micro extruder with 10% silica content

All eight materials showed processability, but according to their initial size and agglomeration, their behaviour displayed several particle sizes after micro extrusion in scanning electron microscopy (SEM). As SEM picture of PP compound with 10 wt % Sipernat 500LS is given in Fig. 2. Particles are evenly distributed on the surface of the polypropylene fibre. The particles can be seen as single particles with an initial particle size of 10.5 µm (D50). Furthermore, the picture shows much smaller particles, which demonstrated that some particles are grinded during extrusion. In Table 1, a detailed overview of all eight particles in a fibre, which is extruded on the micro extruder by a screw speed of 10 rpm, is shown. Diameters may vary due to material filling level and is not due to processing parameters.

Produced fibres had no particular strength since the winding speed was low (50-200 m/min) and the particle content was relatively high (max. 10 wt %). Through this method it was proven that the compound is applicable for the production of fibres. In order to produce fibres with lower elongation and higher tenacity, the material was spun on a larger pilot scale spin line by Fourné located in Alfter, Germany. A bicomponent melt-spinning plant uses two different materials to create a fibre with different properties in the core and sheath. In the case of this particular project, silica particles were only used in the sheath of the fibre. Since the particles need direct contact with the insects to be effective, only the surface of the fibre requires the silica as shown in Fig. 3. The core polymer is the same polymer used in the sheath matrix: polypropylene. PP is one of the most commonly used polymers for a great variety of applications, including textiles and more specifically agrotextiles. Its low cost and desirable mechanical properties make it ideal for creating fibres with a variety of additives and particles. Using the same polymer in both core and sheath furthermore lowers the risk of the occurrence of incompatibilities and process difficulties. [6]

To start creating bicomponent fibres, a compound using particles and PP for the sheath, as well as pure PP for the core, is required in granulated form. The compound for the sheath is manufactured on a twin-screw extruder Ketse 20/40 D by Brabender located in Duisburg, Germany. For the core pure PP resin Moplen HP 561 R from LyondellBasell Industries located in Rotterdam, Netherlands is used. The silica particles must be within the nano and small micron range, since they are filtered with a micron-sized filter (smallest pore size around 80 µm) during the spinning process. Some of the most significant processes in the first processing steps include the homogenous distribution of particles within the matrix, and the maximization of dispersion in the subsequent process. A suitable and spinnable concentration must also be determined. All if these processes must be refined while maintaining the fibre´s lethalness to insects. Therefore, a twin-screw extruder is used for the task; this employs the same material that is used in the matrix (PP) which is used for the core of the fibre. Once the compound and core material are prepared, they can be spun into the actual fibre. For this, both materials are heated and mixed once more in the extruder of the spin line before passing through the filters and nozzles of the spinneret. This forms the fibre at the spinning plate. This fibre is then drawn over several godets while it is cooling, increasing strength while decreasing the diameter. It is then wound, from where it can be further processed into an actual textile. The spinning line is illustrated in Fig. 3. In this process, finding the right combinations of filters for the nozzle and drawing the fibre at the correct speed is key. To make this product viable, the production on large machines has to be ensured. This means that the filter service life has to be high enough to allow for long production cycles without clogging the filter. Past experiments have shown that, especially with high concentrations of particles, as are needed for these fibres, filter service life is reduced drastically due to particles not properly embedded clogging up the filters. A maximum concentration of 5% was successful at spinning, with limited filter clogging. This was achieved by testing a variety of combinations in die setups and drawing speeds. Winding speeds from 250 m/min to 1,750 m/min are feasible with this concentration, but it was easier to process compounds of lower concentration. The upper limit of winding speed is due to the machine settings and not due to fibre breakage. When these fibres were later tested for their influence on insects no toxic effect could be seen. To verify whether the combination of polymer melts and silica reduces the toxic effect of the particle, or whether the concentration of 5% is too low, a masterbatch of granulate at 10% was examined. The masterbatch granulate/resin is tested on insects, in this case *Tenebrio molitor* (mealworms), in a lab environment to determine the toxicity. Only a low level of toxicity was detectable. This masterbatch cannot be extruded on a lab-scale spinning machine due to quick filter plugging, which makes the mass-production of the product ineffective. The fibre with the applied silica in SEM can be seen in Fig. 2. Particles are obviously detectable on the surface of the fibre. The reduced effectiveness of the particles can be explained by the following hypothesis: The silica particles are initially porous, which subjects their pores to contamination with the melt reducing their effectiveness. Higher porosity correlates with higher adsorptive properties, which is more effective against insects. These porous structures might have been filled with polymer melt during processing. This reduces the adsorptive properties of the particles, so that they are no longer effective against insects.

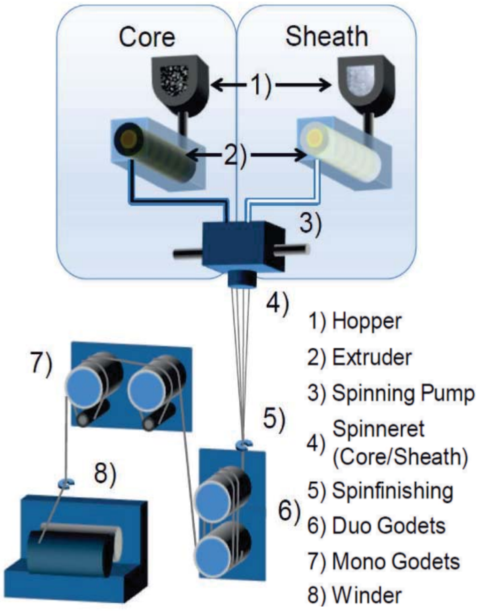


Fig. 3 Spinning line for coextruded fibres [7]

TABLE I
OVERVIEW OF 10 WT% SILICA PARTICLES IN POLYPROPYLENE FIBRES MANUFACTURED WITH A MICRO EXTRUDER IN SEM. DIFFERING DIAMETERS ARE DUE TO THE MATERIAL FILLING LEVEL IN THE EXTRUDER. ALL SAMPLES ARE EXTRUDED WITH 10 RPM AND WOUND WITH 200 RPM

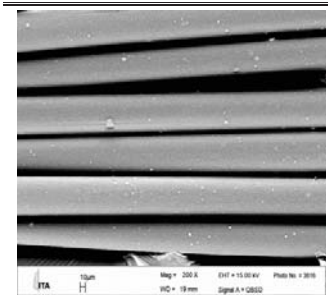
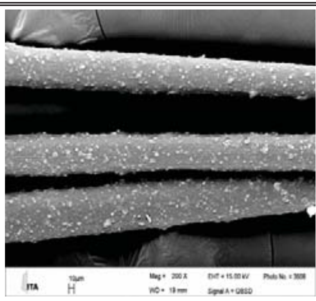
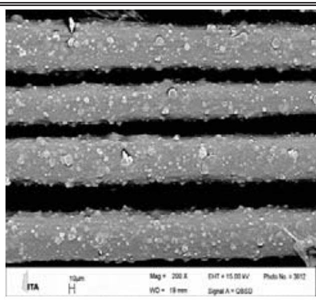
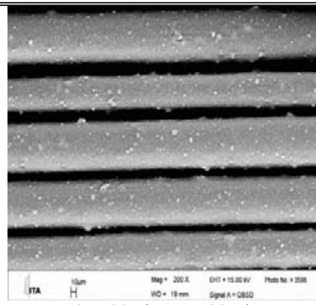
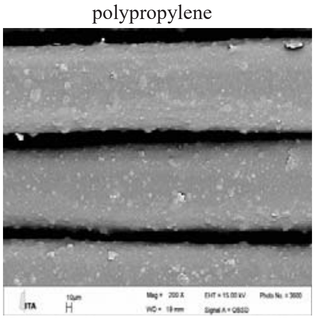
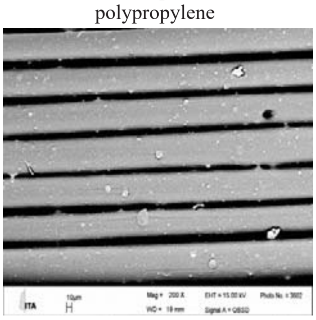
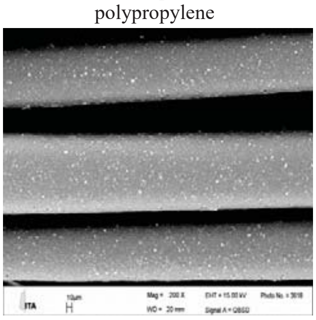
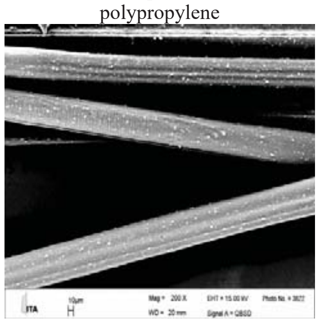
			
10 wt% Aerosil R812 in polypropylene	10 wt% Kostropur 020508 in polypropylene	10 wt% Kostropur 050818 in polypropylene	10 wt% Sipernat 22S in polypropylene
			
10 wt% Sipernat 500LS in polypropylene	10 wt% Sipernat D17 in polypropylene	10 wt% Sylobloc S200 in polypropylene	10 wt% Syloid 244 in polypropylene

Fig. 4 *Tenebrio molitor* with compound

III. Conclusion

Though it was shown that the presented bicomponent fibre can be produced with several machine setups, the fibre did not show the properties for combating insects. Increasing the concentration of silica particles in the polymer melt produced small changes in lethality, but was not processable into the fibres via melt spinning on a pilot spinning line. Therefore, another method for producing bicomponent fibres of silica and polypropylene has to be developed, where higher concentrations can be achieved. Secondly, in the new development the particles should not be applied in the polymer melt, since the particles` effectiveness is dramatically reduced due to the expected plugging of the pores.

IV. An Outlook

The process described above could allow for a variety of other solutions to be realized in the food storage and health sectors. Similar textiles could be invaluable to protect not just the growing crops, but also harvested crops from being destroyed due to insects. Similarly, finer textiles with the same effect could be used to create mosquito nets that are more effective, especially in areas of the world where mosquitoes and the diseases they transfer are still a major health issue. But the technology is flexible and therefore is not just limited to silica particles. The application of this technology can be altered depending on the particles used, since the effect of the particle is what makes the fibre`s unique properties.

Acknowledgments

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