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Manufacture of natural fiber-reinforced polyurethane composites using the long fiber injection process

Summary — This paper gives an overview of recent activities in the production of natural fiber-reinforced polyurethane (PUR) composites. Extensive research is being conducted to develop marketable solutions for the production of bio-based plastics. In composite applications, natural fibers can be used as a substitute for synthetic fibers and help to make a significant contribution towards ecological and efficient lightweight components. In addition, an outlook on current developments in Long Fiber Injection (LFI) processing for the application of natural fiber-reinforced polyurethane composites, specifically in electric vehicles is given.
Keywords: natural fibers, fiber reinforced polymers, long fiber injection, polyurethane.

WYTWARZANIE KOMPOZYTÓW POLIURETANOWYCH WZMOCNIONYCH WŁÓKNAMI NATURALNYMI W PROCESIE WTRYSKIWANIA Z UŻYCIEM DŁUGICH WŁÓKIEN

Streszczenie — Niniejszy artykuł zawiera informacje na temat aktualnych trendów związanych z produkcją kompozytów poliuretanowych (PUR) wzmocnionych włóknami naturalnymi. Zwrócono w nim uwagę na szeroko zakrojone badania nad opracowaniem rozwiązań w zakresie produkcji tworzyw polimerowych na bazie materiałów biologicznych, nadających się do wprowadzenia na rynek. Włókna naturalne mogą być stosowane jako substytut włókien syntetycznych pomagając w otrzymaniu lekkich materiałów i służąc jednocześnie ekologii. Omówiono także perspektywy rozwoju zastosowań procesu wtryskiwania z użyciem długich włókien (LFI z ang. *long fiber injection*) w szczególności do wytwarzania części do pojazdów elektrycznych.
Słowa kluczowe: włókna naturalne, polimery wzmocnione włóknami, wtrysk z użyciem długich włókien, poliuretan.

INTRODUCTION

Natural fiber-reinforced composites have traditionally found applications mainly in the automotive industry, replacing primarily glass fiber-reinforced plastics [1—3]. In addition to the obvious environmental issues, another motivation for natural fiber application is the potential for weight saving, since natural fibers have lower density than glass fibers.

The application of natural fibers gives rise to several challenges, especially with regard to reproducibility of material properties. Further, no limitations in comparison to the currently used synthetic fibers concerning smell, aging or fire behavior are likely to result. To ensure a reproducible quality of a natural product seems to be the ultimate challenge. Here, the fiber preparation and further processing of the natural fibers play a decisive role. For good composite quality, the structure of the fiber bundles and the resulting fiber-matrix adhesion are of special importance. This requires specific solutions, depending on the types of fiber and matrix material used.

Natural fibers are traditionally integrated into fiber composites in the form of mats or other non-woven fabrics [4]. In addition to several other thermoset or thermoplastic matrix systems, especially polyurethanes (PUR) have been reinforced with natural fibers. A classic method for processing non-woven reinforcements is structural reaction injection molding (SRIM). In this method, fiber mats are cut or punched to net shape and further processed into a preform. They are optionally thermoformed and then inlayed into the mold. Comparable to resin transfer molding, the preform is placed in a closed mold with a thermoset polyurethane system. A further possibility for producing fiber-reinforced PUR composites is to spray the reinforcement with the matrix system followed by compression molding. Therefore, various PUR spray coat methods are available.

However, cutting of the semi-finished products as well as preparing and handling the preform represent time and cost intensive process steps. Further, the re-

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maining pieces of mats produce waste, which is harmful from the ecological point of view. For these reasons there is an increasing demand for a cost-effective alternative for the production of reinforced PUR parts. Since products containing long fibers can have properties comparable to a non-woven reinforcement, the long fiber injection (LFI) process was developed by KraussMaffei Technologies GmbH. This highly productive technology is characterized by the direct processing of rovings in a one-step, fully automated process.

Long fiber injection and natural fiber injection process

The LFI process was developed as an economical alternative to SRIM and is characterized by the processing of reactive polyurethane systems in conjunction with long fiber reinforcement [5—7]. It is particularly suited for the production of large lightweight components, especially for carriers or cover panels in interior and exterior of passenger and commercial vehicles [8, 9]. Typical interior applications for example are dashboard carriers, door trim panels, parcel shelves or trunk floors. Exterior components like roof modules are produced in the LFI process using foam-backed thermoplastic films, which eliminates subsequent painting [10].

The operation principle of the LFI process is based on the processing of highly reactive two component polyurethane systems. These are mixed together in a mixing head within a very short time using a high pressure counter-flow injection procedure. The mixing head is presented schematically in Figure 1.

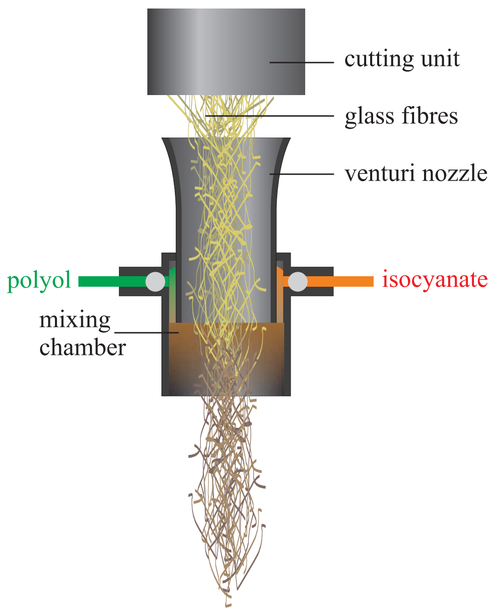

Fig. 1. Scheme of the LFI mixing head

This allows for very low cycle times and thus the production of parts for automobile applications. The reinforcing glass fiber rovings are fed directly from a spool into a cutting unit on the mixing head and then cut to defined lengths. Fiber lengths of 12.5 to 200 mm are theoretically possible, but usually fiber lengths up to maximum 100 mm are used. The chopped fibers are conveyed by means of blowing air through the mixing head to its output, where they are wetted with the output component stream. The spray cone can be influenced by oscillating air, for example to create a wider spray angle or even to align the fibers [11]. During the discharge, the fiber length and fiber mass content can be varied locally and adjusted to the loads of the component.

The fiber-PUR mixture is discharged into an open mold, whose cavity is covered with the material. After the mold is closed, the matrix material cures, whereby it expands to varying degrees, depending on the PUR system used. Due to the spray-up like discharge, the high pressures usually associated with filling the cavity with long fibers are not necessary. Changes in the cross section of the part such as stiffening fins occur during the expansion process of the foaming material. Thereby, expansion pressures usually do not exceed 1 MPa. The moderate process parameters, especially in comparison to compression or injection molding, are advantageous for the integration of functional elements [12, 13].

In comparison to other composite technologies like SRIM, in the LFI procedure processing steps for preparing, thermoforming and handling of textile preforms are eliminated. Consequently, the process time and investment costs of the required installations can be saved. Last but not least, due to the direct processing of rovings, waste of glass can be avoided. Thus, load-adapted lightweight components with high strength and stiffness can be fabricated much more economically and ecologically sustainable then before.

Cover panels manufactured in the LFI process are traditional applications of natural fibers. Early on, especially door trim panels have been reinforced with natural fiber mats [14, 15]. Consequently there is a strong motivation for adapting the LFI technology to the usage of natural fibers. However, since natural fibers cannot be broken such as glass fibers, the cutting technology is a special challenge. The high output rate resulting from the requirements of a serial production with short cycle times is particularly difficult to achieve with natural fibers.

In 2003, KraussMaffei Technologies GmbH presented the natural fiber injection (NFI) process as an evolution of the LFI technology [16]. The cutting system was adapted to the requirements of natural fiber processing, retaining the specific technological advantages of the LFI process. Sisal or sisal hemp-blend fibers were used as reinforcement. Although the method could have proved its functionality, the breakthrough failed to appear. Today, due to an increasing demand for natural fiber applications, the development of appropriate cutting methods for natural fibers is required.

Application of natural fiber-reinforced composites in electric vehicles

As a part of the efforts to reduce the emissions of carbon dioxide, the trend to electrification in the automobile sector is evident. For electric vehicles, lightweight construction is a crucial factor and even more important than in conventionally powered vehicles, due to the currently limited ranges and the heavy weight of batteries. In this purpose and in the context of conservation of resources, the use of natural fiber composites is of particular interest. For this reason, within the framework of the EU-project MATLEV together with the Warsaw University of Technology and SZTK TAPS company, at the Technische Universität Dresden (Institute of Lightweight Engineering and Polymer Technology) novel solutions are in development for the production of high load-bearing lightweight components with improved sustainability for use in electric vehicles. One part of these research activities is the development of the LFI process for the production of natural fiber-reinforced polyurethane composites. This includes extensive manufacturing studies on the application of natural fibers in several forms of reinforcement, such as long fibers or continuous fibers and several specifications concerning linear density, fiber length or fiber preparation. With regard to applications in electric vehicles, adapted material and process parameters are in development to meet the requirements in reproducibility of mechanical properties. For the integration of long fiber reinforcements, suitable cutting methods are being developed.

The variability in terms of fiber mass content and fiber length as well as the resulting specific values in the LFI process are very high, but however, due to long fiber reinforcement, the level of mechanical properties is limited. For highest mechanical loadings, continuous fiber reinforcement is necessary. Therefore, corresponding solutions are developed which enable automated processing of natural fiber textile semi-finished products. This includes appropriate handling systems as well as adapted mold designs for reproducible positioning of the reinforcing layers.

CONCLUSIONS

The motivation for the usage of natural fibers is stronger than ever before. Beyond weight reduction, especially in the automobile industry but also in other industrial fields, there is a high demand on processing of ecologically efficient materials. To further increase natural fiber applications, research is necessary on reproducible qualities in terms of processability and resulting mechanical properties, which both are essential in industrial applications. Beyond improvements in natural fiber processing, corresponding manufacturing technologies have to be developed which enable automated production of fiber composites. Here, the LFI process provides a great potential for the fabrication of long fiber-reinforced composites.

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