# IMPACT PERFORMANCE IN PP WITH PVA FIBER REINFORCEMENT

Claudia Pretschuh[1], Lukas Sobczak[2], Dietmar Salaberger[3], Michael Jerabek[2] and Thomas Lummerstorfer[2]

[1] Division Wood-Polymer-Composites, Competence Centre for Wood Composites and Wood Chemistry (Wood K plus), Altenberger Strasse 69, Linz, Austria
Email: c.pretschuh@kplus-wood.at, Web Page: www.wood-kplus.at

[2]Borealis Polyolefine GmbH, St. Peter Strasse 25, Linz, Austria
Email: thomas.lummerstorfer@borealisgroup.com

[3]University of Applied Sciences Upper Austria, Stelzhamerstrasse 23, Wels, Austria
Email: dietmar.salaberger@fh-wels.at

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**Abstract**
Polymer fibers are an interesting alternative to improve stiffness, strength and impact performance of polypropylene (PP). In addition, owing to the low density of polymer fibers compared to inorganic fillers like talc or glass fibers, they will contribute to weight saving.
Effects of the reinforcement with polyvinyl alcohol (PVA) fibers on the tensile properties and on impact properties have been determined.
Further the effect of coupling on the fiber-pull out behavior was presented by 3-dimensional CT (computed tomography) scanning of fracture surfaces from impact testing. For a PP homopolymer, both notched impact strength and unnotched impact strength increased dramatically with the PVA fiber content to 52 kJ per m² and to 140 kJ per m², respectively. The use of a coupling agent significantly reduced the impact performance at both +23°C, and at -20°C due to reduced fiber pull-out.

## 1. Introduction

Filled polypropylene composites are industrially used for a broad range of applications. To achieve a well-balanced mechanical property profile with a good stiffness-impact ratio, mainly heterophasic PP copolymers (HECOs) in combination with inorganic fillers like calcium carbonate, talc or clay are used. To further expand the mechanical property profile of PP-based compounds fibrous high performance fillers, such as glass fibers (GF) or carbon fibers (CF) are typically used. Among these fillers, polymer fibers such as polyethylene terephthalate or polyvinyl alcohol (PVA), which are rather exotic in the world of reinforced polymers, are an interesting alternative.

Nowadays, the impact performance of polypropylene can be improved by addition of external elastomers; unfortunately, this leads to a significant reduction of stiffness and strength at the same time. Besides, impact performance decreases significantly below the glass transition temperature of the polymer matrix [1]. In contrast, reinforcement and impact modification with polymeric fibers have more promising characteristics: low density compared to GF, flexibility of the fibers allows higher residual fiber length values in finished parts [2].

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In the present study, the reinforcement of PP with PVA fibers was evaluated and the effect of the volumetric fiber content on composite mechanical properties is discussed for PP homopolymer and for PP HECO.

## 2. Materials and Methods

Two PP grades from Borealis were used, HJ325MO is a high flowability homopolymer intended for injection molding and EE050AE is a high impact heterophasic copolymer (HECO) with an ethylene-propylene rubber content of 30 wt%. As coupling agent (CA), the maleic anhydride grafted PP homopolymer (MA-PP) Scona TPPP 8112 FA by BYK Altana was used (2.0 wt%). This CA has a MA graft level of 1.5 wt% (as stated in the datasheet), and is supplied in powder form.
As reinforcement, a PVA fiber type with the trade name “Mewlon 2000 dtex-750F HM1” by the Japanese producer Unitika was used. Their raw density is 1.3 g/cm$^3$. It was supplied as a 4.0 mm cut roving, and was easily suitable at a standard gravimetric feeding equipment.

A parallel, co-rotating twin screw extruder Brabender DSE20 was used for compounding. The PVA fibers were fed through a twin screw side feeder. All compounds were produced with a total throughput rate of 8 kg/h, at a revolution speed of 375 rpm. The actual melt temperature, measured at the screw tip, was 190°C. A water-bath and a strand pelletizer Primo 50 by Rieter were used to granulate the melt.

Specimens of ISO 527-2 1A specified dimensions were prepared on a Battenfeld HM 1300/350 injection molding (IM) machine. The density of the specimens was determined by a buoyancy method, employing a *Sartorius* analytical scale, and following ISO 1183-1. Tensile properties were determined according to ISO 527; tensile strength at a loading rate of 5 mm/min. Charpy impact strength, both notched (1eA) and unnotched (1eU), was tested according to ISO 179; the heat deflection temperature according to ISO 75, in mode A (HDT-A).

For tensile volume strain (VOLS) measurements, the longitudinal force, the full-field strain on the front surface (x and y direction) and also the side surface of the specimen (x and z direction) were measured by means of digital image correlation (DIC) with two cameras. Further details to the DIC test method and data reduction including the evaluation of true stresses and strains are given elsewhere [3].

Residual fiber length was determined from injection molded specimens after PP extraction with boiling xylene, employing a Soxhlet apparatus. The fibers retrieved were then measured with a FASEP Eco Ed. 2013 system, containing a 9000F high resolution scanner by Canon.

## 3. Results and Discussion

### 3.1. Analysis of the Residual Fiber Geometry

The residual fiber length as length-weighted mean value is 2200 – 2500 µm at a content of 20 wt% (which equals to 14.6 v%). These are very high values compared to standard residual fiber length of carbon fiber composites or glass fiber composites [2].
The microsection of an injection molded PP-PVA specimen shows oval cross-sections of the fibers; the dimensions were 23 µm for the long axis and 14 µm for the short axis.

### 3.2. Tensile Properties

Fig. 1 shows that PP-PVA composites follow general expectations as to the effects of fiber reinforcement. For both matrices, there is an almost linear increase of tensile modulus (Tmod) with the

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fiber content. The effect of the coupling agent is almost negligible at low fiber contents. Tensile strength (Tstr) also increases almost linearly with fiber content, but flattens out above 15 v%. Tstr benefits significantly from increasing the fiber matrix adhesion with a coupling agent.

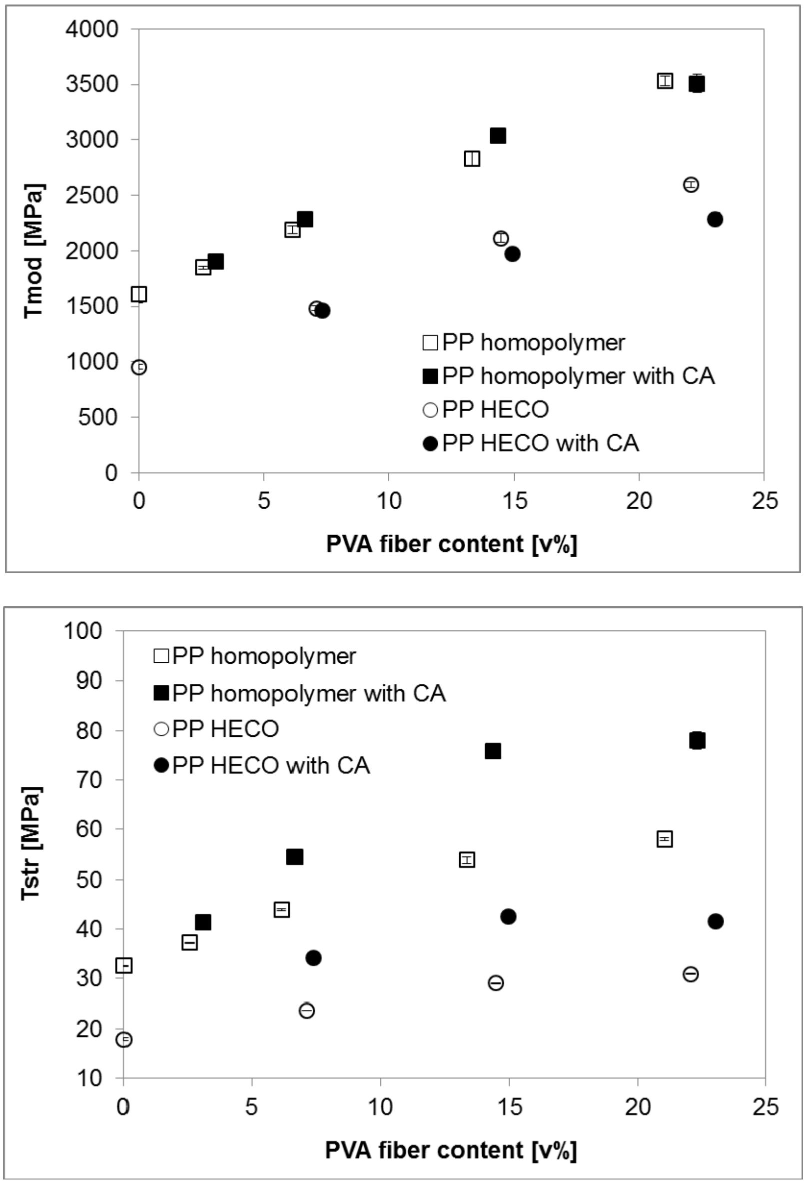


**Figure 1.** Tensile properties of PP-PVA composites as a function of the formulation.

### 3.3. Impact Properties

For the PP homopolymer, the impact strength of the PP-PVA composite was increasing dramatically with high PVA fiber content, as shown in Fig. 2. An improvement of notched impact strength was also detected at -20°C.
The coupling agent significantly reduces the impact performance, especially at higher fiber content. Probably, this is because improved fiber-matrix interaction goes along with a partial suppression of fiber pull-out. Fiber pull-out allows considerable energy dissipation during crack propagation [4; 5].

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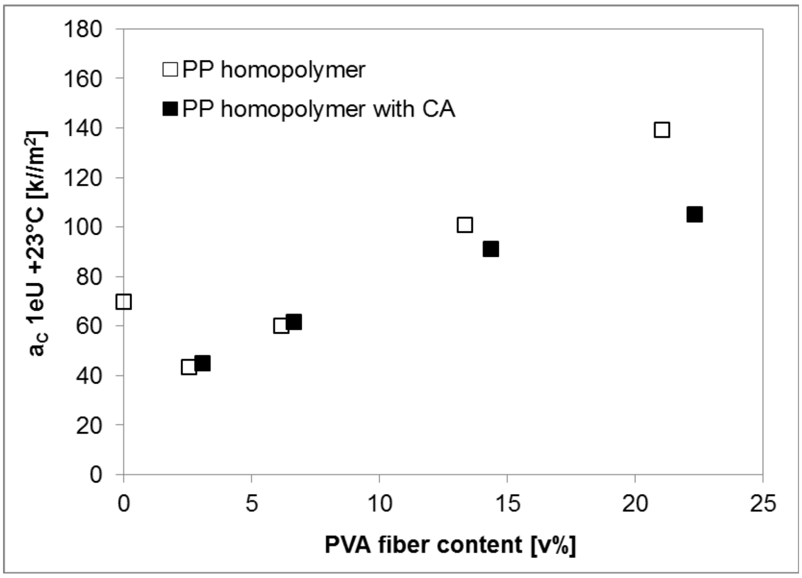
For the PP HECO, the impact strength at 23°C was not improved with the PVA content (data is not shown here).



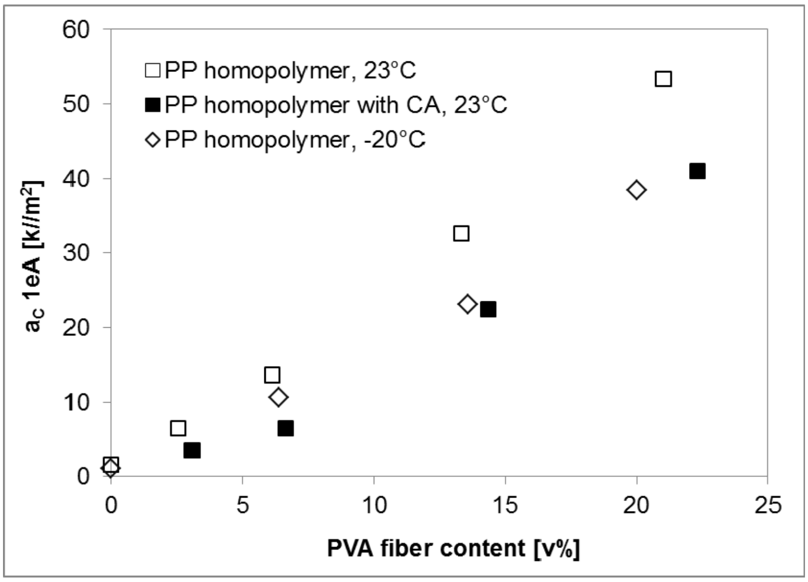




**Figure 2.** Impact properties of PP homopolymer - PVA composites as a function of the formulation. Unnotched impact strength ($a_C$ 1eU) and notched impact strength ($a_C$ 1eA, at 23°C and at -20°C).

### 3.4. Detection of Fiber Pull-out

The effect of coupling on the fiber-pull out behavior is presented by 3-dimensional CT (computed tomography) scanning of fracture surfaces from impact testing, as shown in Fig. 3. Generally, in the absence of the CA, more and longer pulled out fiber ends are visible compared to the coupled composite.

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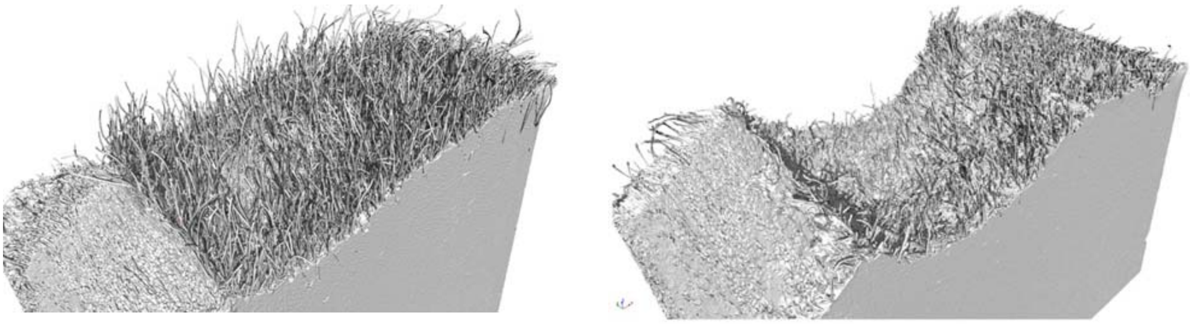

**Figure 3.** CT images of notched impact fracture surfaces of PP homopolymer based composites with 15 v% of PVA fibers; left without CA and on the right with CA.

Further information is supplied by the VOLS measurements presented in Fig. 3. The composites without CA show a larger volume increase during the deformation due to the volume increase caused by fiber pull out.

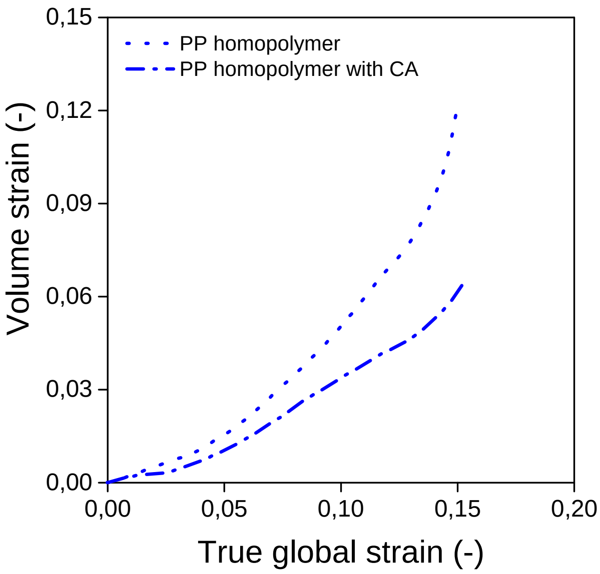


**Figure 4.** Volume strain traces of PVA fiber reinforced PP homopolymer. PVA content: 20 v%.

## 3. Conclusions

PVA fibers are acting as very efficient impact modifier for PP homopolymers. Very high notched impact strength values can be obtained, even at -20°C. Especially at high fiber contents, a coupling agent is counterproductive for the improvement of the impact strength because of reduced fiber pull out. This has been proved by CT scanning and VOLS measurements. Not only the impact strength can be improved, but also the tensile properties; modulus and strength increased for PP homopolymer and also for PP HECO by reinforcement with PVA fibers. Moreover, the heat deflection performance is 10°C higher for both polymers at 20v% PVA fiber content (data is not shown).

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