Coffee Infusion for Plastic Compounds

Bioplastics with Coffee Grounds as a Bio-Based Filler

Coffee grounds are much more than just a waste product. After oil extraction and drying, it can be incorporated into plastic compounds as a filler and coloring agent. It also affects the crystallization behavior and influences the continuative plastics processing. In injection molding, this allows cooling and cycle times to be reduced without significantly affecting the material performance.

Bioplastics are mainly used as a sustainable alternative to conventional plastics. However, the additives often come from fossil sources, which contradicts sustainability requirements. That is why intensive research is being carried out on bio-based additives. One possibility is coffee grounds, for example, which can be used both as a filler and as a coloring agent for bioplastics. The material fulfills the sustainability requirement in two ways: it is bio-based and, as a waste product, it also complies with the cycle concept.

How the material can be used as a filler was examined at the IfBB – Institute for Bioplastics and Biocomposites at the University of Applied Sciences and Arts in Hanover, Germany. The biopolymer used was a stereo complex polylactide (PLA; type: IfBB-Blend HD130x) from the University of Applied Sciences and Arts in Hanover based on PLLA (poly-L-lactide) and PDLA (poly-D-lactide) as well as talc as a mineral filler. This material is already used in the office area and was further modified with coffee grounds for the examinations. Additivating PLLA with PDLA as a nucleating agent and combining it with an increased mold temperature of 100 °C results in what are known as so-called stereo complexes (scPLA) in the injection molding process, which in turn determine the crystallization behavior of the material and favor the material properties, in particular the heat deflection temperature. [1]

The coffee grounds compounds can be used for computer accessories such as a housing of a computer mouse © IfBB

Different Concentrations of Coffee Grounds

In order to analyze the influence of the coffee grounds, these were first added in various concentrations of 5 to 15 wt. %. In addition, a compound with 5 wt. % of coffee grounds and 5 wt. % of talc was produced. This was done to check whether the mineral filler is still necessary as a nucleating agent. The coffee grounds used (particle size: d_{50}-value = 362 µm) were obtained from the company abc – advanced biomass concepts GmbH, Cologne, Germany.

The coffee grounds compounds were produced on an extruder ZE 34 Basic from KraussMaffei Extrusion GmbH. The biopolymer matrix is fed into the melting zone at the beginning of the extruder. The coffee grounds (5.4 wt. % moisture) are metered using a side feeder. Adapted screw configurations allow gentle incorporation without damaging the PLLA and the residual material. A special extruder setup with degassing zones allows moisture to be removed from the process, eliminating the need for pre-drying.

An injection molding machine KM 50–180 AX from KraussMaffei with a mold temperature of 100 °C was used to produce the multi-purpose test specimens (type 1A). In order to prevent material degradation due to hydrolysis, the granulates were dried before processing (moisture content < 500 ppm) [2]. Temperature zones, holding pressure as well as injection time and injection pressure were specifically adapted in order to produce an optimally filled component. Following processing, the mechanical, thermal and rheological material properties were determined according on the relevant standards. The fact that the coffee grounds compounds produced can be used for example for catering supplies, computer accessories and the office area is exemplified by two products made from them at the IfBB: a bottle opener and the housing of a computer mouse (**Title figure**).

Shorter Cycle Times by Combining Coffee Grounds and Talc

The coffee grounds compounds were extruded without any process problems with a throughput of 50 kg/h. In the case of injection molding, it was found that the cycle times increase by up to 28 s with increasing coffee grounds content (5 – 15 wt. %) (**Table 1**). The cooling time had to be extended in order to avoid imprints of the ejectors due to the poor form stability. The addition of the mineral filler has a positive effect on the compound's ability to crystallize. The cycle time can be reduced by a further 9 s compared to the reference.

With increasing coffee grounds content, there is a reduction in tensile strength, tensile modulus of elasticity and impact strength. As with the addition of natural fibers or wood flour, the tensile strength and impact strength decrease depending on the dosing quantity [2]. Compared to the reference (scPLA + 10 wt. % talc), the coffee grounds have no reinforcing effect up to a filler content of 15 wt. %. Thus, there is no significant difference in the mechanical properties as a function of the dosing quantity. The heat resistance is above 100 °C for all materials.

The use of talc in the coffee grounds compound increases the tensile modulus of elasticity compared to the compound with 5 wt. % of coffee grounds. This makes the material stiffer, but not more brittle. Addition of talc has no significant influence on tensile strength and impact strength [3].

Changed Crystallization Behavior

Differential thermal analyses (DSC tests) were carried out in order to analyze the crystallization behavior more precisely, especially with regard to insufficient demolding during injection molding due to the low form stability of some compounds. The DSC cooling curves show that as the proportion of coffee grounds increases, there is a broadening and shifting of the crystallization peak towards »

Material	Cycle time [s]	Tensile strength [MPa]	Tensile modulus of elasticity [MPa]	Impact strength [kJ/m²]	Heat resistance [°C]
	DIN EN ISO 20753/type 1A	DIN EN ISO 527-2/1A/5	DIN EN ISO 527-2/1A/5	DIN EN ISO 179/1eU/23 °C	DIN EN ISO 75/procedure B/120 K/h
scPLA + 10 wt. % talc (reference)	74	39 (±2.4)	4440 (±18)	27 (±2.1)	130 (±9.2)
scPLA + 5 wt. % coffee grounds	92	37 (±0.2)	3390 (±30)	8 (±2.5)	128 (±6.5)*
scPLA + 10 wt. % coffee grounds	102	30 (±0.2)	3420 (±28)	7 (±1.4)	126 (±10.0)*
scPLA + 15 wt. % coffee grounds	102	30 (±0.3)	3440 (±25)	6 (±1.1)	110 (±20.0)*
scPLA + 5 wt. % talc + 5 wt. % coffee grounds	65	36 (±0.1)	3850 (±10)	9 (±1.3)	128 (±4.5)*

*Due to non-norm conforming standard deviation these values can only be considered as guide values.

Table 1. Material properties of the coffee grounds compounds (mold temperature during injection molding 100 °C) Source: IfBB

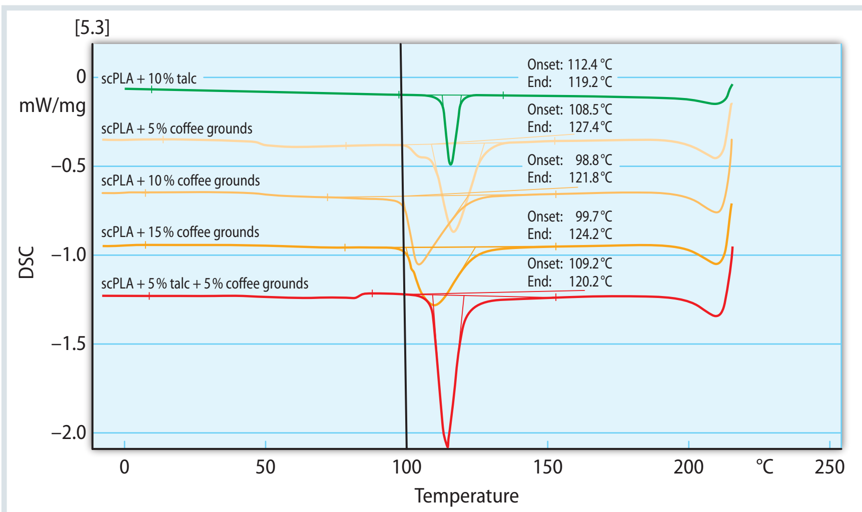

Fig. 1. As the proportion of coffee grounds increases, the crystallization peak is broadened and shifted towards lower temperatures Source: IfBB; graphic: © Hanser

Material	Mold temperature [°C]	Cycle time [s]	Tensile strength [MPa]	Tensile modulus of elasticity [MPa]	Impact strength [kJ/m²]
		DIN EN ISO 20753/type 1A	DIN EN ISO 527-2/1A/5	DIN EN ISO 527-2/1A/5	DIN EN ISO 179/1eU/23 °C
scPLA + 10 wt. % coffee grounds	100	102	30 (±0.3)	3420 (±28)	6 (±1.4)
scPLA + 10 wt. % coffee grounds	90	95	26 (±2.0)	3290 (±22)	5 (±1.2)
scPLA + 15 wt. % coffee grounds	100	102	30 (±0.3)	3440 (±25)	6 (±1.1)
scPLA + 15 wt. % coffee grounds	90	89	26 (±0.4)	3290 (±16)	5 (±0.5)

Table 2. The mechanical properties of the components produced by injection molding differ using different mold temperatures Source: IfBB

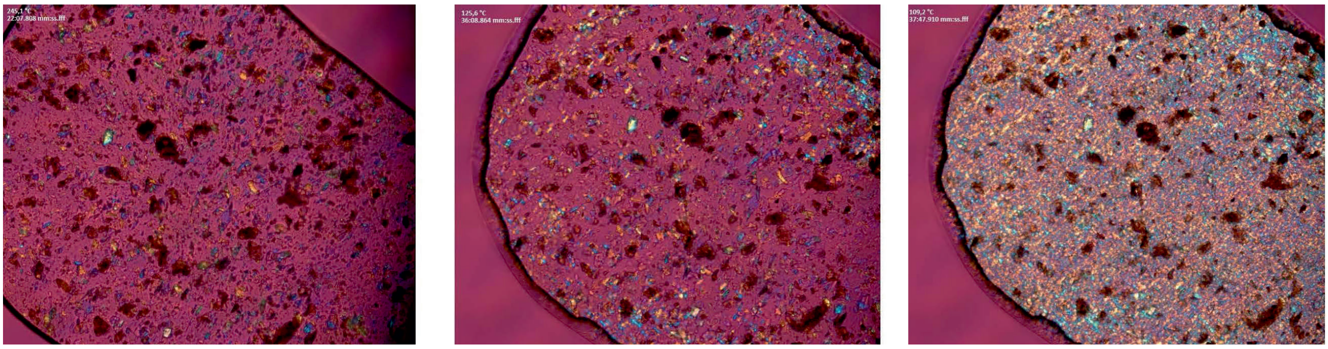

Fig. 2. Hot-stage microscope images for a sample made from scPLA with 5 wt.% of talc and coffee grounds each: the melted state of the sample at 245 °C can be seen on the left. The picture at the middle shows the crystal formation in the edge area at 126 °C. Crystallization is completed at 110 °C (right) © IfBB

lower temperatures (**Fig. 1**). The end of the crystallization of the samples with 10 or rather 15 wt.% of coffee grounds was below the set mold temperature of 100 °C. This suggests that crystallization has not been completed during the injection molding process. Since the crystallization peak shifts towards lower temperatures at higher cooling rates, long cycle times arise. [4]

In order to be able to assess the crystallization behavior more precisely, images were taken under polarized light using a hot stage microscope. The sample was heated above the melting point (175 °C for PLLA; 245 °C for scPLA) and cooled down in a defined manner (10 K/min). The beginning and formation of the crystals during cooling were recorded and evaluated microscopically.

Optimization of the Mold Temperature

The crystallization behavior of the sample added with coffee and talc (scPLA + 5 wt.% talc + 5 wt.% coffee grounds) is shown in **Figure 2**. The polymer portion is completely melted at 245 °C. The pink areas show the liquid, crystal-free state of the compound. The homogeneously distributed coffee particles and the glowing crystalline structures of the talk can be seen. During the cooling process, the first crystals arise in the edge area of the sample at 130 °C. Small spherulites form with decreasing temperature, similar to injection molded components, from the outside to the inside and on the coffee particles. The crystallization is already fully completed between 109 and 110 °C and is therefore 9 °C above the set mold temperature. This result coincides with the result obtained from the DSC cooling curve (**Fig. 1**). The addition of talc leads to an increase in the crystallization temperature (Tc) and thus to nucleation and a shortening of the crystallization period of the coffee grounds compound.

Based on the results, the compounds with 10 and 15 wt.% of coffee grounds were processed and analyzed again at a lower mold temperature of 90 °C. The results show that the cycle time can be reduced by 7 to 12 % by adjusting the mold temperature (**Table 2**). Due to a lower mold temperature the increased crystal formation leads to sufficient form stability and thus to better demolding. This assumption was confirmed by further DSC measurements at the component. As the degree of crystallization increases, the tensile strength decreases by approx. 13 %, the tensile modulus of elasticity by approx. 3 % and also the impact strength.

Conclusion

The industrial processing of the coffee grounds compounds can be realized without any process problems. By adapting and adjusting the peripheries, time and thus costs can be saved. The material properties change due to the addition of coffee grounds, similar to the use of natural fibers or wood flour. Tensile strength, impact strength and also the flowability decrease with increasing coffee grounds content. Especially the combination of coffee grounds and the mineral filler talc is promising. Both material properties and processing parameters such as cooling and cycle times are improved by shortening the crystallization period. ■

The Authors

B. Eng. Daniela Jahn is scientific assistant at the IfBB – Institute for Bioplastics and Biocomposites at the University of Applied Sciences and Arts in Hanover, Germany, where she works in material development and thermal analysis;
daniela.jahn@hs-hannover.de

Dr. Stephen Kroll is senior engineer at IfBB and heads the team sustainability;
stephen.kroll@hs-hannover.de

Prof. Andrea Siebert-Raths is professor for products and processing of renewable raw materials and head of the IfBB;
andrea.siebert-raths@hs-hannover.de

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