SPECIAL:
Compounding & Recycling

Mechanical Recycling of Fiber-Reinforced Plastics

Fiber Dust Formation during the Recycling of FRP

During the shredding of fiber-reinforced plastics, fiber fragments are released that settle on the skin and clothing, which can lead to itching and may possibly also be inhaled. In a project on the subject of fiber dusts, a study is being carried out on how toxic such fiber fragments are, and which shredding technology is most suitable for preventing – or at least reducing – the release of inhalable fibers.

The demand for fiber-reinforced plastics has been increasing for many years [1], because they are highly suitable for lightweight building applications due to their weight-specific and mechanical properties. Especially organic sheet with glass fiber fabrics is being used increasingly in the automotive sector to save both resources and weight [2]. For this reason it can be assumed that, in future, large quantities of fiber-reinforced waste will be produced, which then has to be recycled. One sustainable possibility is mechanical recycling, in other words the further processing of thermoplastic fiber-

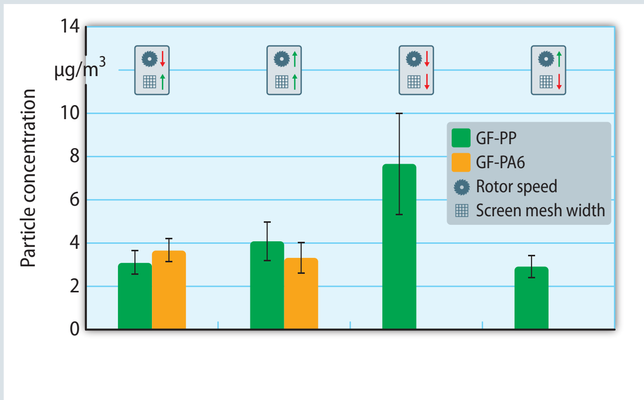

Fig. 1. Mass-based nanoparticle concentration resulting from the shredding of the GF-PP and GF-PA6 organic sheets using different shredding parameters. Source: KTP; graphics: © Hanser

reinforced waste to produce short fiber-reinforced recyclate.

A key processing step in mechanical recycling is the shredding of the waste material. Fiber-reinforced plastics can break down during shredding into inhalable fiber fragments that may be toxic [3, 4]. Fibers with WHO characteristics are considered to be particularly hazardous to health. These are fiber-shaped particles with a length of >5 µm, a diameter of <3 µm and a length-to-diameter ratio of >3:1 [5].

The aim of this project is therefore to obtain know-how about the mechanisms that favor the production of recyclable ground material and, on the other hand, reduce the release of harmful fiber dust.

Previous studies on the topic of shredding technology have shown that the quality of the ground material is dependent on a number of parameters. In order to obtain a particle size distribution that is as narrow as possible and has a large particle size, it is recommended with unreinforced plastics, if possible, to initiate a cutting load into the material [6], to select a large screen mesh width [6, 7], and to prevent brittle fracture [8]. The initiation of brittle fracture – for example, through a high loading velocity, the use of more brittle materials or the deployment of the relevant shredding technology – leads to the crack front of the knife blade running ahead and thus to uncontrolled breaking-up of the material. This results in a high content of fines in the ground material [9, 10].

To what extent these relationships can be applied to the formation of airborne inhalable fiber fragments is not yet known and will therefore be studied as part of the "fiber dusts" project.

Measuring and Analyzing Airborne Fiber Dusts

For the tests on the formation of airborne fiber dust, glass fiber-reinforced organic sheet with polypropylene (Tepex dynalite 104-RG600(x)/47 %) and polyamide 6 (Tepex dynalite 102-RG600(x)/47 %) from Bond Laminates GmbH (Lanxess) were shredded with a single-shaft shredder WSC 250–400 (Weima Smart Cutter) from Weima Maschinenbau GmbH. During this process, the airborne dusts are analyzed. A Scanning Mobility Particle Sizer (SMPS) measures the particles in the nanometer range (9.8 – 414 nm), while an Aerodynamic Particle Sizer (APS) analyzes the particles in the micrometer range (0.5 – 20 µm). Airborne inhalable fiber dust is separated off with a VC25 sampling device on a cellulose nitrate filter and weighed. The rotor speed of the single-shaft shredder is varied from 60 rpm to 120 rpm and the screen mesh width varied from 10 mm to 20 mm. The studies with a smaller screen mesh width were only performed with the GF-PP organic sheet. The organic sheets are fed into the shredder with a size of 250 x 250 mm at a throughput of 1 kg/100 s for approx. 120 min. These parameter settings are shown in the diagrams with corresponding pictograms and arrows. The analysis of the toxicity of the fiber dusts is performed by a cytotoxicity test with a rat macrophage cell line ("lung cleaning cells"). For this, the cells were subjected to an increasing quantity of the produced glass fiber dust, and the negative effect on the energy metabolism was determined as a measure of the cytotoxicity with the fluorescence-based AlamarBlue test. »

Info

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References & Digital Version

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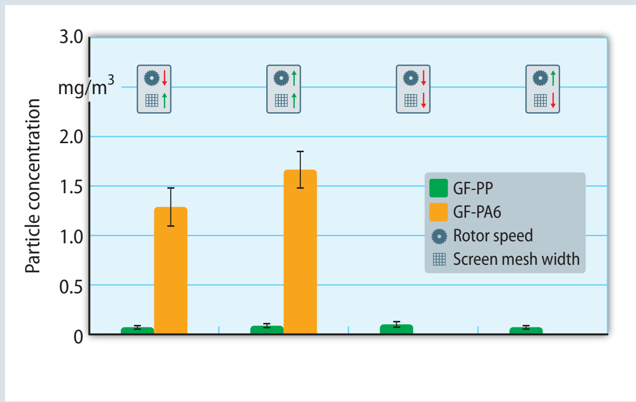

Fig. 2. Mass-based particle concentration in the microscale size range, which resulted from the shredding of the organic sheets under different shredding parameters. Source: KTP; graphics: © Hanser

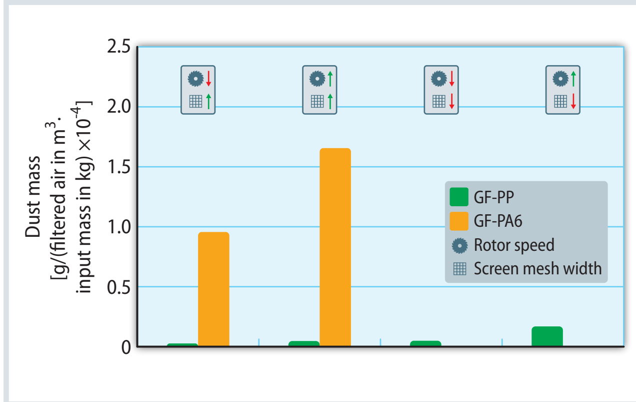

Fig. 3. Inhalable dust mass resulting from the shredding of the organic sheets. The dust mass has been standardized by dividing it through the mass of the input material and the quantity of the filtered air. Source: KTP; graphics: © Hanser

Influence of the Process Parameters

The studies showed that an increase in the rotor speed leads to an increase in the particle concentration and, in turn, to an increase in the inhalable dust fraction. In **Figure 1** it can be seen that the nano-particle concentration, especially at large screen mesh widths, rises with both materials through the increase in the speed. This connection can also be observed for the particle concentration in the microscale size range (**Fig. 2**) and for the fiber dust mass deposited on the filter (**Fig. 3**). The findings confirm the above-mentioned relationships that a higher rotor speed leads to a more brittle fracture behavior of the thermoplastics, producing a higher fines content of the ground material as well as increased release of inhalable fiber dust. The fact that this relationship cannot be recognized for the GF-PP in the micro and nano-scale size range when shredding at lower screen mesh widths is due to the fact that, through the increased friction between the rotor and the material, the particles become electrostatically charged. This leads to the particles sticking to the wall of the shredder or agglomerating to each other.

A reduction in the screen mesh width leads to an increase in the inhalable fiber dust mass (**Fig. 3**) for both speeds. On the one hand, the reduction in the screen mesh width leads to the maximum particle size being reduced, and on the other, the dwell time of the material in the grinding area is increased [6, 7]. The material must be broken down more frequently until it is small enough to leave the grinding area. Also in the nano and micro-scale ranges, a significant increase in the particle concentration can, at low speed, be seen through the reduction in the screen mesh width. This effect is not visible for the high speed because of the electrostatic charging (**Figs. 1 and 2**).

It was also found that the shredding of GF-PA6 organic sheet in comparison with the GF-PP sheet leads to a higher particle concentration in the micro-scale range and to a higher inhalable dust mass. This is also the reason for the greater brittle fracture behavior of the organic sheets through the use of the more brittle matrix material PA6.

The known relationships from the shredding technology for achieving a narrow particle size distribution can thus, for the most part, also be applied to the avoidance of airborne fiber dusts.

Estimating Dust Formation and Recommended Measures

Scanning electron micrographs of the fiber dusts from the cellulose nitrate filter show not only some long glass

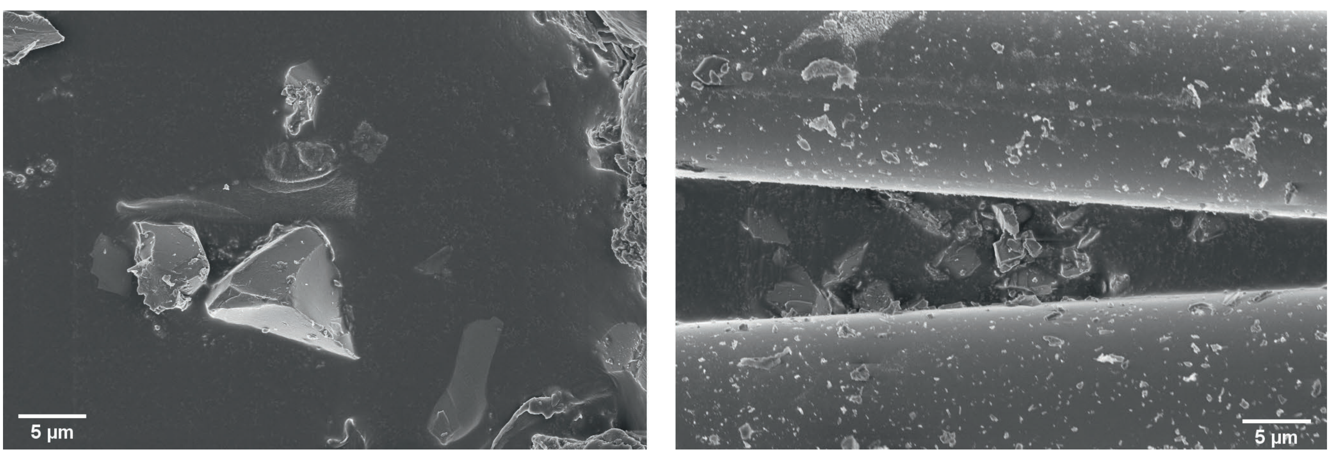

Fig. 4. Scanning electron micrographs of the glass fiber dusts formed during the shredding of the GF-PA6 organic sheets © KTP

fibers but also wedge-shaped glass fiber fragments that are inhalable (<5 µm) and therefore potentially harmful to health (**Fig. 4**). These results support the findings from the measured particle concentrations. In Europe, glass fibers may nevertheless be used if they do not have any marked biopersistence (EU Directive 97/69/EC). Fragments of glass fibers that comply in this way with the requirements for EU approval do not, despite their dimensions, exhibit any chronic toxicity because they do not persist in the respiratory tracts. This is on condition that there is no permanent exposure that constantly triggers inflammatory processes.

Tests on the cytotoxicity of the glass fiber dusts that were deposited on the cellulose nitrate filter during the shredding of the GF-PA6 organic sheets have confirmed this supposition. The determination of harmful particle effects was carried out with the help of the AlamarBlue test (Invitrogen, Life Technologies Corporation, Eugene, USA). This test measures the energy charge of the cells as a measure of the toxicity, using the fluorescence dye and redox indicator resazurin. A reduction in the fluorescence indicates cytotoxicity. **Figure 5** shows the results of the test. The fluorescence is plotted against the concentration of the added particles, and remains unchanged even with very high dust concentrations. The AlamarBlue test thus shows no increase in cytotoxicity, despite the high dust concentrations. Even raising the rotor speed does not lead here to any changes in the evaluation of the toxicity.

These studies can only give a small insight into the topic. Nevertheless, the results show clearly that, in the shredding of fiber-reinforced thermoplastics, inhalable fiber fragments are formed, whose concentration can be reduced by reducing the rotor speed and by using a screen mesh width that is as large as possible. Even if these studies indicate that the glass fiber fragments do not lead to any severe toxicity in the lungs, industrial safety measures should be taken in line with TRGS 521, because, for reasons of preventive health protection, it is important to stop the release of inhalable fibers. ■

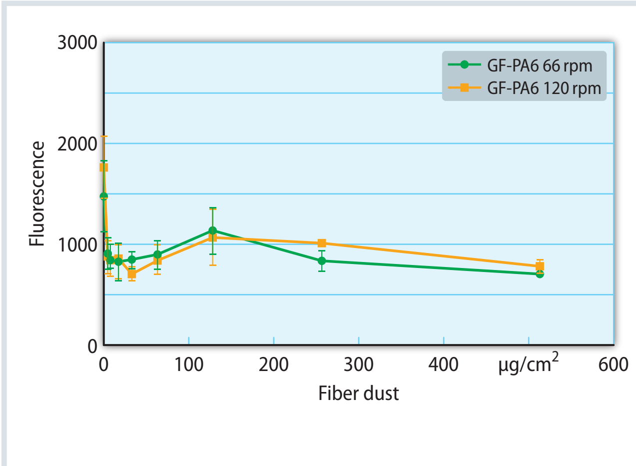

Fig. 5. AlamarBlue Test for glass fiber sheets that were shredded at different speeds but with the same screen mesh width. No cytotoxicity is visible up to the largest quantity in the study. Source: KTP; graphics: © Hanser