Fermentation Residues from Biogas Production Are Turned into Fibers for Composites

# Lightweight Construction with Regional Plant Fiber

Due to the aspect of sustainability, natural fibers are interesting as reinforcements for plastics. To keep their ecological footprint as low as possible, it is advisable to use fibers from regionally grown plants. Therefore, a research project has now investigated the use of silphie fibers from the waste of biogas production.

The "perennial cup plant" is cultivated in Germany for biogas production. The fibers of the plant can be extracted from the resulting fermentation residues and subsequently used for composites. © Christine; AdobeStock

Lightweight construction with fiber-reinforced plastics (FRP) offers a high energy-saving potential in the transportation. Furthermore, the ecological footprint of components made out of FRP can be improved with the use of natural fibers. However, also natural fibers used so far still have potential for optimization. For example, long transport routes for the natural fibers and the explicit cultivation only for the special use case could be avoided. Advantageous for this is the use of regionally grown natural fibers, which ideally are taken from a waste material stream. Such a fiber is the silphie fiber.

Originally from North America, the perennial cup plant Silphium (**Title figure**) can be cultivated in different countries and is increasingly utilized as an energy crop. The plant, which can reach heights up to 3 m, can be grown as a perennial plant and offers a decisive advantage over widespread corn: the long flowering period (July to September) can be a significant contribution to the preservation of existing ecosystems and biodiversity [1].

In relation to cup plants (173 dt/ha dry mass) corn offers more dry mass with 218 dt/ha but also has some disadvantages [2]: corn is an annual plant and has been criticized, among other things, for its over fertilized fields in order to reach high yields [3]. The cup plant on the other hand requires hardly any fertilization [1].

As with other energy crops, a digestate remains when the cup plant is used in biogas plants. Due to its nutrient content, it can be used as fertilizer for agriculture [4]. However, its use as fertilizer poses the problem that the digestate contains a significant amount of nitrogen, which pollutes the groundwater [5]. An alternative use of the digestate is offered by the company OutNature, Neckarsulm, Germany, where the fiber digestion takes place in a steam explosion plant. Currently the fibers obtained in this way are used as an alternative in paper production [6]. Due to the chemical composition and dry mass content of cellulose [7], the silphie fiber is similar to the kenaf fiber [8].

## *Compounding the Silphie Fiber with PLA and Bio-PE*

At the Institut für Kunststofftechnik (IKT) of the University of Stuttgart, Germany, the use of silphie fibers for FRP was investigated. To prepare and break up the fiber lumps, the silphie fibers were first homogenized. For this purpose an SM1 mill from Retsch GmbH, Haan, Germany, with a square screen insert with an edge length of 4 mm was used. Various fiber volume fractions were realized to identify the material which is suitable for the application and to investigate the fiber influence. The selected matrices were bio-based polyethylene (Bio-PE) and polylactide (PLA). Both materials were provided by the company Tecnaro GmbH, Ilsfeld, Germany. Bio-PE was chosen due to its bio-based origin and the experience already gained regarding the recyclability and PLA was chosen due to its bio-based and biodegradable property.

For the compounding process a co-rotating twin-screw extruder ZSK 26 K 10.6 from Coperion, Stuttgart, Germany, was used for compounding (screw concept in **Fig. 1**). The addition of the dry blend, consisting of plastic granules and silphie fibers, were added in zone 1 with a feeder also from Coperion. After the exit of the strand in zone 11 (single-hole die with a diameter of 10 mm), the melt was first cooled by using air convectors and afterwards within a water bath. The subsequent pelletizing was carried out with a pelletizer SGS 50E from Reduction Engineering GmbH, Korntal-Münchingen, Germany. The eleven processing zones of the twin-screw extruder were heated according to **Table 1**. The feeding zone, respectively zone 1, was not actively heated.

For Bio-PE the final fiber volume fraction of various compounding trials were between 5 and 10 vol.%. Higher fiber volume fractions in combination with Bio-PE could not be realized due to the tearing of the melt strand. However, additional variants with fiber volume fractions of 5 %, 10 %, 15 % and 20 % could be produced with PLA. In order to reduce the moisture content after the cooling process in the water bath, the FRP with fiber volume fractions of less than 10 % were dried in a vacuum furnace (type: VDL E2, manufacturer: Binder, Tuttlingen, Germany) for about 12 h. The drying was performed at 60 °C for PLA and 80 °C for Bio-PE. FRP with fiber volume fractions above 10 % were dried in a silo dryer (type: DR 205 HAT; manufacturer: Bierther, Bad Kreuznach, Germany) for at least 15 h.

## *Characterization of the Cup Plant FRP*

To determine the mechanical characteristics standard test specimens for tensile tests were produced according to »

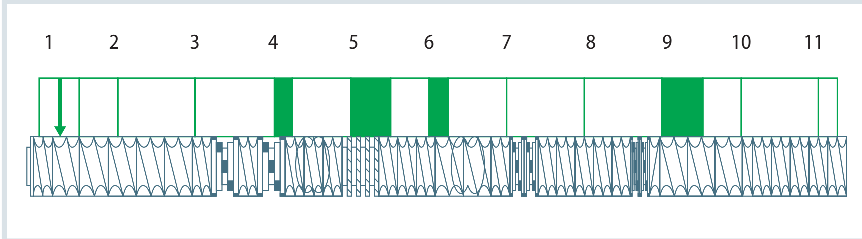


**Fig. 1.** Screw concept for material processing: the different zones were heated differently for PE and PLA. Source: IKT; graphic: © Hanser

| Zone | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bio-PE | – | 120 °C | 150 °C | 190 °C | | | | | | | |
| PLA | – | 100 °C | 130 °C | 170 °C | | | | 175 °C | 180 °C | | |

**Table 1.** Temperature profiles for the two matrix materials during the compounding process. Source: IKT

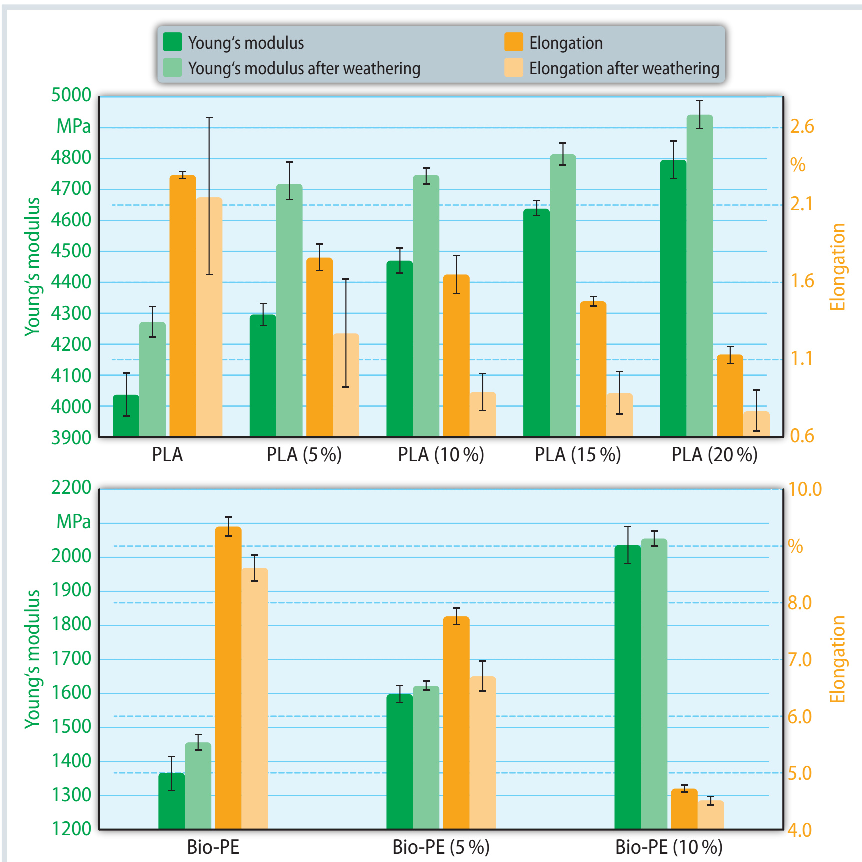


**Fig. 2.** Results of the tensile tests at a standard climate and after weathering: by adding the silphie fibers (volume content in parentheses) the stiffness of both PLA and Bio-PE increases and the elongation decreases. Source: IKT; graphic: © Hanser

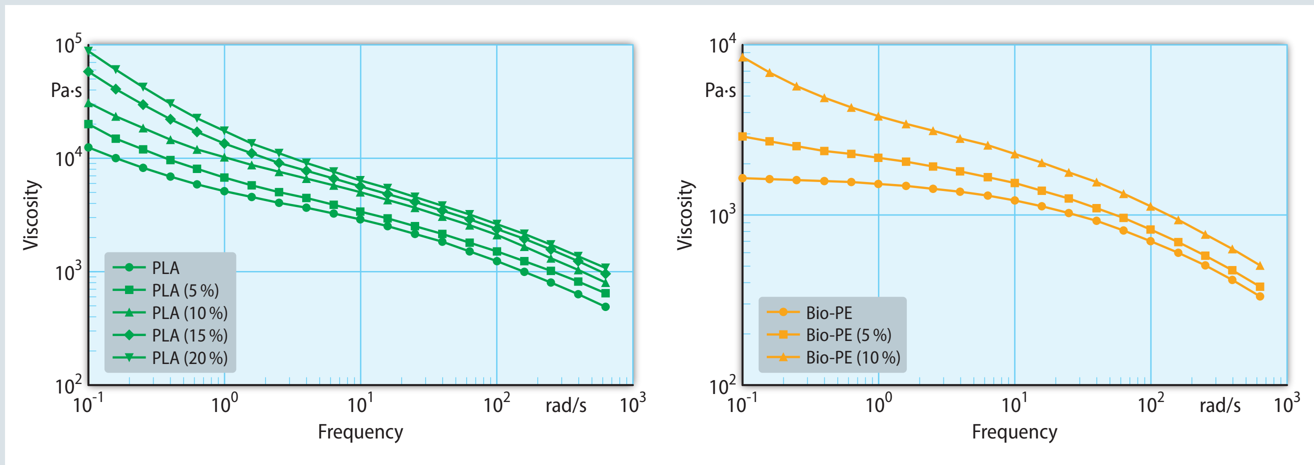


**Fig. 3.** Viscosity of PLA and Bio-PE in frequency ranges relevant for processing: the viscosity of both materials is increased by adding silphie fibers. Source: IKT; graphic: © Hanser

| | PLA | PLA (5 %) | PLA (10 %) | PLA (15 %) | PLA (20 %) | Bio-PE | Bio-PE (5 %) | Bio-PE (10 %) |
|---|---|---|---|---|---|---|---|---|
| Density [g/cm$^3$] | 1.29 | 1.34 | 1.34 | 1.19 | 1.17 | 1.03 | 1.04 | 1.08 |

**Table 2.** Measurement results of the density determination for the reinforced PLA and Bio-PE according to DIN EN ISO 1183–1 method A (volume content of the silphie fibers in parentheses). Source: IKT

## Info

### Text

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### References & Digital Version

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DIN EN ISO 527-4, type 1B, on an Allrounder 370 S 700-10/70 injection molding machine from Arburg, Lossburg, Germany. The settings of the processing parameters were based on both empirical values and the material data sheets. The temperatures in the heating zones were set at 160 to 195 °C, the mold temperature was set to 40 °C. For basic characterization, the mechanical values were determined in a tensile test on a universal testing machine 1455 (E 2918-02E) from ZwickRoell, Ulm, Germany. As expected, the stiffness increased and elongation decreased with the addition of the fibers for both matrix materials (**Fig. 2**). This behavior was also observed in the weathering tests carried out according to DIN 75220. For these tests, the injection molded standard specimens were stored for 240 h in a climatic test chamber beneath a UV lamp with a radiation intensity of 1000 W/m$^2$, a relative humidity of 60 % and a temperature of 42 °C. For this purpose a climatic chamber type SolarClimatic Test Cabinet SC 1000 MHG from the company Weiss Technik, Reiskirchen, Germany, was used.

Further material characterizations, such as differential scanning calorimetry (DSC) using the DSC 204 from Erich Netzsch GmbH & Co. KG, Selb, Germany, revealed the temperatures relevant for processing. According to the results, the melting temperature range of the Bio-PE remained almost constant by adding the cup plant fibers. The peak temperature was at 136 °C. The PLA-FRP showed similar behavior and the double peak temperatures were also unchanged at 175 °C and 179 °C, respectively. DSC also showed that for all the FRPs produced, the melt enthalpies also remained constant after adding the silphie fiber.

## *Strikingly Small Increase in Density*

However, as expected the addition of fibers caused an increase in viscosity (**Fig. 3**). For the viscosity measurements a Discovery HR2 type rotary rheometer with parallel plate configuration from TA Instruments, New Castle, DE/USA, was used. For better comparison, all compounds were measured at 180 °C. Additionally, the densities of the newly compounded materials were determined with the Archimedes method. For this purpose, the materials were pressed into sheets and then cubes with an edge length of about 10 mm were sawn out. As expected, it is noticeable that the density slightly increases with a higher filling degree. However, PLA with 15 and 20 % silphie fibers shows an unexpected decrease in density (**Table 2**). A possible cause for this could be larger air inclusions inside of the sawn-out cubes and thus measurement inaccuracies.

### Conclusion and Outlook

The study shows that the silphie fibers can be incorporated into a thermoplastic polymer matrix without further additives and within suitable processing parameters. Studies with kenaf fibers were used as a comparison for the reinforcing effect [9]. For these, the increase in Young's modulus from the unfilled to the kenaf fiber compound filled with 10 % mass fractions is about 1.7 %. PLA compounds with 10 % silphie fibers have a higher Young's modulus of about 10.7 % compared to unfilled PLA. For Bio-PE, studies of PE filled with 10 % flax can be used for comparison [10]. The flax compounds achieve an increase in Young's modulus of 40 %, while Bio-PE reinforced with 10 % silphie fibers achieves an increase of 49 %.

Nevertheless, how the silphie fibers prove themselves in the future will be further investigated using a lightweight construction product within a two-year research project at the IKT. This project is being funded by the Baden-Württemberg Ministry for Food, Rural Areas and Consumer Protection within the framework of the R&D funding program "Sustainable bioeconomy as innovation engine for rural areas". As a technology demonstrator a transport box of an electric cargo bike was selected. Previous materials, such as aluminum or resin-impregnated wood should be replaced by the newly developed silphie fiber-reinforced lightweight material. IKT is working together in the project consortium with the project partner, the Gemeinnützige Werkstätten und Wohnstätten GmbH (GWW), the owner of the cargo bike brand XCYC (**Fig. 4**). In the research process also extensive and comprehensive testing of the material and the development of a sustainable design will take place. Nevertheless, the aim of this project is to improve the properties of the individual material components such as the silphie fibers. The project is accompanied by the preparation of a life cycle assessment by the Institut für Gebäudeenergetik, Thermotechnik und Energiespeicherung of the University of Stuttgart (IGTE). In the future, the results of the study and the two-year innovation project phase will be applied to other areas such as the automotive sector and the packaging industry. ■

**Fig. 4.** The use of silphie fibers is applied to transport boxes for cargo bikes of the XCYC brand. © GWW

**Polyolefin Elastomers with Lower Carbon Footprint**

## Walking on Bioplastics

Plastic manufacturer Dow has announced the launch of more sustainable polyolefin elastomers. The new brand, called Engage Ren, will help the footwear industry to unlock a lower carbon footprint and develop more sustainable products which offer the same high-performance results. According to the company, the key benefits that the new polyolefin elastomers will offer manufacturers in the footwear industry are improved foam quality and polymer consistency, a better resilience, lighter foams with equivalent hardness and improved abrasion resistance and durability.

Engage Ren polyolefin elastomers are produced using renewable energy and plant-based feedstocks such as used cooking oil. As only waste residues or by-products from an alternative production process are utilized, these raw feedstock materials do not consume extra land resources nor compete with the food chain. The plant-based polymers deliver equivalent performance in the final application as fossil-fuel counterparts and therefore do not require reformulation.

"Manufacturers, brands, retailers and consumers all recognize the role they play in reducing the impact of climate change and as a result, are seeking out more sustainable options," said Imran Munshi, Global Bio-Polymers and Consumer Market Manager at Dow.

Crocs is the first footwear brand to go-to-market with this new material technology. © Dow

Crocs is the first footwear brand to go-to-market with this new material technology. Dow has begun supplying plant-based polymers for use in Crocs' manufacturing process of its proprietary Croslite material, which have an even lower $CO_2$ impact than their current material. The company will take a mass balance approach to scaling the percentage of plant-based polymers into its footwear over time.

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