FTPO Faculty of Polymer Technology

PolyMetal

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Material characterization

Characterization of thermal/mechanical/physical/haptic/wear properties of composites with high thermal conductivity

Content:

Scope of the report: 23 pages

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1 Introduction

Material characterization encompasses the comprehensive material characterization of materials that were presented in WP 1 on the basis of the product requirements of the partner companies Gorenje gospodinjski aparati d.o.o. and Intra lighting d.o.o. have been selected. The research partner Faculty of Polymer Technology (FTPO) manufactured the test specimens from these materials (compounding and injection moulding) and together with project partner Montanuniversitaet Leoben (MUL) and Polymer Competence Center Leoben GmbH (PCCL) comprehensively examined the samples thermal/mechanical/physical/haptic/wear properties. The final polymers surfaces were analysed with new developed cool touch test method by all project partners. The aim of these activities was to find the most suitable material (polymer) for optimization and manufacture of the protypes with a demonstrator tool. The report is divided into three content parts. In the first part the material composition is described. In the second part the cool touch test method generation with results is presented. In the third part the measured properties are presented. The conclusion includes further measures required for the optimization and production of composites with high thermal conductivity. Finally, the publications resulting from WP3 are listed in the last point.

2 Materials for characterization

In Table 1, the samples with their composition are presented. For greater transparency, the following abbreviations were used in the table:

- **PE-HD** – polyethylene high density; DOW HDPE 25055 E NATURAL
- **PP** – polypropylene; Ineos 100-GA02 DTA 1105
- **PA** – polyamide; Akulon K222-D Natural
- **ABS** – acryl-nitrile-butadiene-styrene; Elix ABS P2H-AT/0101083 LNS 202
- **PS** – polystyrene; Edistir SR550 257869
- **PC** - Sabic Lexan 243 R
- **Al** – aluminium dust from the company Talum, Slovenia
- **C** – compatibilizer; for PE-HD: Exxelor PE 1040; for PP: Exxelor PO 1020; C-SEBS: Graftbond SEBS-GMA ; C-TPU: U TU-S5265
- **BN** – boron nitride; 3M Powder BN CF Platelets 012P
- **WP** – waste paper from Papirnica Vevče
- **T**- talc; Plustalc H15
- **GF** – glass fibres; 3B Fiberglass DS 1128-10N
- **W** – Wollastonite; Aspect 3992
- **CaCO3-S** – $CaCO_3$ with small particle size; Calplex Extra
- **CaCO3-B** – $CaCO_3$ with big particle size; Calplex 40
- **L** – lubricant; Croda ER
- **MB1** – Master Batch metallic silver - Maxithen HP7BA5567 Metallic silber
- **MB2** – Master Batch metallic blue - Maxithen HP5BB4417 Metallic blau
- **MB3** – Master Batch metallic grey - Maxithen HP9BA8837 Metallic grau
- **MB4** – Master Batch metallic violet - Maxithen HP5BB4397 Metallic violett
- **MB5** – Master Batch metallic brown - Unimax UNS8BA5427 Metallic braun

Samples from 822_2019_0103_06 to 822_2019_0103_09 are commercially available high thermal conductive composites and were used as reference samples. For all other samples the project partners confirm composition and all of them were compounded at FTPO on twin screw extruder and injection moulded to get samples for further laboratory characterization.

Table 1: Materials used for the characterization – overview with the composition for the composites compounded within the project. Commercially available samples are written in red.

Sample Nr.	Composition
822_2019_0103_00	PE-HD
822_2019_0103_01	PE-HD 5Al 10C
822_2019_0103_02	PE-HD 5Al 30C
822_2019_0103_03	PE-HD 20Al 10C
822_2019_0103_04	PE-HD 20Al 30C
822_2019_0103_05	PE-HD 12.5Al 20C
822_2019_0103_06	N2003-M
822_2019_0103_07	Makrolon TC8030
822_2019_0103_08	Konduit PX11313
822_2019_0103_09	Konduit PX13012
822_2019_0103_10-1	TPU Al foil 20
822_2019_0103_10-2	TPU Al foil 30
822_2019_0103_10-3	TPU Al foil 50
822_2019_0103_10-4	TPU Al foil 100
822_2019_0103_10-5	TPU Al foil 200
822_2019_0103_10-6	TPU Al foil 300
822_2020_0056_01	PE-HD
822_2020_0056_02	PE-HD 10T
822_2020_0056_03	PE-HD 20T
822_2020_0056_04	PE-HD 30T
822_2020_0056_05	PE-HD 10T 2C
822_2020_0056_06	PE-HD 20T 4C
822_2020_0056_07	PE-HD 30T 6C
822_2020_0127_01-1	PE-HD 10CaCO3-S
822_2020_0127_01-2	PE-HD 20CaCO3-S
822_2020_0127_01-3	PE-HD 30CaCO3-S
822_2020_0127_01-4	PE-HD 10CaCO3-S 2C
822_2020_0127_01-5	PE-HD 10CaCO3-S 4C
822_2020_0127_01-6	PE-HD 10CaCO3-S 6C
822_2020_0127_02-1	PE-HD 10CaCO3-B
822_2020_0127_02-2	PE-HD 20CaCO3-B
822_2020_0127_02-3	PE-HD 30CaCO3-B
822_2020_0127_02-4	PE-HD 10CaCO3-B 2C

822_2020_0127_02-5	PE-HD 10CaCO3-B 4C
822_2020_0127_02-6	PE-HD 10CaCO3-B 6C
822_2020_0164_01	PP 50BN 2L 3C
822_2020_0164_02	PP 50BN 2L 4C
822_2020_0164_03	PP 50BN 2L 5C
822_2020_0164_04	PP 50BN 2L 6C
822_2020_0164_05	PP 50BN 2L 7C
822_2020_0164_06	PP 40BN 10WP 2L 5C
822_2020_0164_07	PP 30BN 20WP 2L 5C
822_2020_0164_08	PP 25BN 25WP 2L 5C
822_2020_0164_09	PP 60BN 2L 5C-SEBS
822_2020_0164_10	PP 70BN 2L 5C-SEBS
822_2020_0164_11	PP 80BN 2L 5C-SEBS
822_2020_0190_00	PC
822_2020_0190_01	PC 50BN
822_2020_0190_02	PC 50BN 5C-TPU
822_2020_0190_03	PC 50BN 5C2-PE
822_2020_0190_04	PC 50BN 5C1-SEBS
822_2020_0218_01	PP 60BN 2L 5C
822_2020_0218_02	PP 55BN 5GF 2L 5C
822_2020_0218_03	PP 50BN 10GF 2L 5C
822_2020_0218_04	PP 45BN 15GF 2L 5C
822_2020_0218_05	PP 40BN 20GF 2L 5C
822_2020_0218_06	PP 35BN 25GF 2L 5C
822_2020_0218_07	PP 30BN 30GF 2L 5C
822_2020_0218_08	PP 25BN 35GF 2L 5C
822_2020_0218_09	PP 20BN 40GF 2L 5C
822_2021_0015_15	PA6 30BN 30W 2L
822_2021_0015_16	PA6 30BN 30GF 2L
822_2021_0015_17	PA6 30BN 30T 2L
822_2021_0015_18	PA6 30BN 30CaCO3B 2L
822_2021_0015_19	PA6 30BN 30CaCO3S 2L
822_2021_0015_20	PA6 30BN 30W 2L 5C
822_2021_0015_21	PA6 30BN 30GF 2L 5C
822_2021_0015_22	PA6 30BN 30T 2L 5C
822_2021_0015_23	PA6 30BN 30CaCO3B 2L 5C
822_2021_0015_24	PA6 30BN 30CaCO3S 2L 5C

822_2021_0015_25	PA6 10BN 20CaCO3B 20GF 2L 5C
822_2021_0015_DoEnew	PA6 20BN 28CaCO3B 2GF 2L 4C
822_2021_0015_DoEnewMB	PA6 20BN 28CaCO3B 2GF 2L 4C 3MB
822_2021_0015_MB	PA6 15BN 5CaCO3B 30GF 2L 4C 3MB
822_2021_0109_00	PA6 60BN 4C
822_2021_0109_01	PA6 60BN 4C 5MB1
822_2021_0109_02	PA6 60BN 4C 5MB2
822_2021_0109_03	PA6 60BN 4C 5MB3
822_2021_0109_04	PA6 60BN 4C 5MB4
822_2021_0109_05	PA6 60BN 4C 5MB5
822_2021_0110_00	PP 60BN 4C
822_2021_0110_01	PP 60BN 4C 5MB1
822_2021_0110_02	PP 60BN 4C 5MB2
822_2021_0110_03	PP 60BN 4C 5MB3
822_2021_0110_04	PP 60BN 4C 5MB4
822_2021_0110_05	PP 60BN 4C 5MB5
822_2021_0111_00	PC 60BN 4C
822_2021_0111_01	PC 60BN 4C 5MB1
822_2021_0111_02	PC 60BN 4C 5MB2
822_2021_0111_03	PC 60BN 4C 5MB3
822_2021_0111_04	PC 60BN 4C 5MB4
822_2021_0112_00	ABS 60BN 4C
822_2021_0112_01	ABS 60BN 4C 5MB1
822_2021_0112_02	ABS 60BN 4C 5MB2
822_2021_0112_03	ABS 60BN 4C 5MB3
822_2021_0112_04	ABS 60BN 4C 5MB4
822_2021_0112_05	ABS 60BN 4C 5MB5
822_2021_0113_00	PS 60BN 4C
822_2021_0113_01	PS 60BN 4C 5MB1
822_2021_0113_02	PS 60BN 4C 5MB2
822_2021_0113_03	PS 60BN 4C 5MB3
822_2021_0113_04	PS 60BN 4C 5MB4
822_2021_0113_05	PS 60BN 4C 5MB5
822_2021_0164_01	PC 60BN 4C 5MB1
822_2021_0166_01	ABS 60BN 4C 5MB1
822_2021_0180_01	PBT 40BN 20GF 4C 5MB4

3 Cool touch testing of selected materials

For the evaluation of cool touch, the thermal conductivity measurements are not always feasible due to the shape and dimensions of the tested object. Therefore, the project partners decided to develop a new test method to evaluate cold touch to be able to perform evaluation also on the uneven surfaces directly on the devices where those parts are installed. For the evaluation, the produced test parts from two selected technologies: IML (in mould labelling) and compounded high thermally conductive composites were used, namely all samples with production number 822_2019_0103. The aim of this evaluation was cool-touch feeling, tests independently of each individual and the test procedure must be quick without limitation regarding shape of the tested object. To produce test specimens the tool with the dimensions 60 mm x 60 mm x 4 mm was used. In Figure 1 the produced parts are presented.

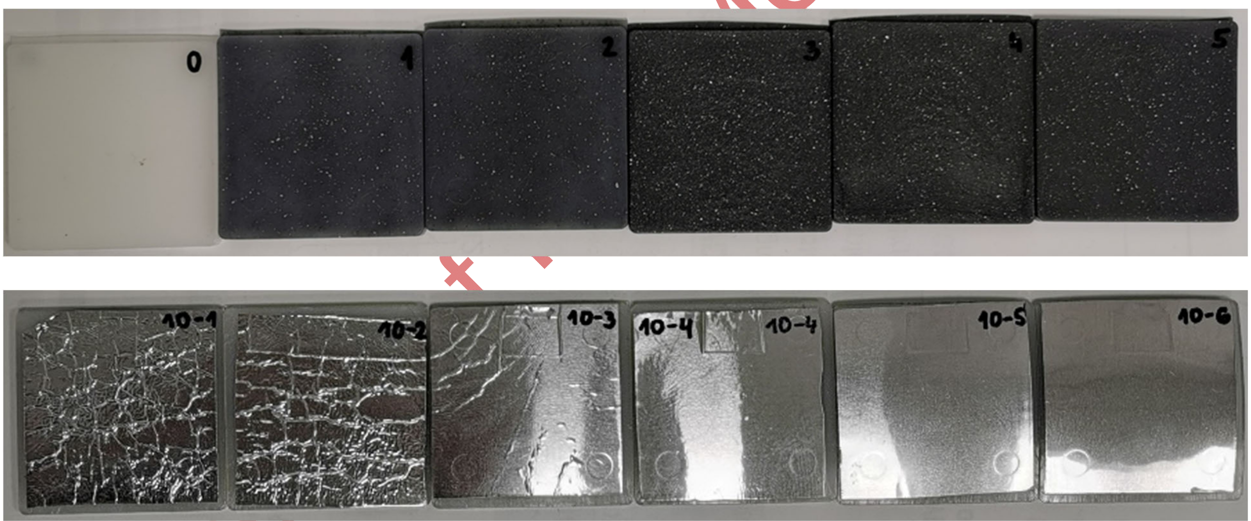


Figure 1: Produced samples for the cool touch method evaluation (822_2019_0103).

First step was developing the cool-touch method at each project partner. The limitations during test performance were evaluated as well as results. In the second step the common method was developed and the samples selection for the next generation of cool-toch test method. Test were performed again at all project partners together with evaluation of the results. For this step the samples 822_2019_0103_06, 822_2019_0103_08, 822_2019_0103_09, 822_2019_0103_10-4, 822_2019_0103_10-5 and 822_2019_0103_10-6 were chosen. After the evaluation of all results the test method was defined:

- tempering of samples for at least 24 hours at 23 °C,
- before touching each sample, metal plate is touched for 5 seconds with palm,
- test samples are touched with the same palm and waited for 3 seconds,
- the evaluation of feeling is made (lower number for cooler feeling, higher number for warmer feeling),
- each sample must have different number of evaluations,
- maximum number of samples is 6.

In Figure 2, the collected results from the selected samples are presented.

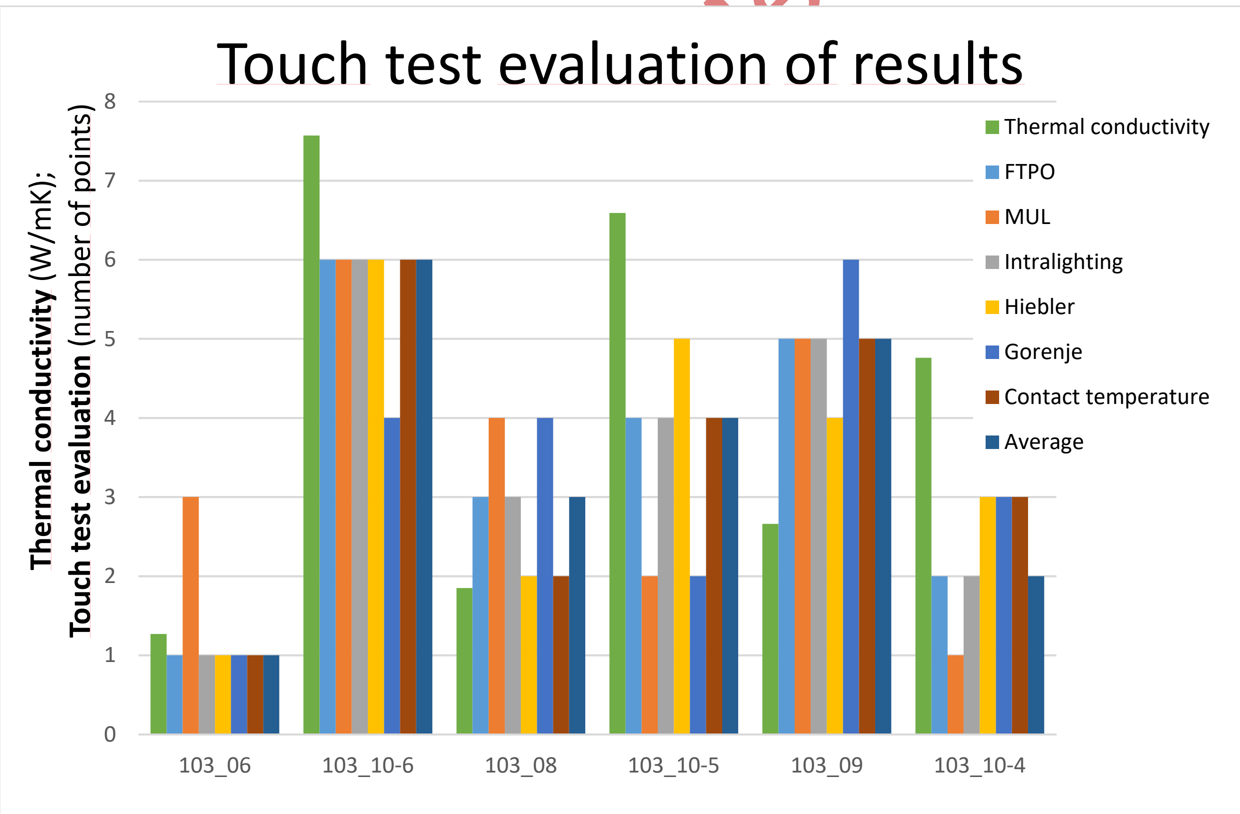


Figure 2: Collected evaluation from the developed Cool-touch test method with the thermal conductivity measurements (green bulks) and contact temperature calculations (brown bulks).

4 Thermal/mechanical/physical properties of the materials

Not only cool touch, but also thermal, mechanical, and physical properties of the materials are crucial for the composites with high thermal conductivity. The characterization of the produced samples was mainly conducted at FTPO, PCCL, and MUL. To achieve one of goal of the project – closer cooperation between institutions – the Round Robin tests were conducted for the DSC method and Hot Disk method.

The Round Robin test for DSC was done at FTPO and PCCL and the results are presented in the Figure 3. It is obvious that the results are well comparable, which indicates a high level of scientific expertise in carrying out the measurements.

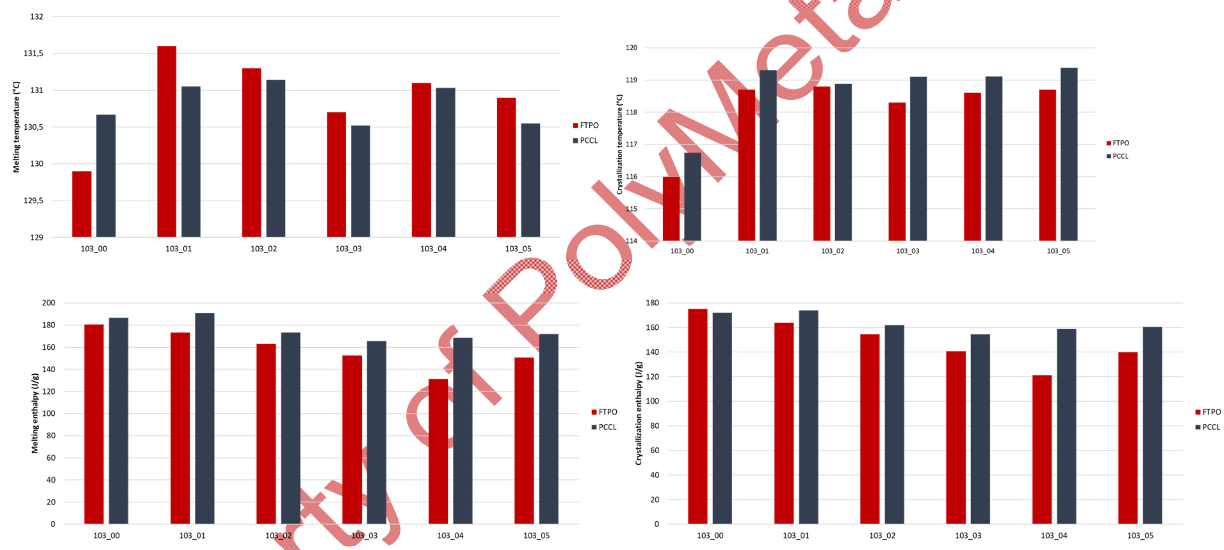
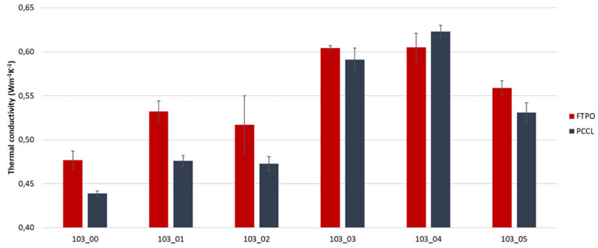


Figure 3: Round Robin DSC test results for the samples from 822_2019_0103_00 to 822_2019_0103_05 (melting temperature top left, crystallization temperature top right, melting enthalpy bottom left, crystallization enthalpy bottom right).

Round Robin tests were performed also for the thermal conductivity at FTPO, PCCL, 3M and C3. The results are presented in Figure 4. The values obtained at FTPO and PCCL match closely, a lager and unexplainable difference is found at C3.



Sample Nr.	λ (W/mK) – FTPO 2 mm	λ (W/mK) – C3 2 mm	λ (W/mK) – 3M 2 mm
822_2020_0164_11	4,41	8,73	4,17
822_2020_0190_02	1,79	4,84	1,07
822_2020_0218_07	0,83	3,01	0,77

Figure 4: Round Robin Hot Disk test results for the samples from 822_2019_0103_00 to 822_2019_0103_05 (FTPO-PCCL) on the left and samples 822_2020_0164_11, 822_2020_0190_02 and 822_2020_0218_07 (FTPO-C3-3M) on the right.

All the samples produced at FTPO with injection moulding technology were tested and characterized at FTPO (thermal, mechanical, and physical properties), some of them were also tested at PCCL (DSC, thermal conductivity, haptic, and wear) and MUL (material data required for a filling simulation, e.g., c_p, λ, η, and pvT). Close to project end also the tribological properties were characterized at PCCL. The findings will be described in section 5.

Nevertheless, the decisive property for the samples was thermal conductivity. With the addition of different fillers, the thermal conductivity was enhanced from 0,48 W/mK to 0,61 W/mK (PE 20Al), 0,72 W/mK (PE 30T), 0,56 W/mK (PE CaCO3-S) and 0,57 W/mK (PE CaCO3-B). With the addition of BN the thermal conductivity was more enhanced, but with bigger amount of added BN. For the composites with PP matrix the influence of the BN amount in the composite on the thermal conductivity is presented (Figure 5). As evident from the Figure 5, the thermal conductivity enhancement is linear to app. 40 % addition of BN. With the higher amount of BN in the PP matrix the thermal conductivity increase is exponential. At the samples 822_2020_0164 the amount of compatibilizer was varied and the highest thermal conductivity was achieved with 5 % compatibilizer. Composites without compatibilizer had lower thermal conductivity compared to the composites with compatibilizer. Addition of the GF instead of BN lowered thermal conductivity. In the composites with the PA6 matrix and 30 % BN and 30 % inorganic fillers (samples from 822_2021_0015_05 to 822_2021_0015_19) the highest thermal conductivity had composites with GF. After the addition of the compatibilizer (samples from 822_2021_0015_20 to 822_2021_0015_24) the thermal conductivity raised to higher values and the highest thermal conductivity showed addition of GF. Also, after addition of metallic Master Baches the thermal conductivity was enhanced. The results are presented in the Table 2.

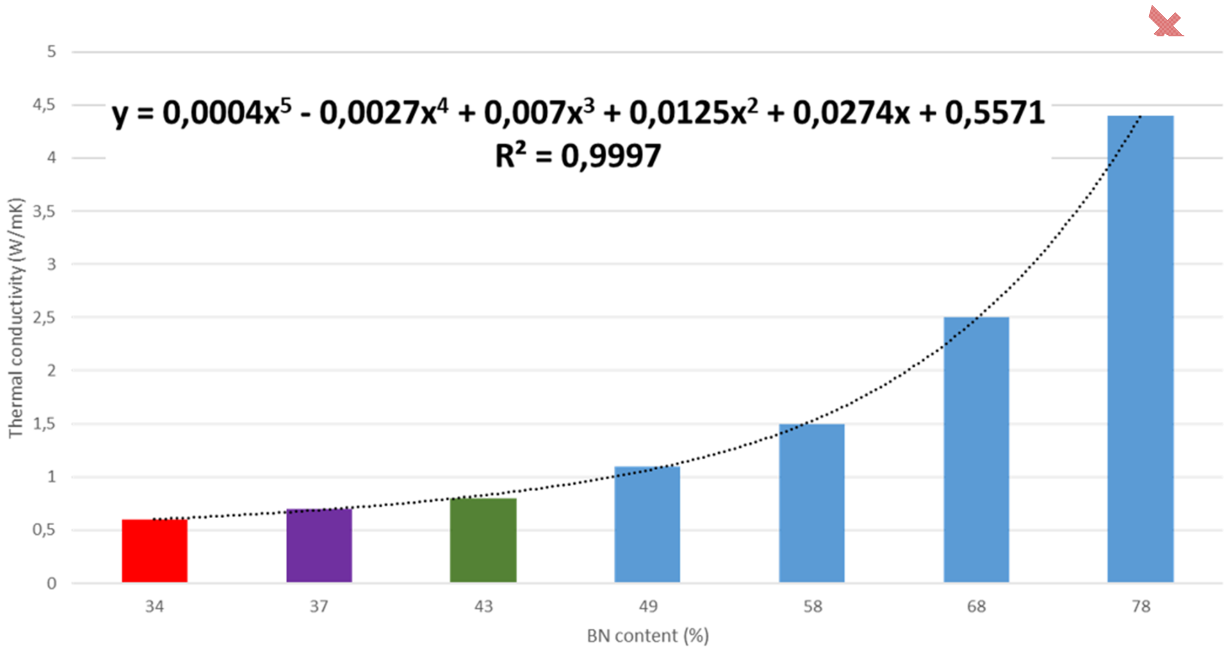


Figure 5: Thermal conductivity as a function of added BN in the PP matrix.

Table 2: Thermal conductivity of the composites with the addition of 60 wt.% of BN.

Matrix	**PA 6**	**PP**	**PC**	**ABS**	**PS**
Number	109	110	111	112	113
Master Batch	λ (W/mK)	λ (W/mK)	λ (W/mK)	λ (W/mK)	λ (W/mK)
without	**2,74**	**1,95**	**1,97**	**2,41**	**2,01**
Maxithen HP7BA5567 Metallic silver	**3,48**	**2,26**		**2,63**	**2,16**
Maxithen HP5BB4417 Metallic blue	**2,93**	**2,4**		**2,68**	**2,03**
Maxithen HP9BA8837 Metallic grey	**3,05**	**2,22**		**2,84**	**2,42**
Maxithen HP5BB4397 Metallic violet	**3,81**	**2,31**		**2,54**	**2,67**
Unimax UNS8BA5427 Metallic braun	**2,92**	**2,36**		**2,8**	**2,15**

Mechanical properties are influenced on the amount of BN addition. Till 50 % BN the stiffness and strength are enhanced if the composite is properly compatibilized. With higher amount of BN, stiffness, and strength dropped. The toughness decreased with the increasing addition of BN. At the addition of WP the stiffness remained on the same level, the strength was enhanced and also toughness. With the addition of Al the strength and stiffness are enhanced, and the toughness remained at the same level due to good compatibilization of the composites. Addition of talc and small $CaCO_3$ enhanced strength and stiffness and lowers toughness, with the compatibilizer even better. At the addition of bigger $CaCO_3$ the strength and stiffness were enhanced in the presence of the compatibilizer, and the toughness remained at the same level. The addition of GF into the PP based BN composites, the stiffness reached max. value at 25 % GF, the strength reached max. value at 15 % GF. Addition of wollastonite enhanced stiffness and strength less than talc and talc less than GF. Addition of $CaCO_3$ enhanced stiffness and strength less than wollastonite.

Huge influence on thermal properties has addition of BN for HDT. It was increased for all samples. Additionally, the HDT is enhanced with the addition of GF, talc and CaCO3-S and CaCO3-B. HDT is enhanced also with the addition of WP till 20 %.

The most interesting was the influence of the compatibilizer type on the thermal and mechanical properties of the PC based composites with 50 % BN (Table 3 and 4 as well as in Figure 6 and 7). The stiffness reached between 3,8 GPa and 9,8 GPa (from 7,5 GPa for PC 50BN and 2,0 GPa neat PC) and the strength between 39 MPa and 64 MPa (from 49 MPa for PC 50BN and 101 MPa neat PC). The glass transition temperature dropped to 97 °C to 128 °C (from 130 °C for PC 50BN and 143 °C neat PC). Detailed information about that topic could be found in the publication of Bolka et al. [1].

Table 3: Flexural tests collected results for the samples 822_2020_0190.

Sample	Flexural modulus (GPa)	Flexural strength (MPa)	Flexural strain at flexural strength (%)
822_2020_0190_00	1,97	101,4	8,12
822_2020_0190_01	7,53	49,5	0,78
822_2020_0190_02	9,77	64,2	0,77
822_2020_0190_03	3,77	38,8	1,43
822_2020_0190_04	7,1	63	1,38

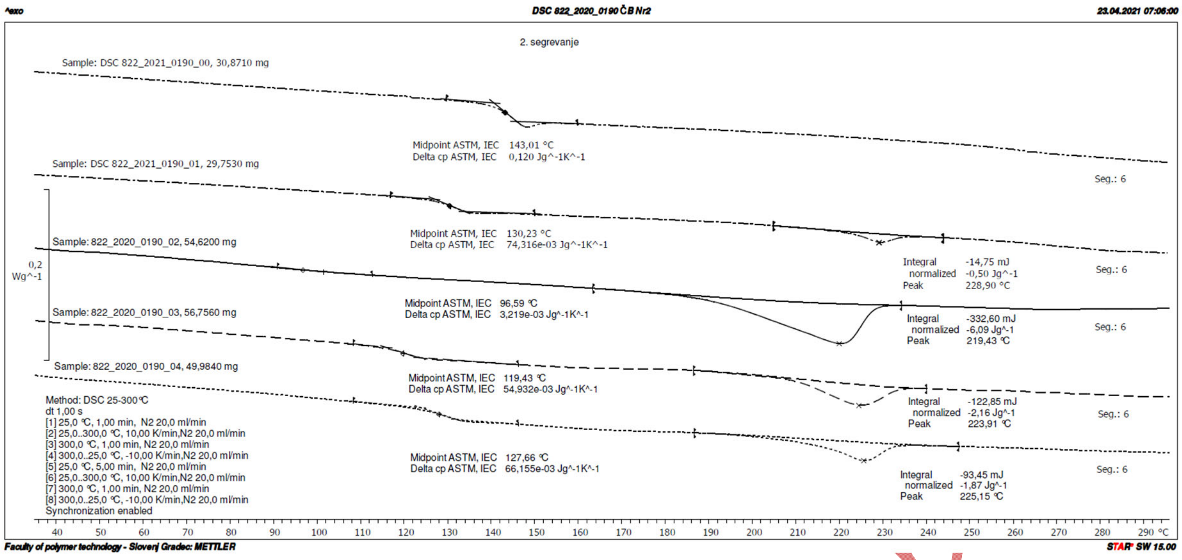


Figure 6: DSC thermograms for the samples 822_2020_0190 – evaluations of second heating.

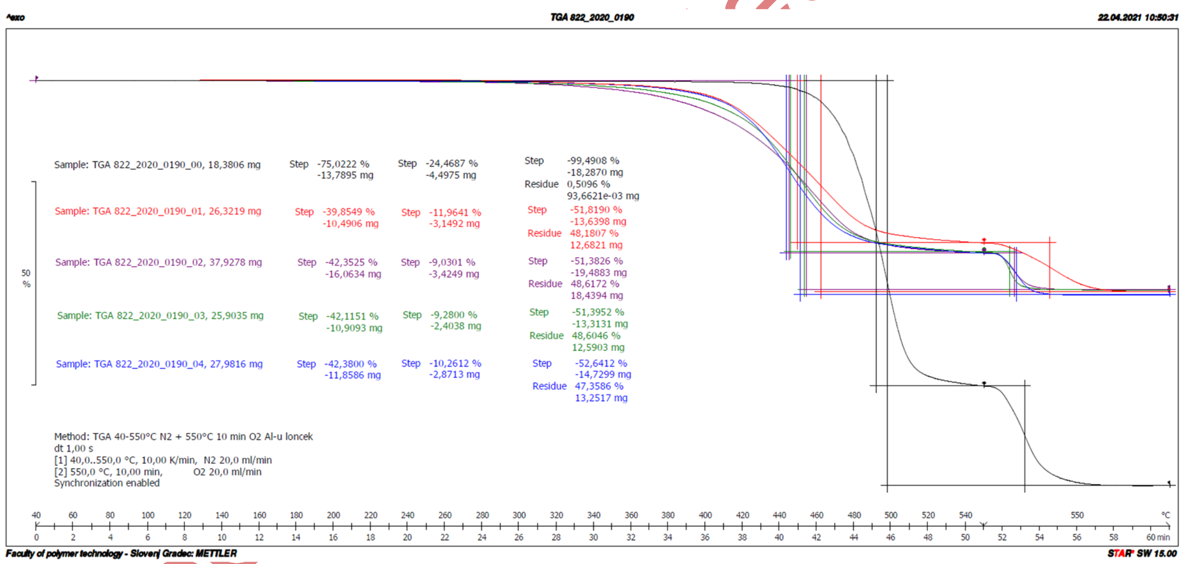


Figure 7: TGA thermograms for the samples 822_2020_0190.

Table 4: DMA collected results for the samples 822_2020_0190.

Sample	E' at 30 °C (GPa)	HDT (°C)	T_g at tan δ (°C)	Peak at tan δ (-)
822_2020_0190_00	1,98	147,4	158/197	1,715/0,814
822_2020_0190_01	5,41	145,5	149/174	1,218/0,903
822_2020_0190_02	7,8	129,6	134/157	1,234/0,939
822_2020_0190_03	3,84	140	146/174	1,375/0,902
822_2020_0190_04	5,19	147,4	151/182	1,274/1,057

5 Haptic/wear properties of selected materials

PCCL and MUL supported the WP-Leader FTPO with different measurements to strengthen the cross-border cooperation on the one hand and to achieve the required project goals on the other hand. The main focus of PCCL was set on: (i) several bilateral meetings with FTPO and MUL to define the material formulations (see Table 1) and discuss the obtained results, (ii) determination of the haptic properties of selected materials in terms of roughness measurements, and (iii) investigation of the wear properties of samples with production number 822_2020_0190 (PC50BN with 3 different compatibilizer).

5.1 Determination of the haptic properties of selected materials in terms of roughness measurements

Preliminary investigations showed that the roughness of the molded part varies significantly depending on the material used while utilizing an injection mold with a standard insert ($\mathrm{R_a} = 0{,}26\ \mu\mathrm{m}$, Figure 8). For more details, see Kerschbaumer et al. [2].

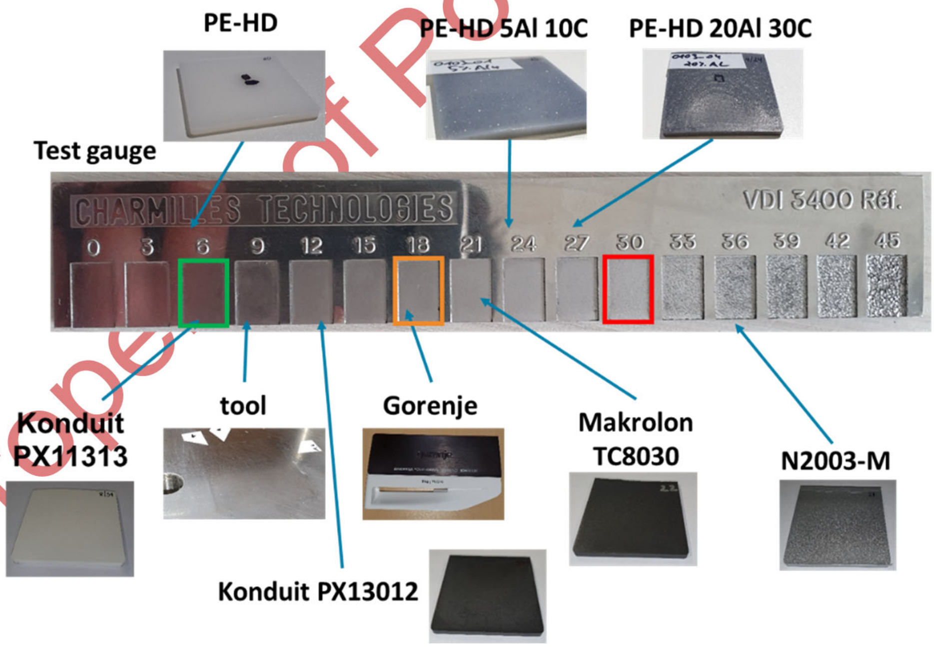


Figure 8: Ranking of the preliminary investigations on the impression quality of commercially available thermoplastics by means of a confocal microscope and employing a standard insert with a line roughness of $R_a = 0{,}26\ \mu m$.

Consequently, this hypothesis was formulated: The shape, the amount and the size of the fillers used are decisive for how the surface of the mold will be formed. The whole consortium decided to investigate this hypothesis in a scientific way, as the microstructure of molded parts has a decisive influence on the touch-feel sensation. For this purpose, three inserts with significantly different roughness values were provided by the partner Richard Hiebler GmbH. The applied equipment for the production of injection molded parts is shown in Figure 9 and the used materials were based on PE-HD containing different filler content, filler size, and compatibilizer (production number 822_2020_0056 and 822_2020_0127 in Table 1).

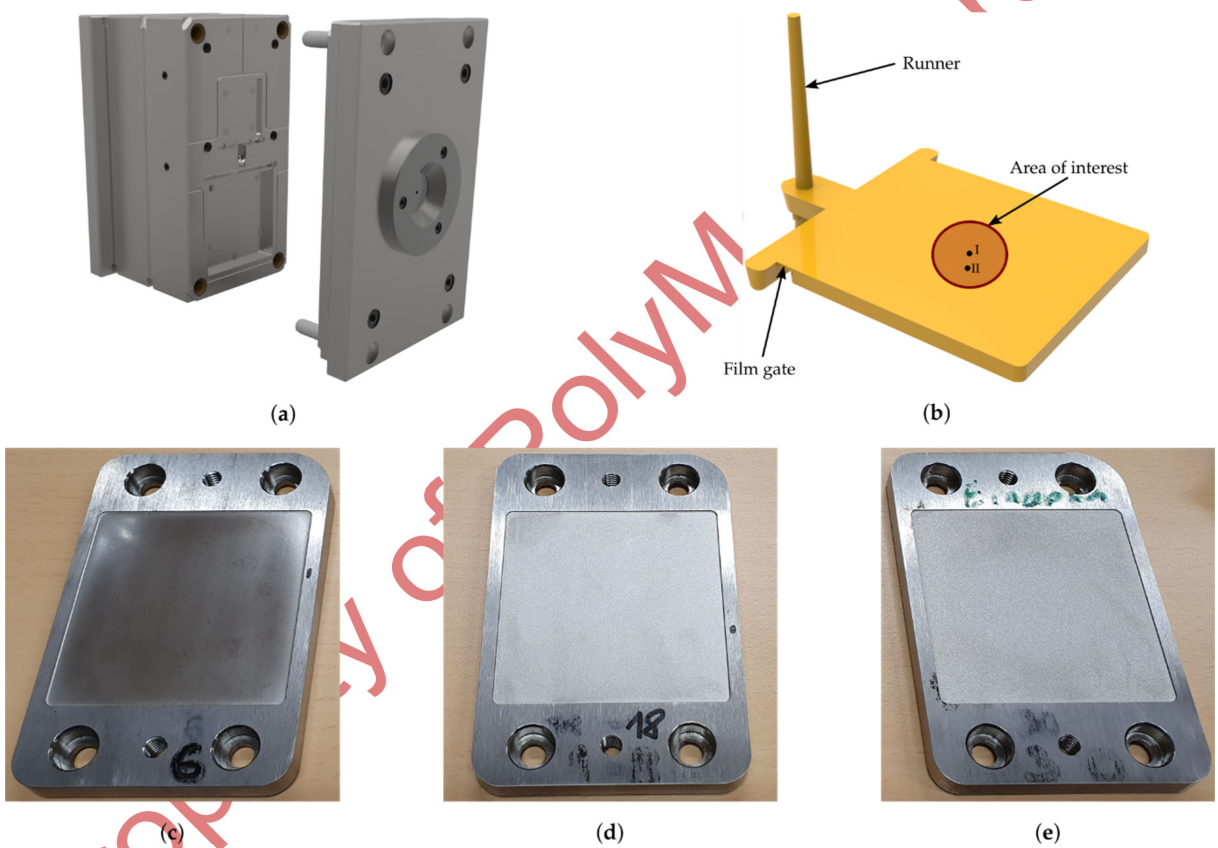


Figure 9: Applied equipment for the production of injection molded parts with specified roughness values. (a) Mold with interchangeable inserts. (b) Injection molded part with a dimension of 60 mm x 60 mm x 4 mm applying an insert without a specified roughness. (c–e) Provided mold inserts from Richard Hiebler GmbH., Stainz, Austria, with target line roughness values R_a of 0,2 µm, 0,8 µm, and 3,2 µm to produce rectangular shaped parts with a dimension of 60 mm × 60 mm × 2,5 mm [3].

As a result, and illustrated in Figure 10, a distinction must be made between two cases, whether it is possible for the unfilled matrix polymer to flow to the bottom of the valleys or not. If the flow front of filled thermoplastics does not solidify before reaching the bottom of the valleys, an increase of the filler diameter and of the filler content causes an increase of $\Delta\bar{R}_a$, i.e., the molded part becomes rougher compared to the selected insert roughness. Another influencing factor is related to the size of the filler, i.e., whether it fits into the valleys or not. However, if this is not the case, e.g., when using inserts with R_a-values lower than 0,8 µm and the filler CalPlex 40 with a D50-value of 16 µm–25 µm, the geometry of the filler is primarily molded. Once the flow front solidifies before reaching the valleys, e.g., as observed for insert roughness of 3,2 µm, this generally leads to significantly smoother specimens. Any addition of filler as well as a change in the quantity of filler or compatibilizer reveals no significant effect on the impression quality.

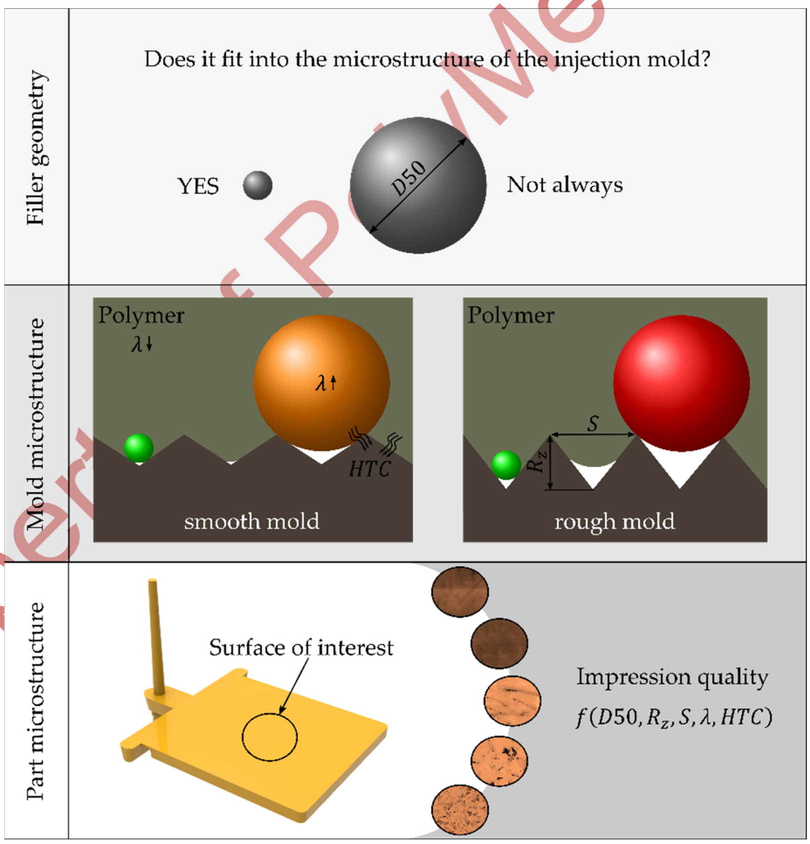


Figure 10: Impact on the impression quality for a general case [3].

In summary, the impression quality is a function of the filler size, the dimension of the valley of the microstructure represented by R_z and S, the thermal conductivity of the filler as well as of the matrix polymer, and the heat transfer coefficient. Detailed information about that topic could be found in the publication of Kerschbaumer et al. [3].

In order to improve the impression quality, the occurring melt temperature and the wall shear rate during the filling process was calculated on the basis of a filling simulation (see Figure 11). The required material data were determined at MUL as well as the simulation was conducted at MUL.

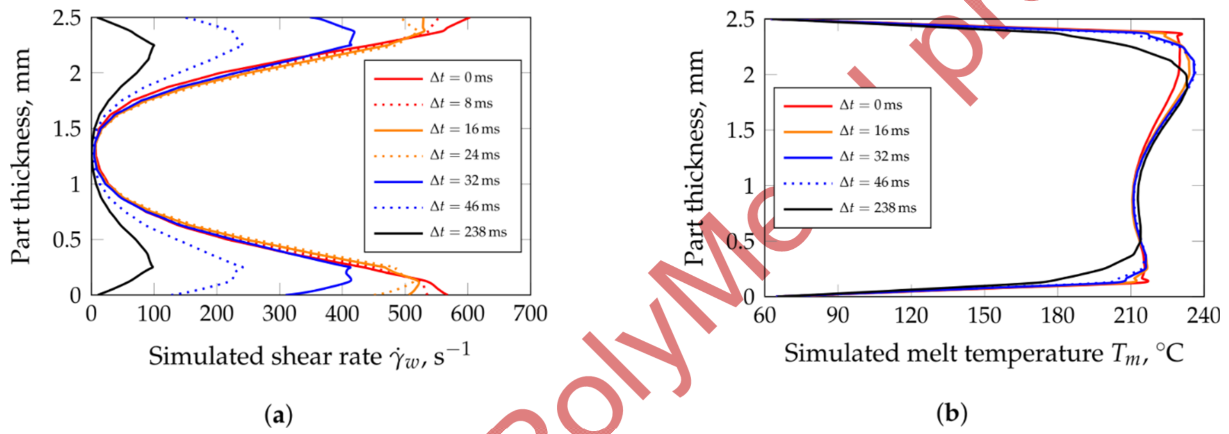


Figure 11: Simulated (a) shear rates and (b) temperature distributions 297 ms after the start of the filling phase (PE-HD, center of the molded part). The time steps represent the decrease due to solidification processes at the cavity wall [3].

Subsequently, viscosity measurements at MUL were carried out applying the simulated parameters ($\dot{\gamma} = 500\ s^{-1}$, $T = 215\ °C$) with the objective of correlating the impression quality with the material viscosity. On the basis of these investigations (Figure 12), the assumption that an equal viscosity at given process conditions leads to an identical impression quality could not be confirmed. Compare impression quality for green and red marked values in Table 5. Formulations exhibiting the same viscosity at given process conditions revealed a factor of up to 3 in impression quality.

Table 5: Correlations of viscosity values η and impression quality $\Delta\bar{R}_a$ of the insert with low roughness for selected formulations. Viscosities were determined in the linear viscoelastic range (strain of 10 %) at a test temperature of 215 °C and a shear rate of 500 s^{-1}. Compatibilizer is marked as C and the filler as F [3].

Formulation	**CaCO3-S**		**T**		**CaCO3-B**	
PE-HD	**η, Pa s**	**$\Delta\bar{R}_a$, µm**	**η, Pa s**	**$\Delta\bar{R}_a$, µm**	**η, Pa s**	**$\Delta\bar{R}_a$, µm**
+10 wt.% F + 2 wt.% C	188±8	0,17	186±1	0,51	183±11	0,65
+20 wt.% F	193±15	0,47	186±1	0,48	192±11	1,11
+30 wt.% F + 6 wt.% C	304±6	0,53	303±1	1,14	255±16	3,51

η: mean value of three measurements

However, as already described in section 4, differences in the compatibilizer have a significant effect on the thermal and mechanical properties of the PC-based composites with 50 % BN (production number 822_2020_0190). As shown in Figure 12, a variation in compatibilizer do not influence the roughness of the produced part.

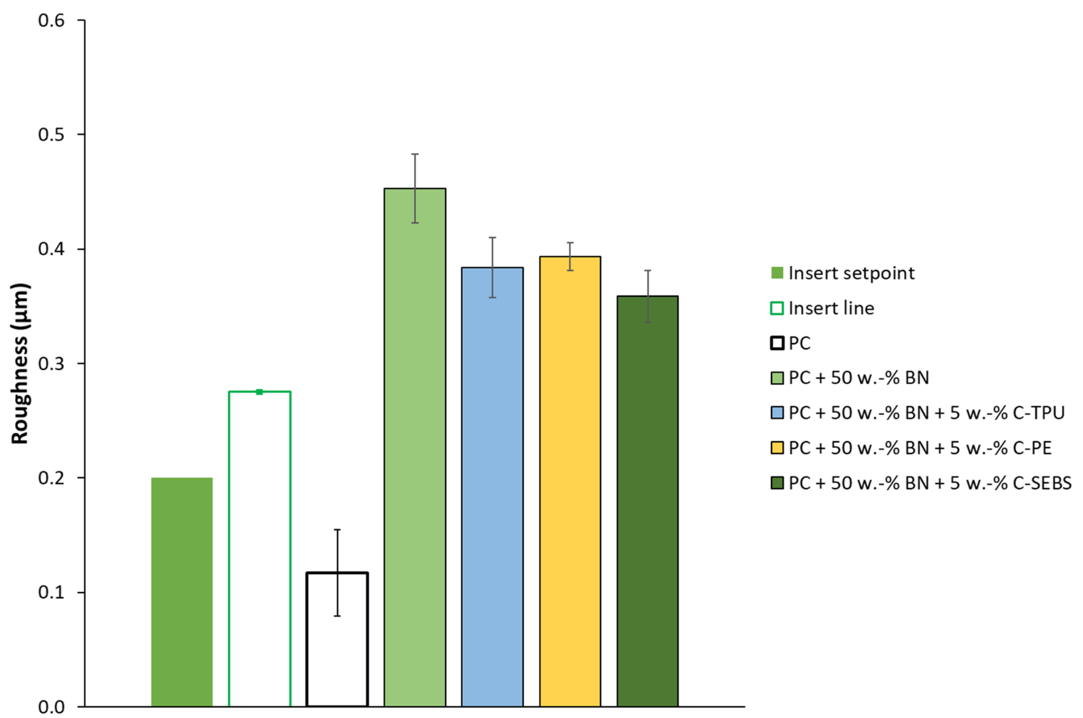


Figure 12: Impact of different compatibilizer on the roughness of the produced part.

5.2 Wear properties of selected formulations based on tribological investigations

Shortly before the end of the project, the tribological properties of PC-based composites (production number 822_2020_0190) were characterized at PCCL in order to correlate the results with the material behavior determined so far by FTPO. First, preliminary tests were carried out to define suitable test conditions. As shown in Figure 13, the test conditions were set to F_N=1 N, v=0.1 ms^{-1}, and t=1 h.

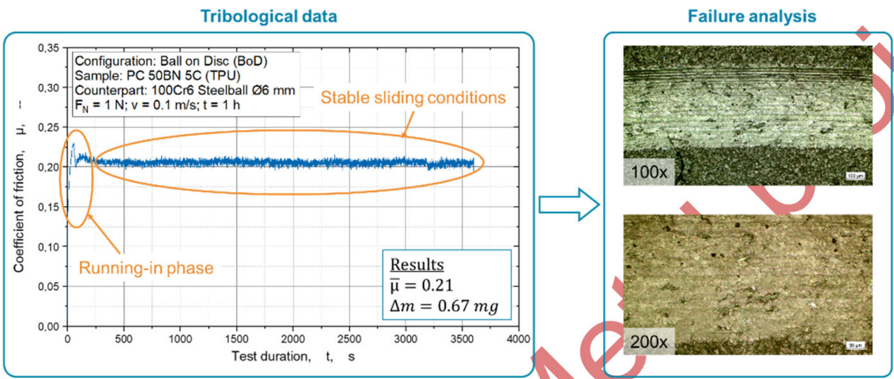


Figure 13: Preliminary tribological tests (Ball on Disc-(BoD) method) to define suitable test conditions.

Thereafter, the reproducibility was checked. It could be shown that the reproducibility is given for all 3 tested samples per formulation. An example for formulation PC 50 BN 5 C-TPU is given in Figure 14 and 15.

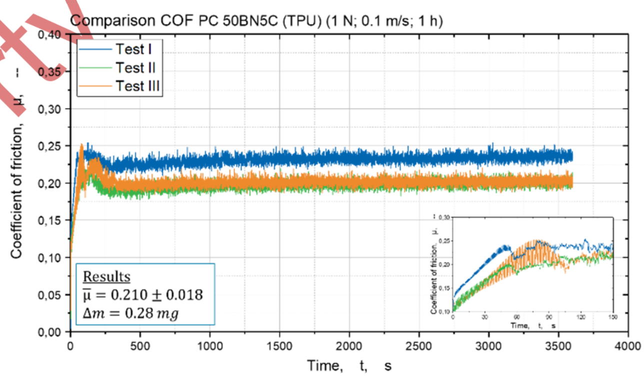


Figure 14: Reproducibility of BoD-method is given for all 3 tested samples per formulation (PC 50 BN 5 C-TPU).

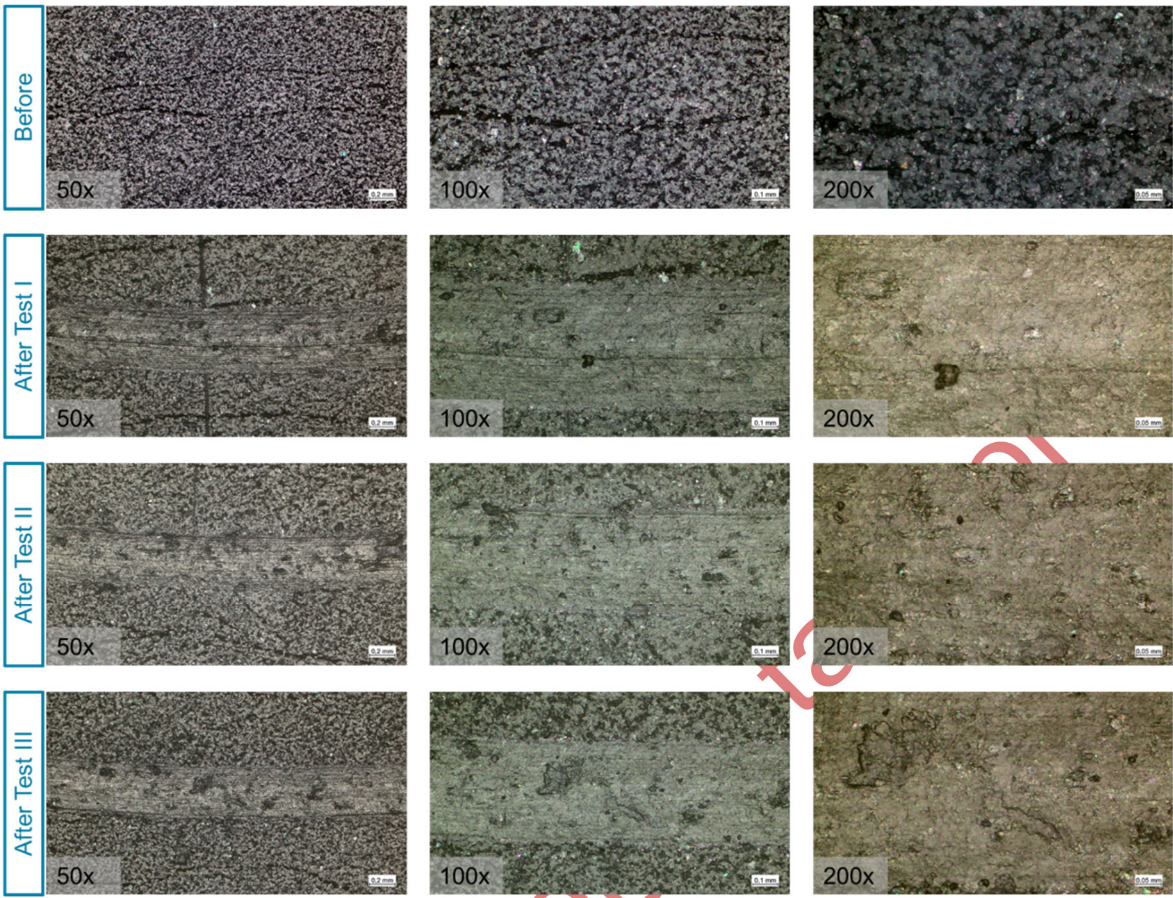


Figure 15: Optical investigation of Ball on Disc (BoD)-tested samples PC 50 BN 5 C-TPU.

Adding the filler boron nitride (BN) to the neat PC significantly reduces the coefficient of friction (COF). Note, that the introduction of different compatibilizer into the PC 50 BN formulation has no effect on the COF, at least after a test period of t=1h (Figure 16).

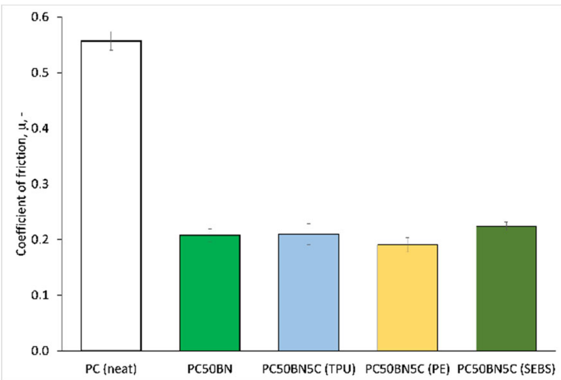


Figure 16: The introduction of different compatibilizer into the PC 50 BN formulation has no effect on the COF at a test time of 1h.

Accordingly, final BoD-tests were performed with a test duration of only 20 s. After that short test time, a trend could be observed (Figure 17). The influence of different compatibilizers is now clearly visible. PC with 50%BN and compatibilizer TPU exhibit the lowest COF, the highest could be obtained with compatibilizer SEBS.

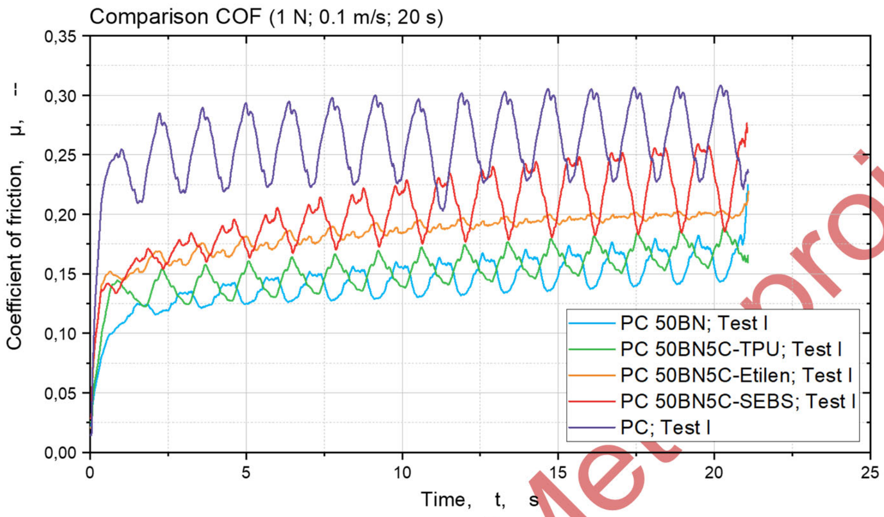


Figure 17: CoF of formulations based on PC 50 BN after a test time of 20s.

Finally, comparing the results (Bending, DMA, DSC, and thermal properties), the following correlation could be found: A low CoF is the result when the material exhibits a higher thermal conductivity, a lower heat deflection temperature, and a lower glass transition temperature.

6 Conclusions

The project was conducted with 103 different material formulations, 91 compounding cycles, 103 injection moulding cycles, 108 thermal conductive measurements and 345 other laboratory measurements.

Due to the cooperation between all project partners and also other institutions and SME´s new test method for the cool-touch was developed. The selection of the materials opens also new research field (influence of the particle size and shape on the roughness of the injection moulded parts) very interesting also for the industry partners. The further development in this area will be done with the characterization of the tribological properties with the emphasis on the used compatibilizer. The compatibilizer influence on the mechanical and thermal properties at the composites with PC matrix opened new field of the research and new possibilities to create costume-wished composite´s properties. The composites with high thermal conductivity were compounded, injection moulded and characterized. With the use of the proper compatibilizer and lubricant the wished properties were achieved and prototypes were made at Intra lighting and Gorenje. Injection moulding of the composite with high thermal conductivity is proper technology for the project partners Intra lighting and Gorenje. The wished thermal conductivity was achieved with the addition of 60 % BN into the thermoplastic matrix, the wished look was achieved with the addition of 5 % metallic Master Batch. For further optimization of the properties and especially the price of the composites, the mixture of BN with GF and talc or $CaCO_3$ must be made in the future.

7 Publication

[1] Bolka, S.; Pešl, T.; Kerschbaumer, R.C.; Nardin, B. *Effect of compatibilizers on surface roughness, mechanical, and thermal properties of thermoplastic composites with high thermal conductivity*. V: MEŠL, Maja (ur.), et al. Plastic Gears Conference 2021 : book of abstracts : 17th-18th June, 2021, Slovenj Gradec, Slovenija, 21. https://www.ftpo.eu/Plasticgears

[2] Kerschbaumer, R.C.; Mesl, M.; Bolka, S.; Teja, P; Meza, M.; Mihelic, A.; Dovzak, A.; Stückler, S.; Reumüller, R. (2021) *Impact of Different Thermoplastic Materials on the Impression Quality of Injection Molded Parts*. In: Walter Friesenbichler (Hg.): 29th Leoben-Conference on Polymer Engineering and Science. 50 years Polymer Engineering and Science at Montanuniversität Leoben, Band 10. Leoben: Eigenverlag (Band 10), S. 217–218, doi: 10.13140/RG.2.2.36361.36963

[3] Kerschbaumer, R.C.; Bolka, S.; Pesl, T.; Duretek, I.; Lucyshyn, T. *The Relationship between a Defined Microstructure within the Mold Surface and the Corresponding Roughness on the Part: A Systematic Study on Particle Size, Filler-, and Compatibilizer Content. Polymers 2021*, 13, 2757 https://doi.org/10.3390/polym13162757