The mechanical short-term and long-term properties of PP recyclate blends

J. Hinczica[1], J. Geier[1], U. Kirschnick[2], C. Holzer[3], A. Frank[1], G. Pinter[4]

[1] Polymer Competence Center Leoben GmbH (PCCL), Roseggerstraße 12, 8700 Leoben, Austria – jessica.hinczica@pccl.at
[2] Montanuniversität Leoben, Chair of Processing of Composites, Otto Glöckel-Straße 2, 8700 Leoben, Austria
[3] Montanuniversität Leoben, Chair of Polymer Processing, Otto Glöckel-Straße 2, 8700 Leoben, Austria
[4] Montanuniversität Leoben, Chair of Material Science and Testing of Polymers, Otto Glöckel-Straße 2, 8700 Leoben, Austria

INTRODUCTION AND MOTIVATION

- Beside polyethylene, with a market share of **20 % polypropylene** (PP) is the **most common** polymer in Europe [1].
- In 2018 the overall collected **post-consumer waste** in Europe was about **29.1 Mio** tonnes [2]. After sorting, 32 % of the post-consumer waste is sent to recycler.
- **Only 13 %** of the whole collected post-consumer waste is used in **new products,** [2] with the highest amount of **46 %** in the field of **building & construction** [1].
- By **adding virgin material**, the mechanical properties of recyclates can be **improved significantly** and a **higher amount of recyclates** can be processed into **new products** [3].
- **Rheological** and **mechanical** properties are **decisive** for determining **usability** of the material in the manufacturing process and the field of application [4].
- For **long-term performance** the crack resistance is a **critical property** as it describes the resilience of the material against initiation and growth of quasi-brittle cracks at application relevant loading conditions.
- The **aim** of the presented study is to **evaluate** changes in mechanical and long-term **properties** of a **virgin material** (vPP) by adding **post-consumer recyclate** (rPP), as well as determining which **basic characterization method** is **sensitive** to changes in material properties.

SCIENTIFIC APPROACH AND RESULTS

- **Two blends** with different virgin (vPP) and recyclate (rPP) weight fractions rPP-10 & rPP-40 were **compounded** with a double screw extruder and granulated.
- Of each material and blend, injection moulded multipurpose specimens for tensile tests and Charpy impact tests were produced as well as compression moulded sheets for the CRB-test.

materials in wt%	vPP	rPP-10	rPP-40	rPP
virgin	100	90	60	0
recyclate	0	10	40	100

Table 1: Weight fraction of the different blends.

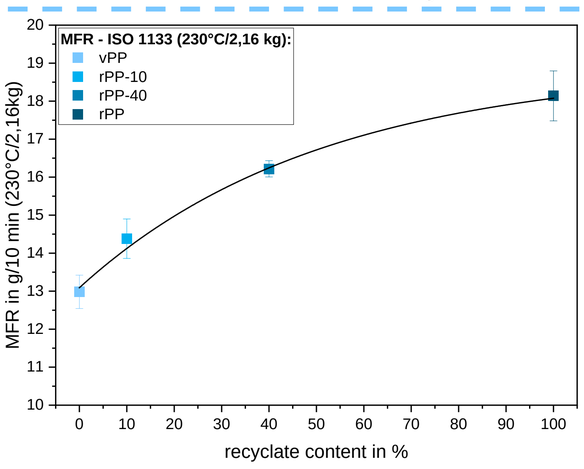

Fig. 1: Melt flow rate (MFR) to determine the rheological properties → useful for processing.

- The melt flow rate (MFR) provides information about the rheological properties, which are important for processing.
- The MFR **increases** almost 40 % from vPP to rPP.
- A **higher MFR** corresponds to **lower viscosity** and average **molecular weight**.
- Materials with a **low MFR** are used in **extrusion** process, and with **high MFR** value in **injection molding**.

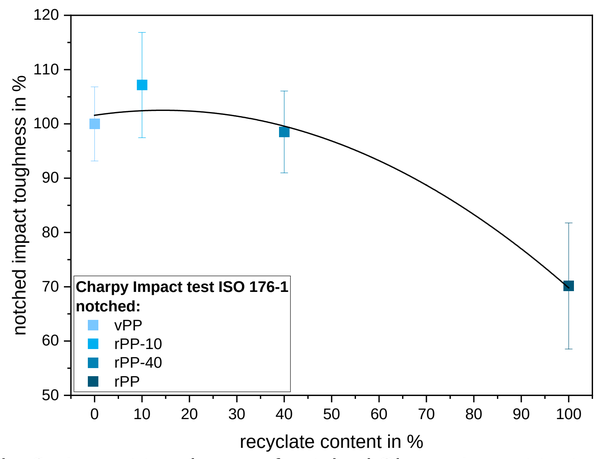

Fig. 3: Impact toughness of notched Charpy Impact tests to determine the sensitivity to notches.

- **No significant** changes of the notched impact toughness **until** a recyclate content of **40 %.**
- This method is **not suitable** to **detect difference** in mechanical properties of the materials.
- Due to the introduced notch, **location of failure** is **predefined**, the specimen **does not fail** at the **weakest point**.
- This **reduces** the **influence** of **inorganic impurities**.

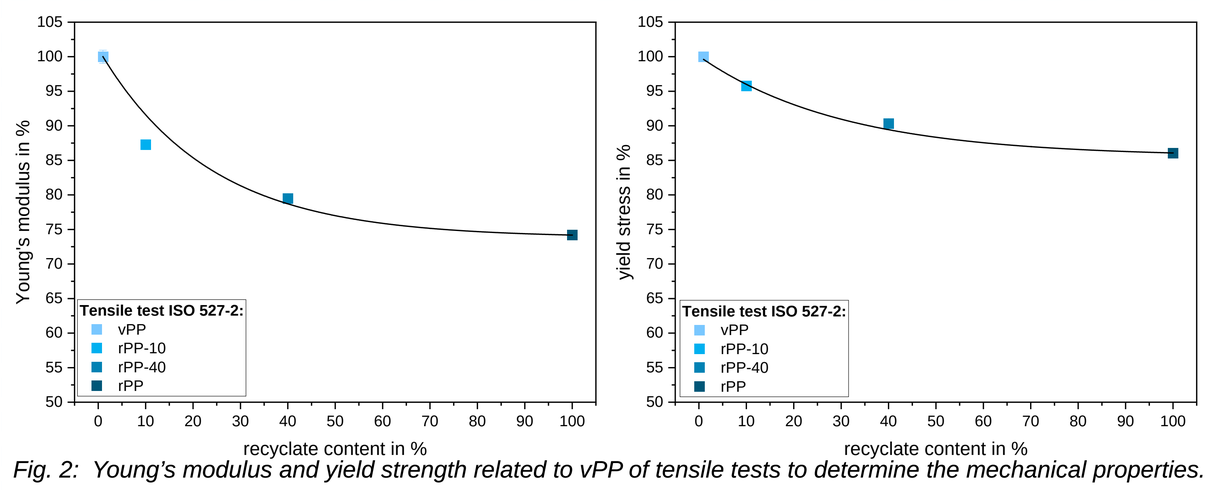

Fig. 2: Young's modulus and yield strength related to vPP of tensile tests to determine the mechanical properties.

- For determining the mechanical properties **tensile tests** are one of the most important method.
- **Young's modulus** and **yield stress decrease** with **increasing** recyclate content.
- **Contaminations** with particles and their size or polymers of different types and grades **play a role** in **deterioration of the mechanical properties.**

- To determine the **crack resistance**, which is a **crucial parameter** for **long-term performance** of the materials, the cracked round bar (CRB) test, according ISO 18489 was performed.
- By increasing recyclate content the number of cycles until failure N_f decreases, hence the **crack resistance decreases**. The long-term performance and lifetime of the material is **significantly shorter**.
- For comparing the materials and blends, N_f of the different materials at a stress level of $\Delta\sigma_0$ **= 9 MPa** was evaluated. In this **semi-logarithmic** diagram a **linear correlation** can be observed. Even **10 % rPP reduces** the long-term performance **by 50 %.**

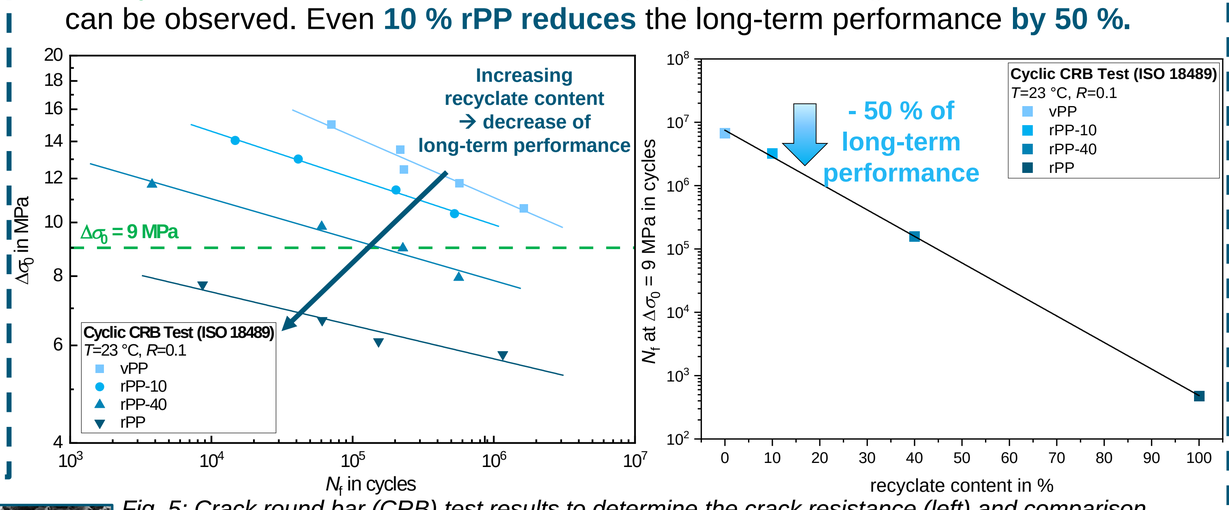

Fig. 5: Crack round bar (CRB) test results to determine the crack resistance (left) and comparison of the different materials/blends (right).

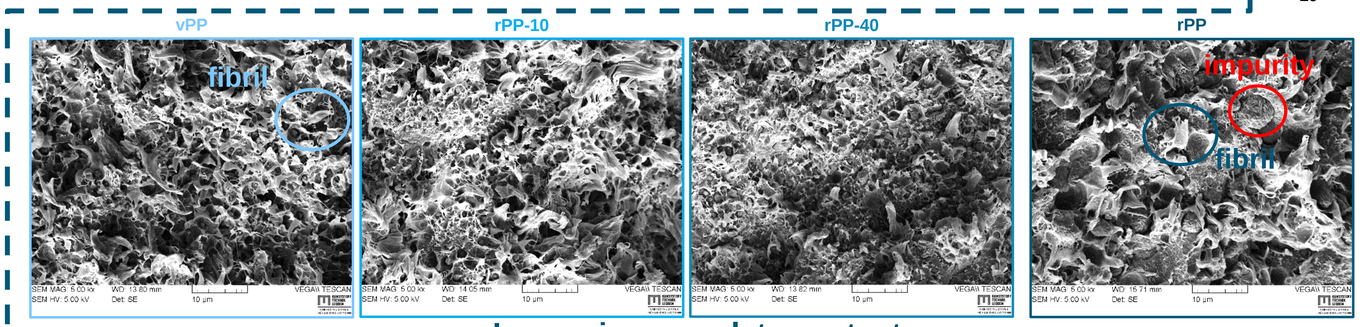

Fig. 6: Fracture surface investigation via SEM (left).

- **Brittle failure** is dominant failure mechanism, in the SEM images indicative fibrils are visible.
- The **size** of **fibrils decreases** with increasing **recyclate content** due to the **lower molecular weight** (higher MFR) of the **blends**.
- Pure recyclate **rPP** has a **high amount** of **impurities**, this leads to **larger fibrils**, although the rPP has a lower molecular weight (higher MFR) compared to vPP and blends.

CONCLUSION

- Different material **properties** are **influenced** by blending virgin material with post-consumer recyclate.
- The **MFR**, **tensile test** and **CRB test** are **usable** to evaluate changes of specific properties. In comparison, the **Charpy Impact test** is **not sensitive enough** to detect the changes.
- Blending virgin PP to recycled PP significantly **improves crack resistance**, which is a **crucial** material property in **structural long-term application**.
- **Mechanical properties** are **decreasing exponentially** in a **linear diagram** to the values of the pure recyclate rPP.
- With **CRB test**, provides a good ranking of crack resistance for the pure materials and their blends. The **crack resistance** already **decreases significantly by 50 %** with 10 % recyclate content.
- The results are **only valid for the investigated virgin material, recyclate** and **their blends**.

ORCID ID

For a study on PP waste bales, see also following poster:
J. Geier - "Analysis of different polypropylene waste bales – evaluation of the source material for PP Recycling"

[1] PlasticsEurope (2020): Plastics – the Facts 2020.
[2] PlasticsEurope (2018): The Circular Economy for Plastics: A European Overview.
[3] L.A. Utracki, C.A. Wilkie (2014): Polymer blends handbook, 2nd ed., Springer, Dordrecht.
[4] C. Aumnate, N. Rudolph, M. Sarmadi (2019): Recycling of Polypropylene/Polyethylene Blends: Effect of Chain Structure on the Crystallization Behaviors. In: Polymers 11 (9). DOI: 10.3390/polym11091456

The research work was performed within the COMET-project „ Processing and lifetime performance of virgin pipe grades blended with recyclates" (Project-No.: VII-3.08) at the Polymer Competence Center Leoben GmbH (PCCL, Austria) within the framework of the COMET-program of the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology and the Federal Ministry for Digital and Economic Affairs with contributions by Montanuniversitaet Leoben, Technical University Wien and DYKA, Fränkische Rohrwerke Gebr. Kirchner GmbH & Co. KG, Pipelife International GmbH, Polypipe Ltd., Rehau AG & Co. KG, European Plastic Pipe and Fittings Association (TEPPFA), Vynova Group, Staatliche Versuchsanstalt – TGM Kunststoff- und Umwelttechnik and Wavin T&I. The PCCL is funded by the Austrian Government and the State Governments of Styria, Lower Austria and Upper Austria.

p.p. M. Messiha – mario.messiha@pccl.at