Detection and separation of multilayer films in post-consumer waste packaging streams

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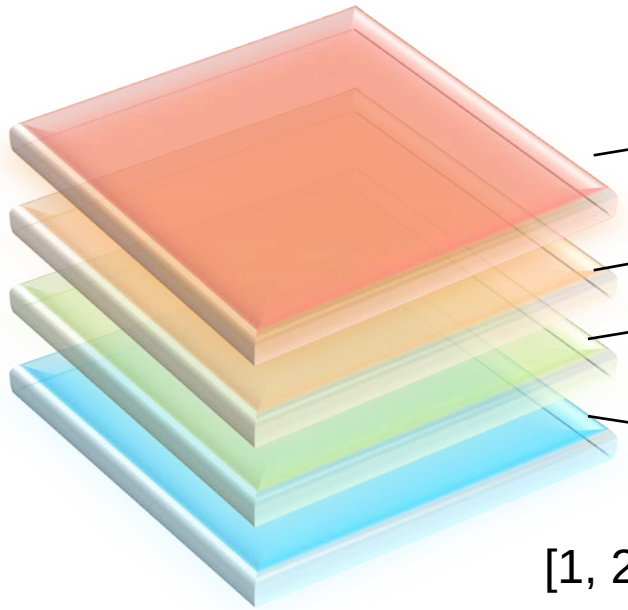
A multilayer packaging film might contain from 2 up to 17 layers



[1, 2]

Outer layer → improves compatibility with prints and mechanical stability (HDPE, OPP, PS, paper)

Tie layers → ensure good adhesion (polyolefin based or PU)

Functional layers → barrier properties against oxygen (EVOH, PA, Al, PVDC), moisture (PE, PP, PVA, ionomers) and light (Al, TiO_2)

Inner layer → sealability (LLDPE, LDPE, PP, PA)

Where do we find multilayer packaging materials?

- Food
- Non-food applications (stretch films for transportation)

[1] Anukiruthika, T.; Sethupathy, Priyanka; Wilson, Anila; Kashampur, Kiran; Moses, Jeyan Arthur; Anandharamakrishnan, Chinnaswamy (2020): Multilayer packaging: Advances in preparation techniques and emerging food applications. In *Comprehensive reviews in food science and food safety* 19 (3), pp. 1156–1186. DOI: 10.1111/1541-4337.12556
[2] Horodytska, O.; Valdés, F. J.; Fullana, A. (2018): Plastic flexible films waste management - A state of art review. In *Waste management (New York, N.Y.)* 77, pp. 413–425. DOI: 10.1016/j.wasman.2018.04.023.

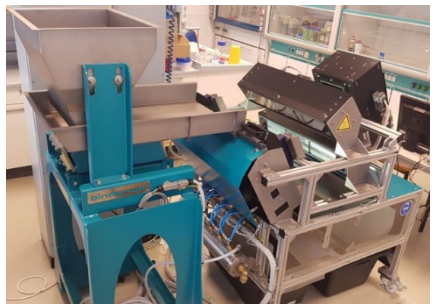
Multilayer Detection
Objectives

Deep Learning & Co. in der Sortiertechnik (15)
10.11.2022, 11:15 **M. Bredács**

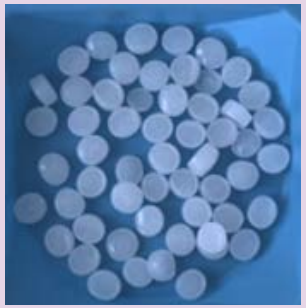
Foliensortierung (23)
10.11.2022, 14:50 **G. Koinig**

Identification of multilayer packaging materials via **destructive and non destructive techniques**

Optimization of the current state of the art **sorting devices** based on **Near Infrared (NIR) technology** to identify and separate multilayer packaging films from monolayers



Characterization of chemical, physical and mechanical properties of **recyclates** produced using the optimized sorting process



Identification of the layers constituting the polymer films via **destructive** and **non destructive** methods

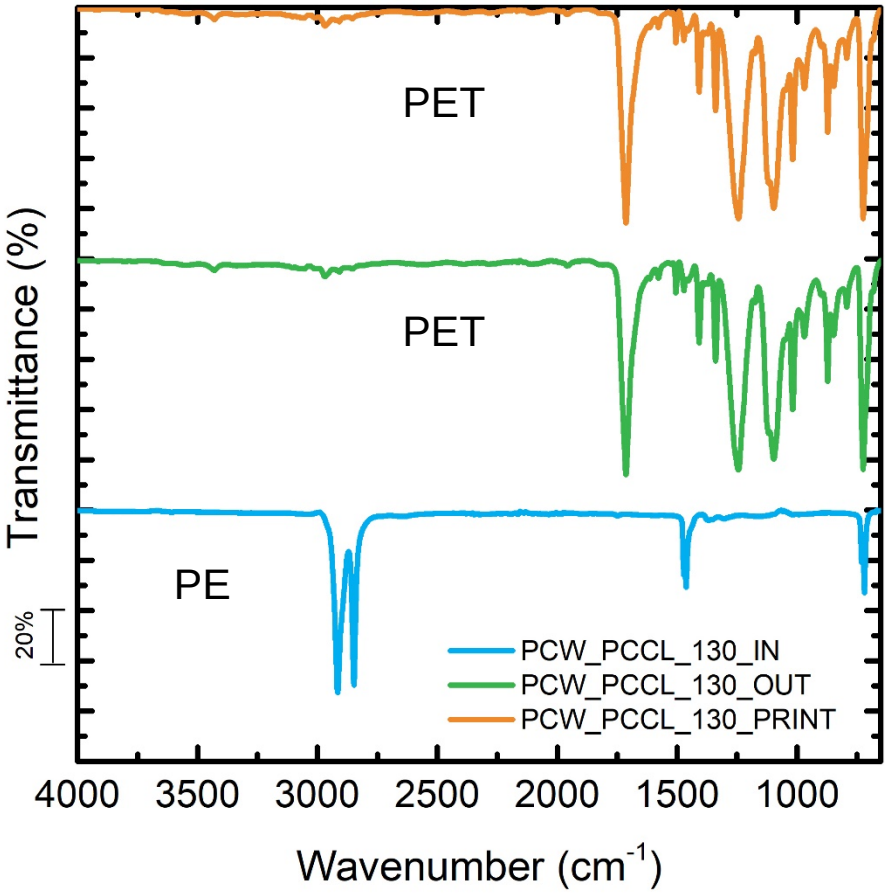
Destructive methods	Non-destructive methods
Differential Scanning Calorimetry (**DSC**)	Fourier Transform Infrared Spectroscopy (**FTIR**) in Attenuated Total Reflectance (**ATR**) and **transmission** mode
Confocal Raman Spectroscopy	**Fluorescence Spectroscopy**
FTIR-ATR imaging	**UV Fluorescence imaging**

Non-destructive characterization
FTIR spectroscopy

Identification of the layers constituting the polymer films via **destructive** and **non destructive** methods

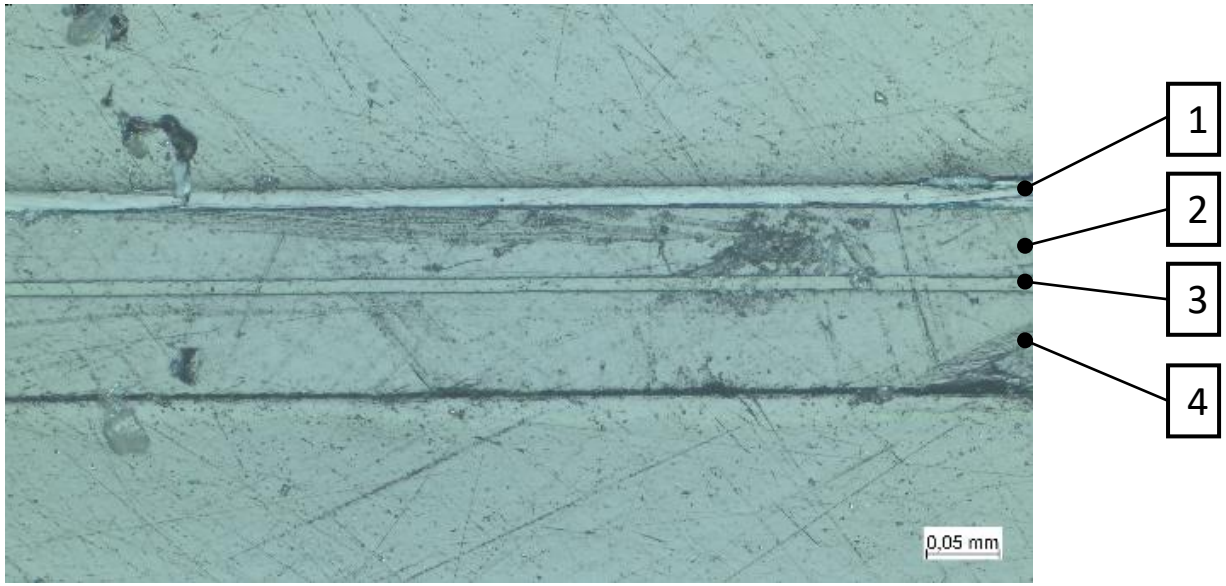
- Fast
- Clear material identification

- Not applicable on a sorting line
- Surface method (ATR) → No information about inner layers
- Transmission (inner layers) → sample thickness < 50 µm



Destructive characterization
Raman spectroscopy

Identification of the layers constituting the polymer films via **destructive** and **non destructive** methods



Spectrum → Material identification

- Raman spectroscopy is typically a non-destructive technique
- It was used here in a destructive way

- Identification of the intermediate layers
- Thickness determination

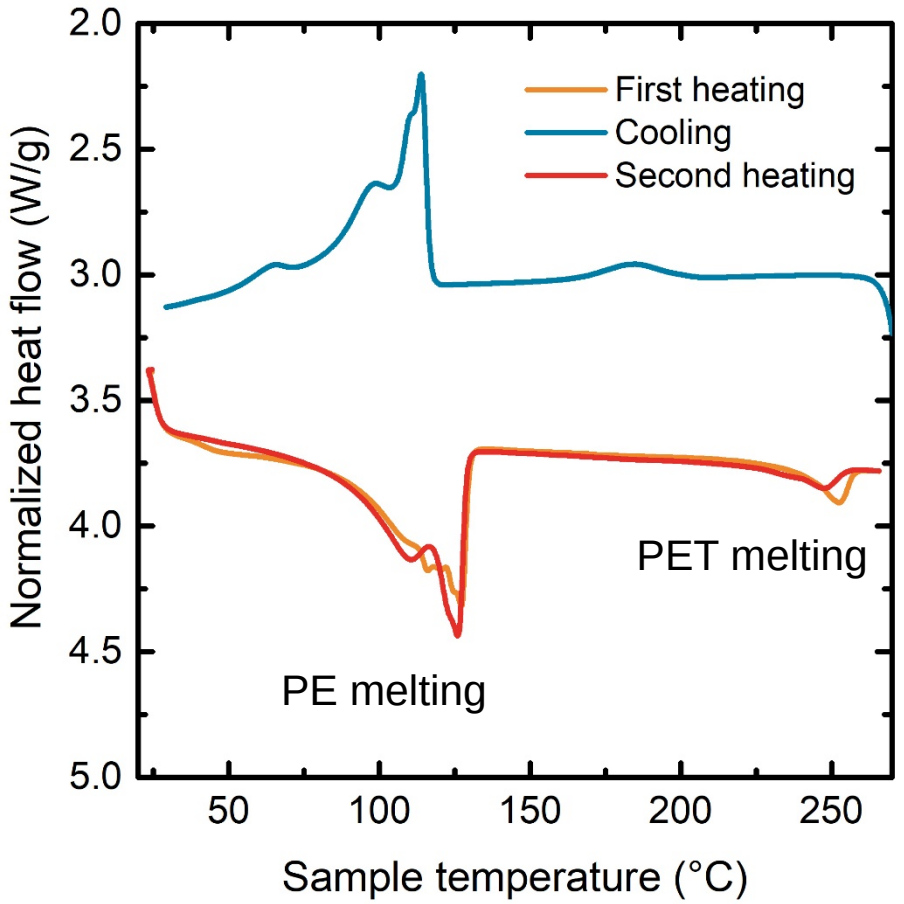
- Not applicable on a sorting line
- Complex sample preparation (embedding and polishing are necessary)
- Time consuming

Destructive characterization
DSC

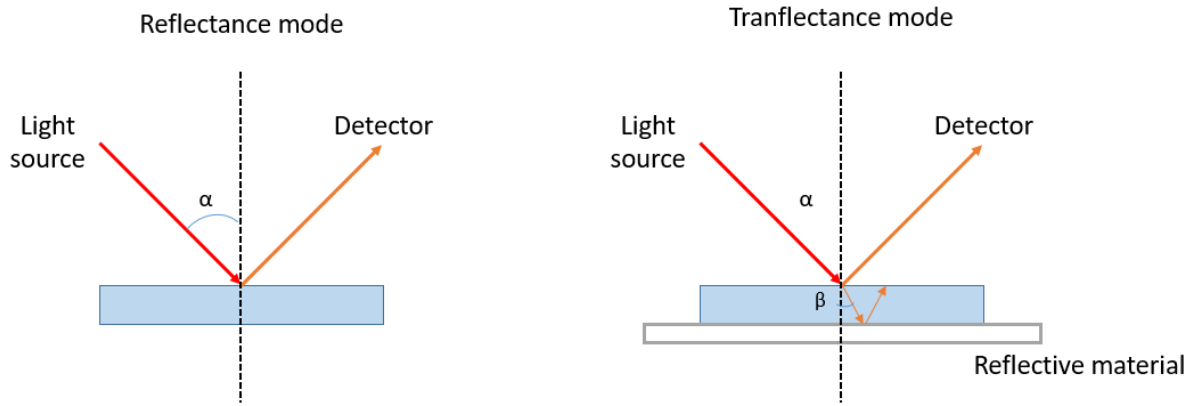
Identification of the layers constituting the polymer films via **destructive** and **non destructive** methods

- Information about intermediate layers

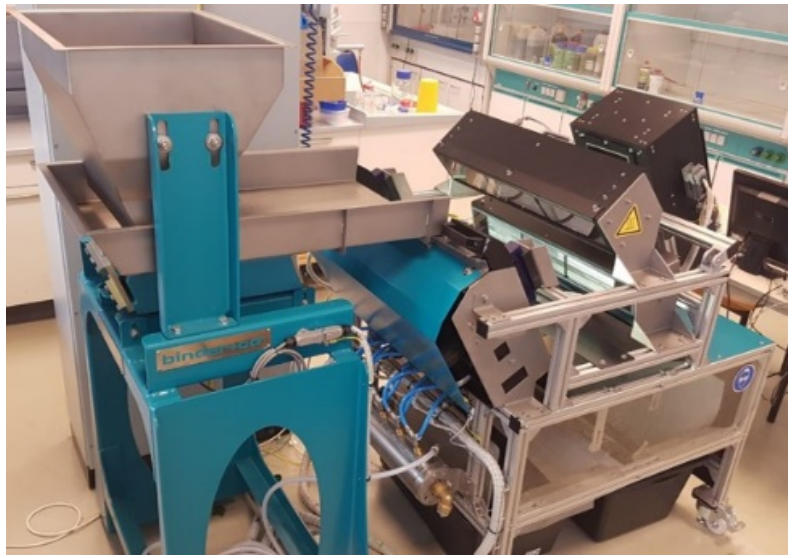
- Not applicable on a sorting line
- Relatively complex sample preparation
- Time consuming



Sorting of materials



Mixed small film waste [3]



Polyethylene – Transflectance (**PE/TR**), 98%

Polypropylene – Transflectance (**PP/TR**), 94%

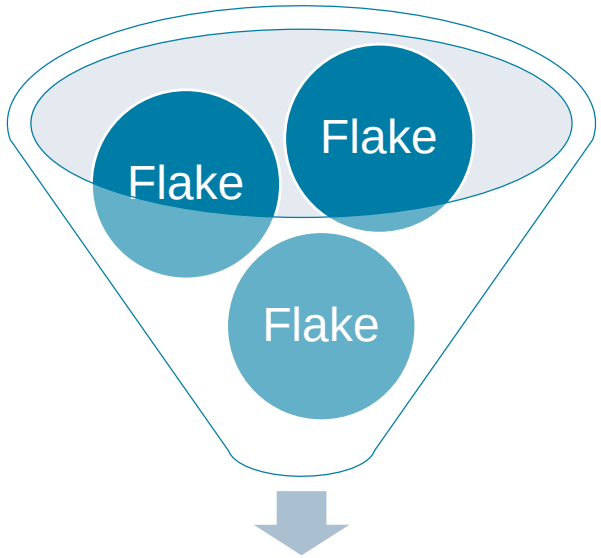
Polyethylene – Reflectance (**PE/RE**), 87%

Polypropylene – Reflectance (**PP/RE**), 30%

[3] Koinig, Gerald, Nikolai Kuhn, Chiara Barretta, Karl Friedrich, and Daniel Vollprecht. 2022. "Evaluation of Improvements in the Separation of Monolayer and Multilayer Films via Measurements in Transflection and Application of Machine Learning Approaches" Polymers 14, no. 19: 3926. https://doi.org/10.3390/polym14193926

Processing of the sorted fractions

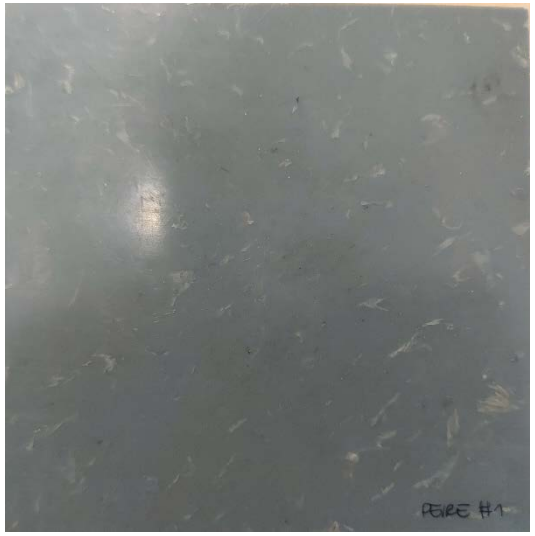
Characterization of chemical, physical and mechanical properties of recyclates produced using the optimized sorting process



Homogenized fraction

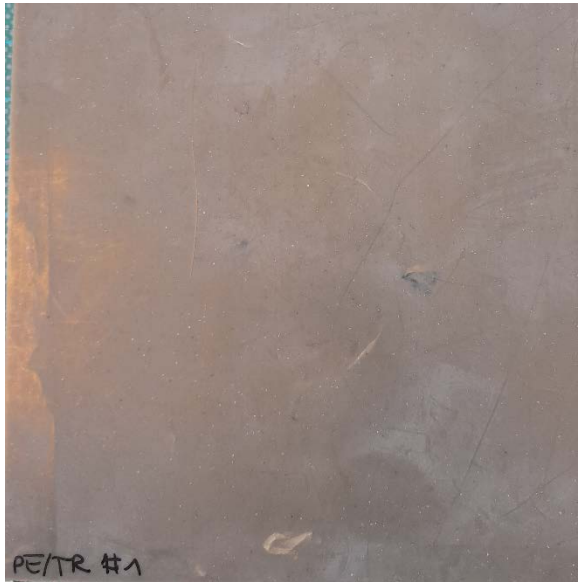
Compression molding

1 mm thick plates

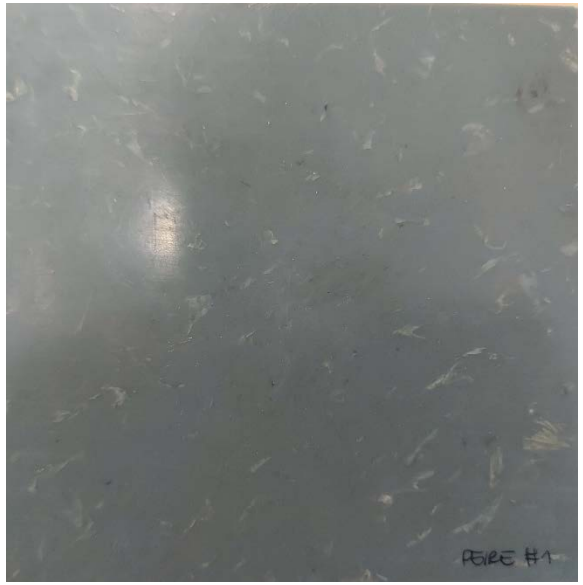


Characterization of material properties

Processing, all pictures



PE/TR

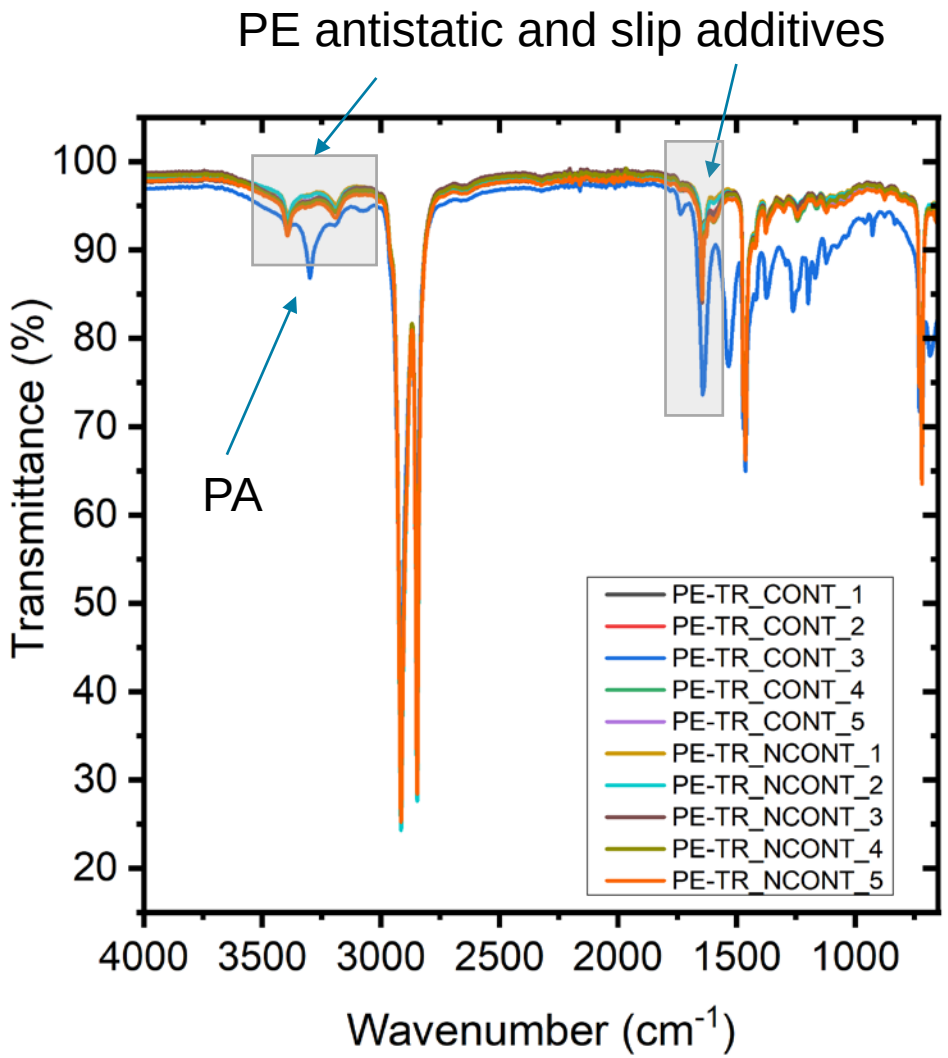


PE/RE

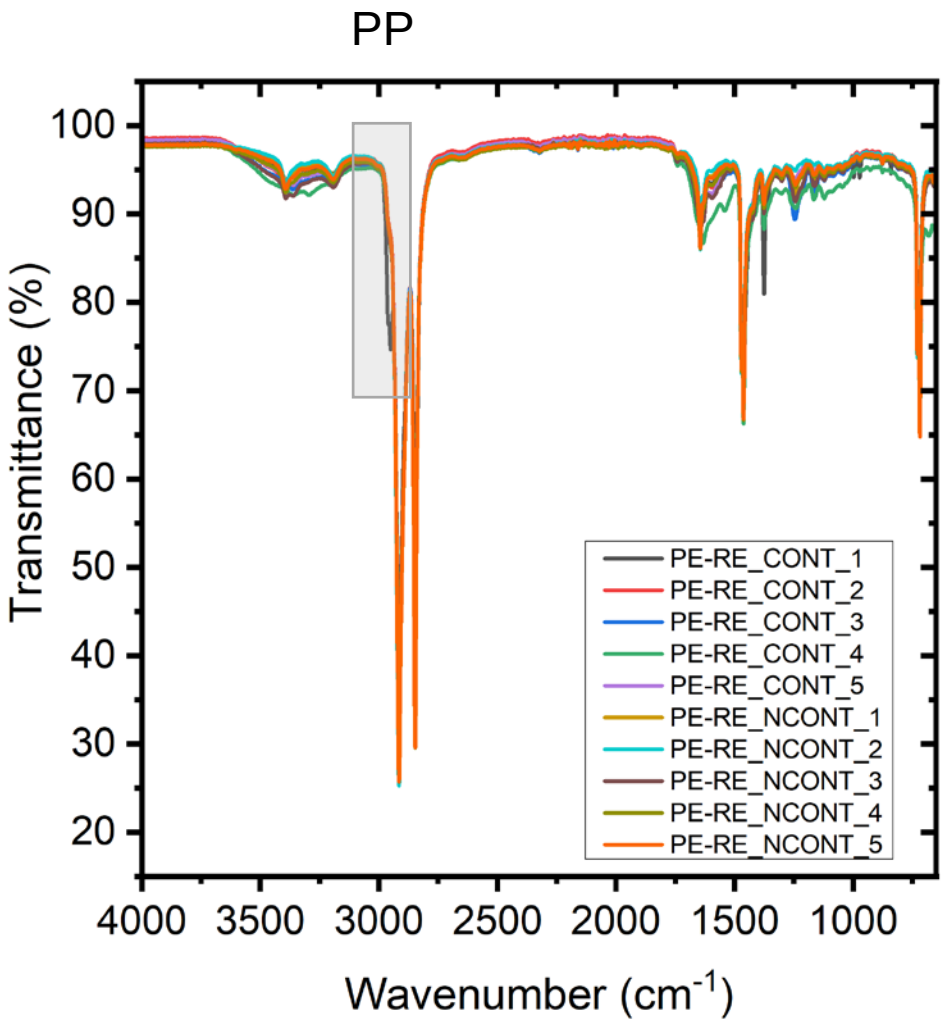
PP/TR

PP/RE

More contaminations in the samples sorted with traditional reflectance-based technology

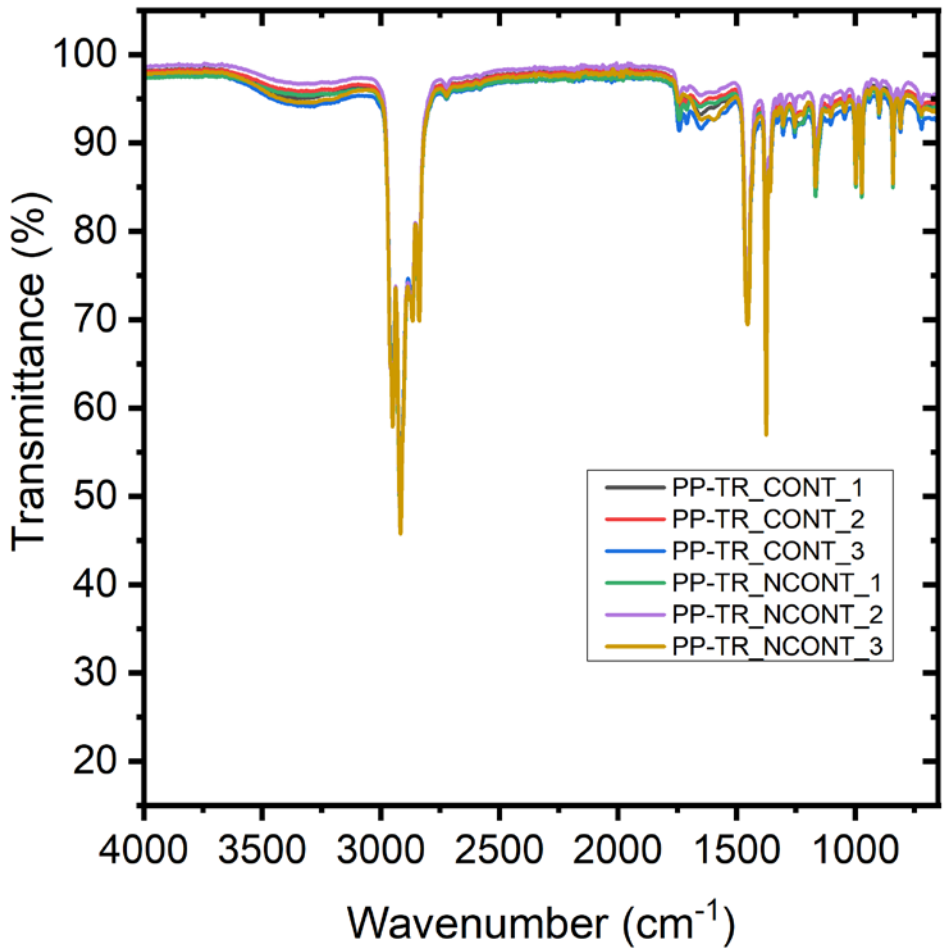

PE antistatic and slip additives
PA
Transmittance (%)
Wavenumber (cm-1)
PE-TR_CONT_1
PE-TR_CONT_2
PE-TR_CONT_3
PE-TR_CONT_4
PE-TR_CONT_5
PE-TR_NCONT_1
PE-TR_NCONT_2
PE-TR_NCONT_3
PE-TR_NCONT_4
PE-TR_NCONT_5

PE-TR

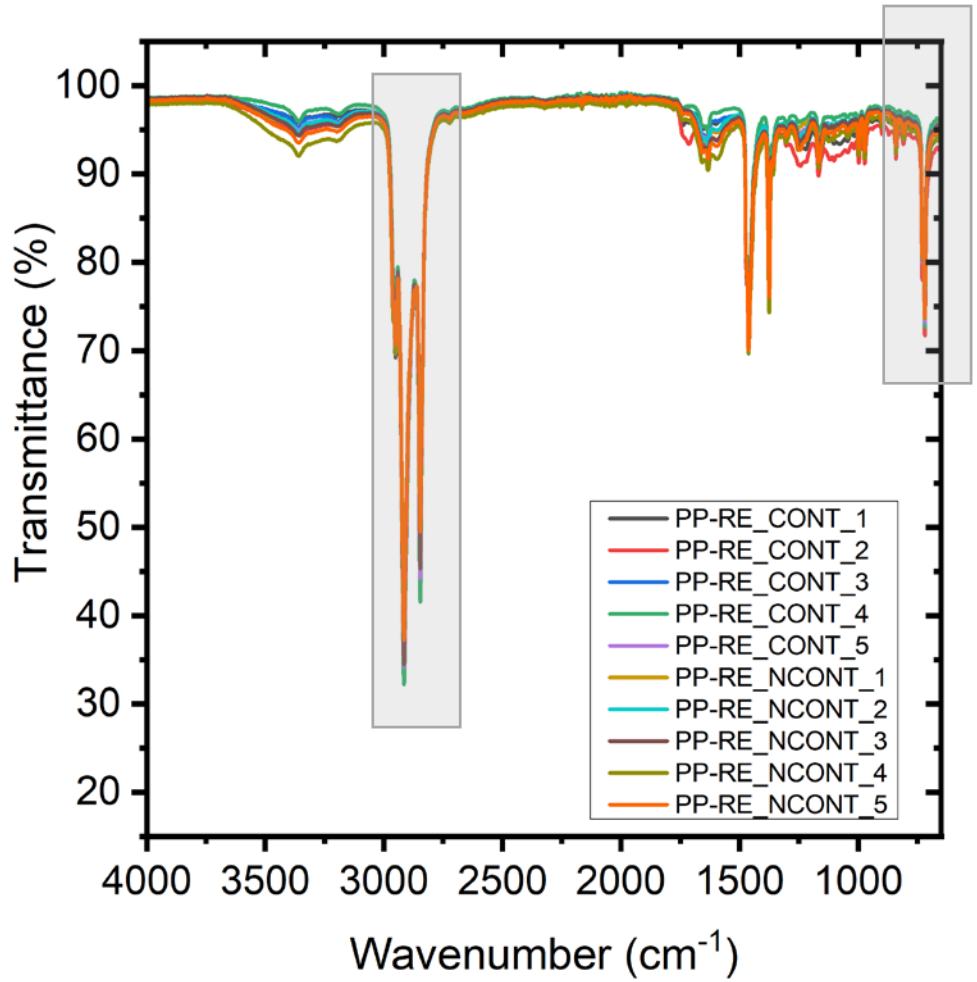

PP
Transmittance (%)
Wavenumber (cm-1)
PE-RE_CONT_1
PE-RE_CONT_2
PE-RE_CONT_3
PE-RE_CONT_4
PE-RE_CONT_5
PE-RE_NCONT_1
PE-RE_NCONT_2
PE-RE_NCONT_3
PE-RE_NCONT_4
PE-RE_NCONT_5

PE-RE

Results
FTIR ATR – PP



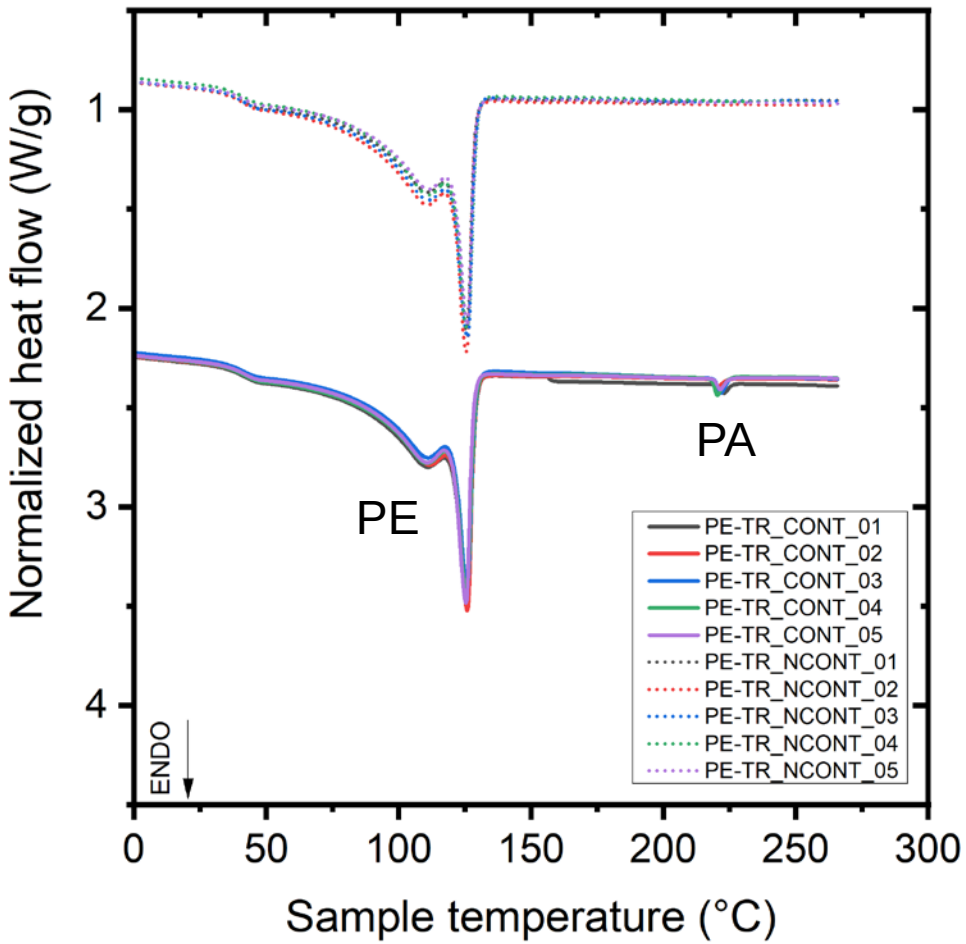
PP-TR



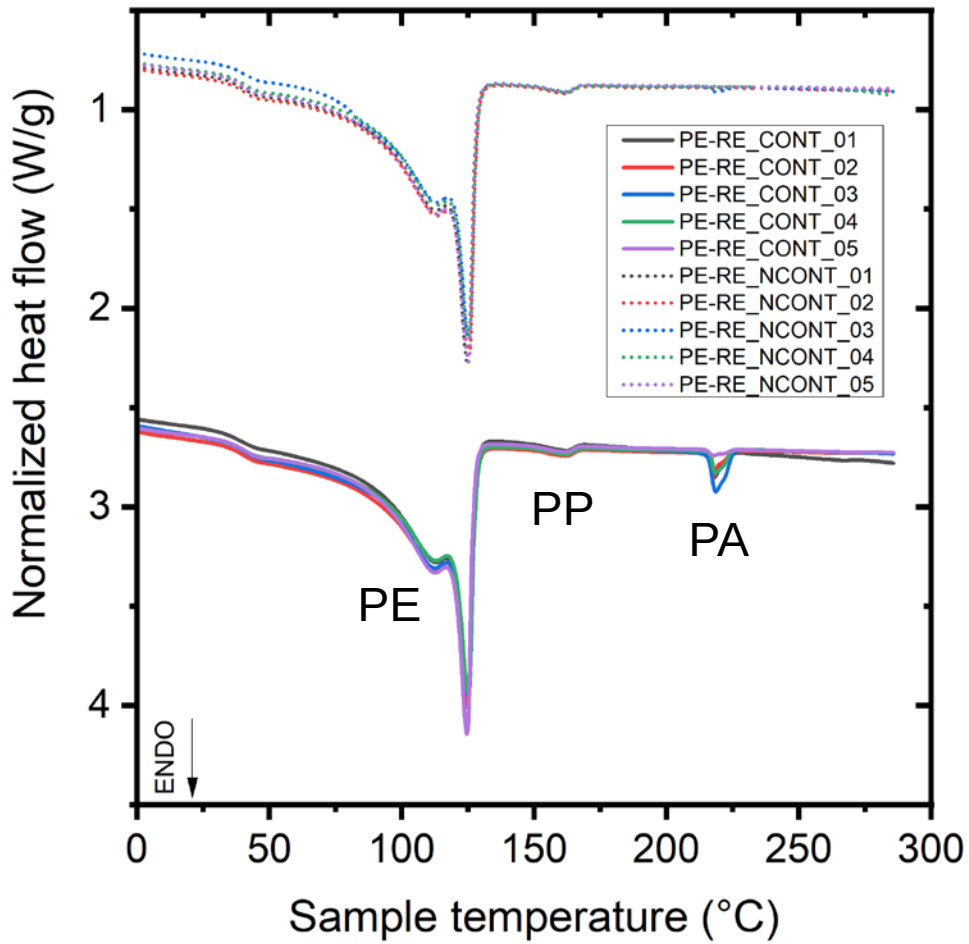
PE

PP-RE

Results
DSC – PE

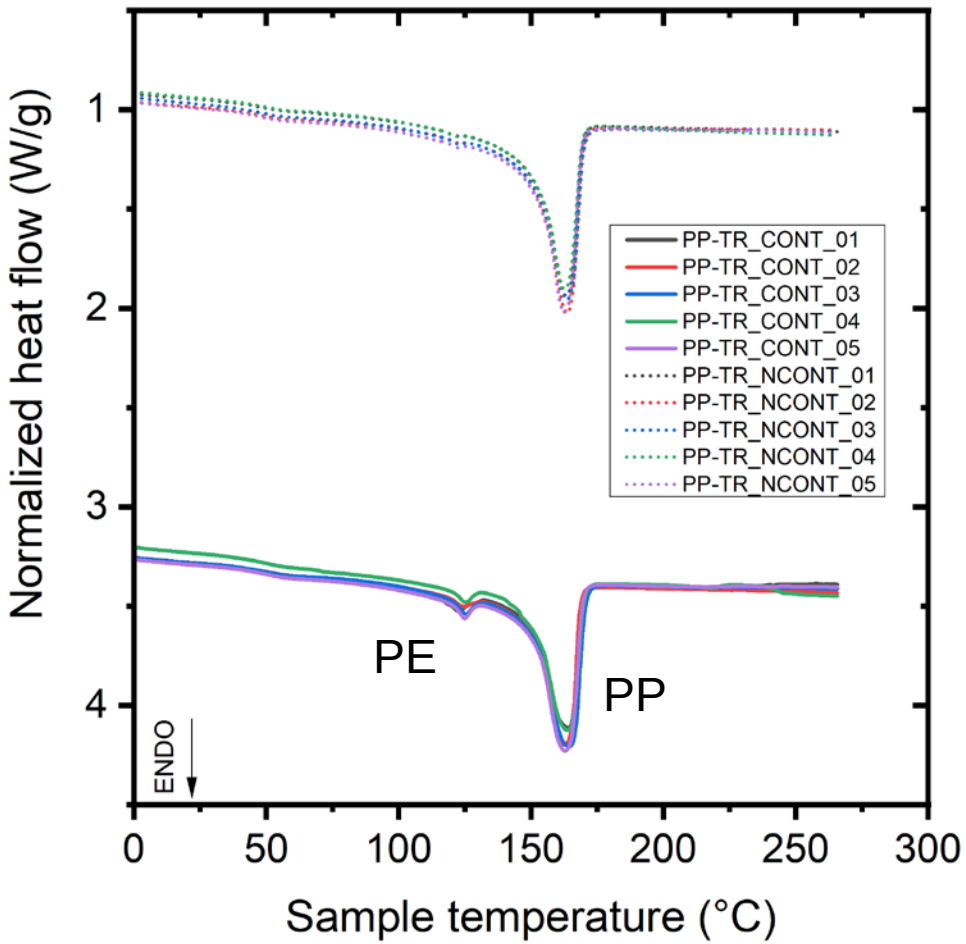


PE-TR

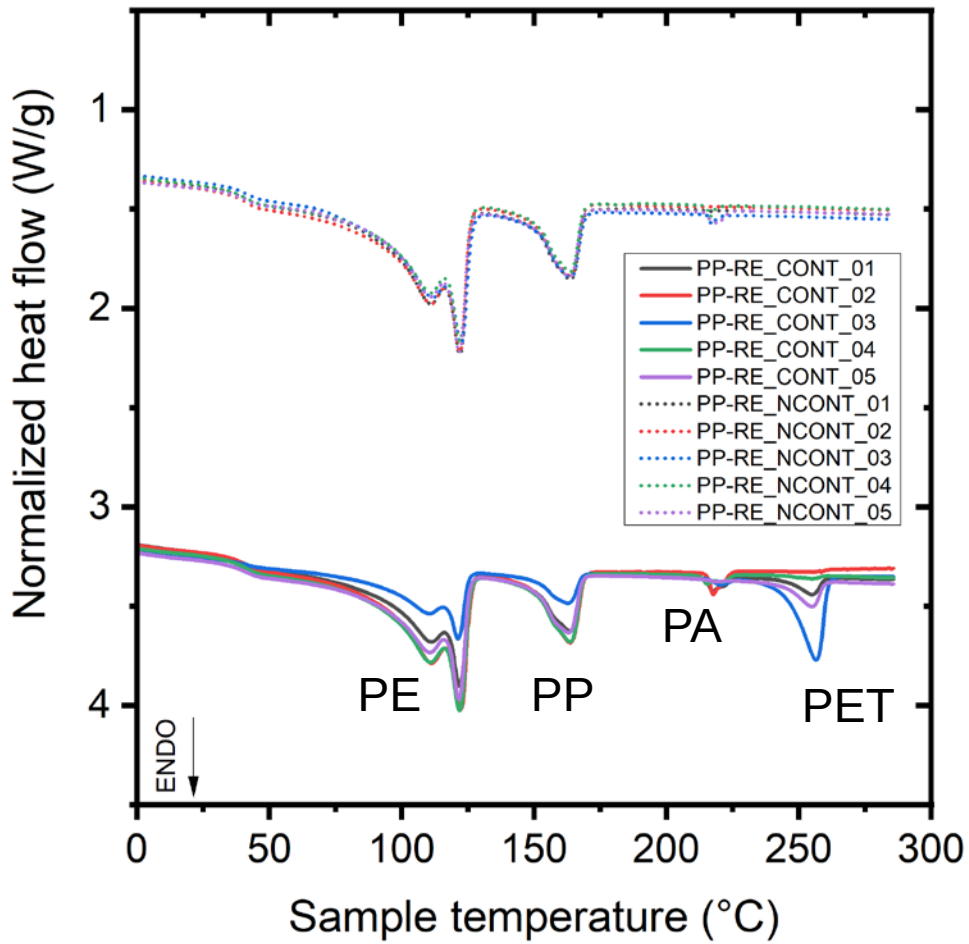


PE-RE

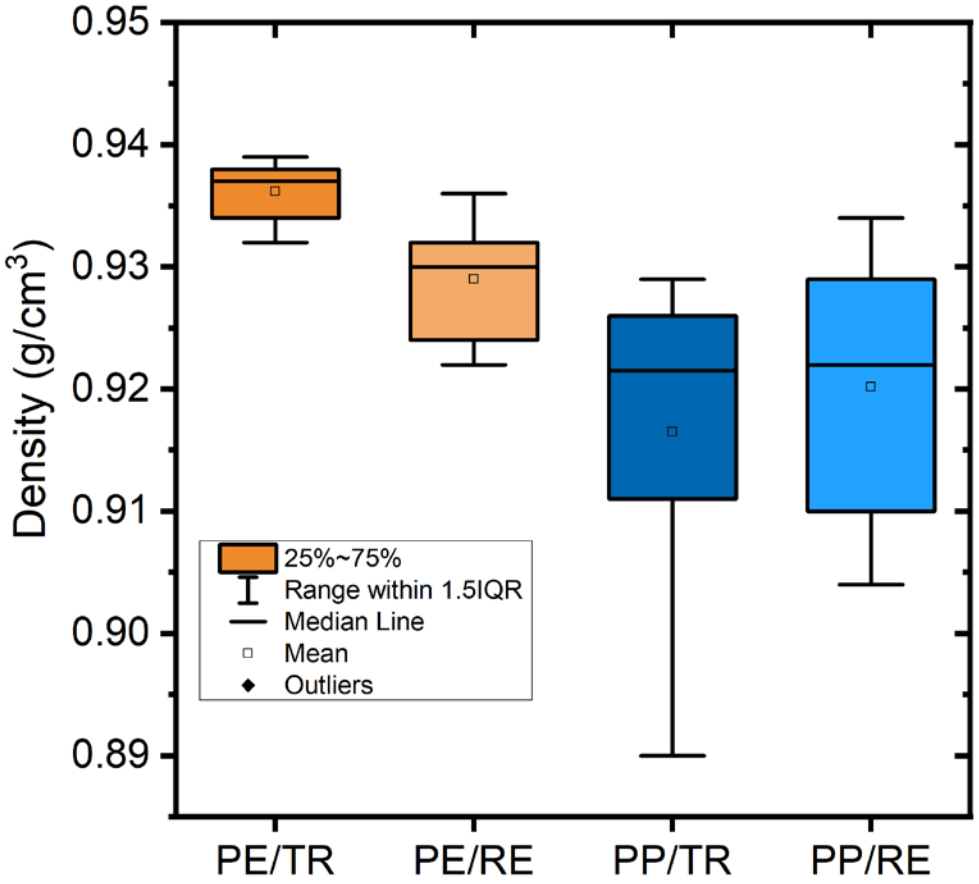
Results
DSC – PP

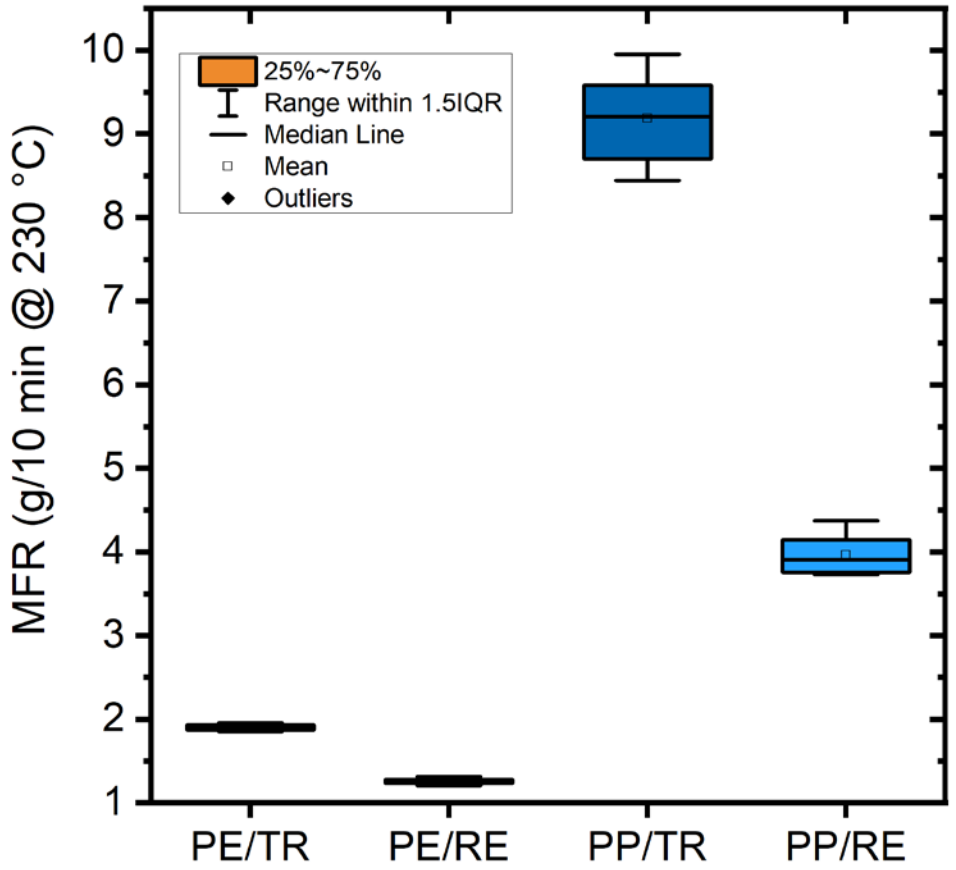


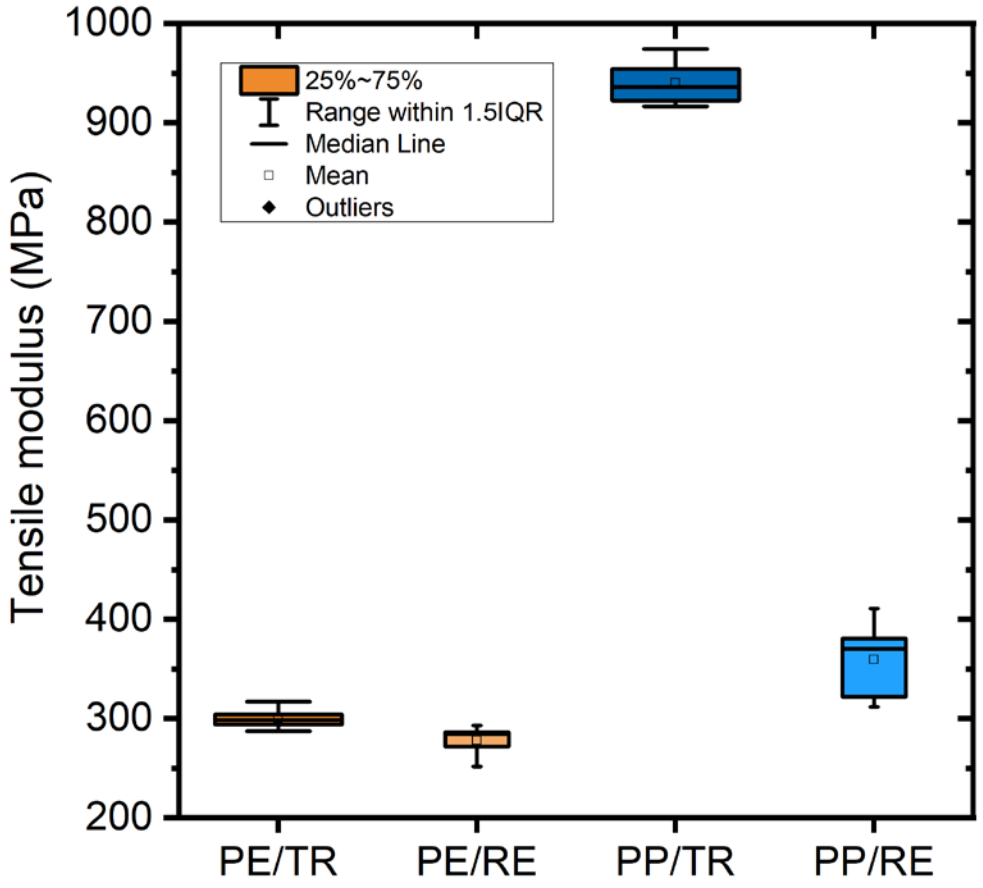
PP-TR

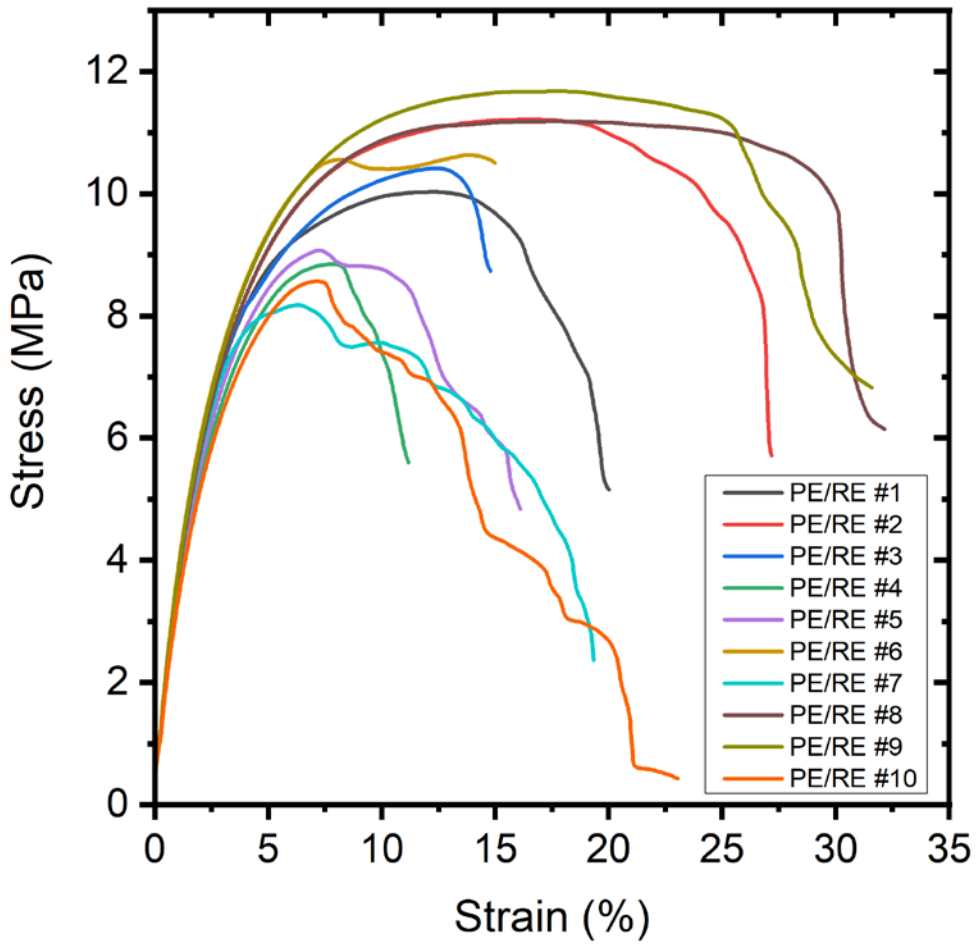


PP-RE


Density (g/cm³)
0.95
0.94
0.93
0.92
0.91
0.90
0.89
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
PE/TR
PE/RE
PP/TR
PP/RE


MFR (g/10 min @ 230 °C)
10
9
8
7
6
5
4
3
2
1
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
PE/TR
PE/RE
PP/TR
PP/RE

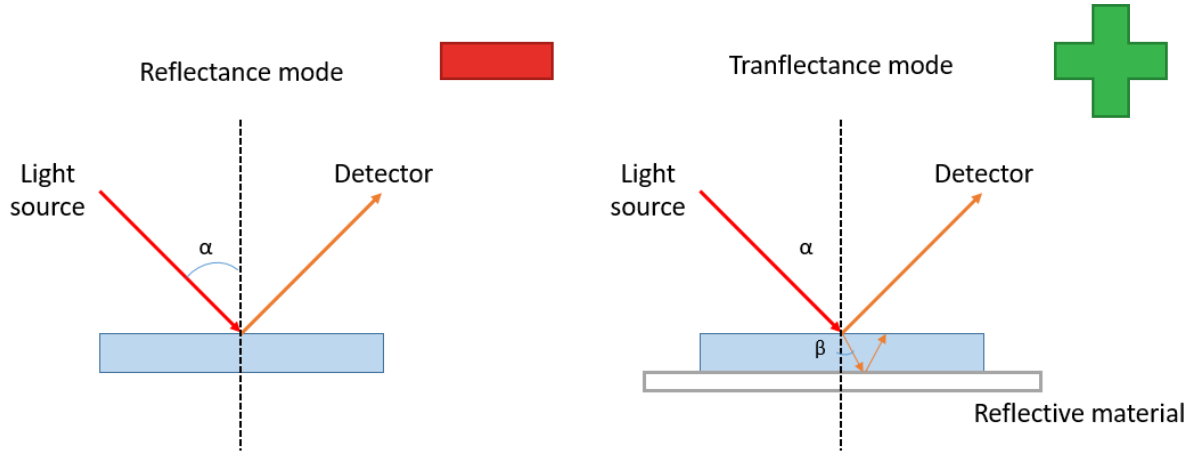

Tensile modulus (MPa)
1000
900
800
700
600
500
400
300
200
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
PE/TR
PE/RE
PP/TR
PP/RE


Stress (MPa)
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
Strain (%)
PE/RE #1
PE/RE #2
PE/RE #3
PE/RE #4
PE/RE #5
PE/RE #6
PE/RE #7
PE/RE #8
PE/RE #9
PE/RE #10

Summary

Good knowledge

Good separation



Melt filtration is necessary to remove impurities

PE/TR 98%	**PP/TR** 94%
PE/RE 87%	**PP/RE** 30%

- Homogeneity
- Better thermal properties and processability
- Better mechanical properties

Acknowledgements

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Thank you for your attention!

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