



**BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS  
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**DEVELOPMENT OF INJECTION MOLDABLE,  
THERMALLY CONDUCTIVE POLYMER COMPOSITES**

**THESIS BOOKLET**

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The referees' opinion and the minutes of the PhD examination can be inspected at the Dean's Office of the Faculty of Mechanical Engineering of the Budapest University of Technology and Economics Introduction

## 1. Introduction

Polymers are popular engineering materials because of their relatively low density, low cost, good chemical resistance, low thermal conductivity and ease of processability compared to other materials. In the last few decades there has been an increasing demand for polymer-based structural materials to replace or complete metallic parts. So far the goal of researches has been to improve the mechanical properties of synthetic polymers to approach the strength of steel. The basis of these developments was the application of fiber-like reinforcements. On the other hand, metals do not only have better mechanical performances but also have higher thermal conductivity than polymers. There is a great demand for structural materials which are good thermal conductors but also good electrical insulators. Such materials are required in electronics, where good heat dissipation is vitally important to extend the lifespan of the devices, while electrical insulation is essential to eliminate the short circuit failures and other errors.

In the past few years developments in technology have resulted in smaller devices with higher performance (sensors, controlling units, transformers, amplifiers, integrated circuits and so on). As a result of this development heat dissipation in electronics, especially microelectronics, has an ever-increasing importance. Besides, heat dissipation has a great influence on lifespan. Generally, metallic parts are used as heat sinks to dissipate heat, but metal parts are heavier, often more costly and more difficult to process than plastic parts. In the last years thermally conductive polymer composites are receiving more and more attention in the industry. These special materials have a potential in the cooling of electric and mechatronic devices. Hence thermally conductive and electrically insulating polymer composites can be innovative new materials in device development.

It is well-known that polymer materials are good thermal insulators as their thermal conductivity varies between 0.1 and 0.5 W/mK. Traditionally, conductive polymer composites are obtained by the dispersion of conductive fillers in an insulating polymer matrix. These fillers are mainly graphite, carbon black and carbon fibers, ceramic or metal particles. If the dielectric behavior of the composite is an important requirement, thermally conductive but electrically non-conductive particles should be applied. Ceramic fillers, such as boron nitride, aluminum oxide, aluminum nitride, silica, talc and many others can be used in such cases. The fillers can significantly influence the thermal behavior of polymers. To obtain composite materials with the appropriate thermal conductivity, high filler content is usually required, although this will increase processing difficulties. Although flow properties

is reduced in this case, thermal conductivity is increased significantly, which leads to more rapid cooling of the part and thus a reduction of polymer molding cycle times.

The main goal of this dissertation is to develop new polymer-based composite materials of high thermal conductivity. A further important aspect is good electrical insulation behavior so that they can be used directly as electronic packaging without a thermal barrier material. It is important to extend the use of these materials so that they can replace conventionally used ceramic and metal cooling units, whose production is costly compared to the production of polymer composites. On the other hand, the modeling and prediction of the thermal conductivity of these special materials is important to tailor their properties to the needs of users.

## **2. Summary of the literature, objectives of the dissertation**

The aim of the literature survey was to show the possibilities of application and development of thermally conductive polymers. At the beginning the theory and physics of thermal conductivity and its measurement methods were reviewed. Next, methods to improve thermal conductivity were surveyed, such as the effect of molecular orientation, crystallinity, processing methods and fillers. The three main groups of fillers (metallic, ceramic and carbon-based fillers) were also analyzed. It was also concluded that fillers can significantly influence the flow properties of polymers.

The thermal conductivity of polymers can be modified in many ways. If the crystallinity of the polymers is increased, thermal conductivity also increases. This statement can prove that fact that amorphous polymers have lower thermal conductivity than semi-crystalline polymers. Research shows that the molecular weight also has a significant influence; polymers with higher molecular mass also have higher thermal conductivity. The orientation of the polymer chains can improve conductivity as well, but the material will be anisotropic. Thermal conductivity increases in the direction of the orientation and decreases perpendicular to that. These methods only have a slight effect on thermal conductivity. The best results can be obtained with the use of solid fillers, which was proved by many researchers. Metallic and carbon-based fillers are the best for this purpose, but the composite will also be an electrical conductor. As the goal of this research is to produce dielectric polymer composites of high thermal conductivity, these fillers can be applied up to the percolation threshold. In contrast, ceramic fillers have better properties, such as good thermal conductivity, low density and good electrical insulating properties.

In the literature, many different results can be found for the same type of fillers or matrices. These differences can be attributed to the different measuring methods or different processing methods. Many different measuring techniques exist, such as the hot plate, hot-wire, laser flash methods and others, and these methods work on different principles. To analyze the effect of different processing methods and processing parameters is essential to understand their effect on filler distribution within the matrix. Hence the segregation effect could not be neglected. Segregation can be through the thickness (shell-core effect) and along the flow length. Segregation can decrease the thermal conductivity of the part and cause inhomogeneity regarding the thermal and mechanical properties.

In most articles the authors only used a single filler to produce conductive compounds. Generally these fillers were copper, carbon black, graphite, carbon nanotubes, silicon-dioxide, talc, aluminum-nitride and boron nitride. Only a few articles investigated polymer composites with a hybrid filler system. So far I have not found any articles applying only dielectric fillers to utilize the advantages of the hybrid effect between different fillers.

It is important that the thermal conductivity of polymer composites should be tailored to requirements. Although numerous empirical, semi-empirical and theoretical models have been developed for the prediction of the thermal conductivity of two- or multiphase polymer composites, its reliable and precise prediction still remains a challenge. The theoretical models often underestimate the results and can be used around up to 30 vol% filler content. The semi-empirical models give better correlation with the experiments, but they need more experimental parameters.

Improving thermal conductivity with solid fillers can cause difficulties in material processing. The viscosity of the polymer increases drastically as filler concentration is increased. Generally, in the literature conductive polymer composites with a thermoplastic matrix were prepared with internal mixing and compression molding, or simply a low viscosity thermosetting matrix was used. These techniques are too slow for mass production and can compromise design freedom. On top of that, only a few articles were published on the injection molding of thermally conductive polymers, therefore this is a new area to investigate. Also, only a few articles can be found on the thermal properties of highly filled polymers and so there is not much information on the influence of fillers on the glass transition temperature and the crystallinity of thermally conductive polymers.

***Based on the literature survey, I have set out the following objectives of this PhD dissertation:***

1. The development and investigation of a novel thermally conductive polymer, which is an electrical insulator.
2. The investigation of the effects of different parameters (matrix, filler, processing technology, etc.) on the effective thermal conductivity of polymer composites.
3. The development of a polymer composite with a dielectric hybrid filler system to enhance effective thermal conductivity with the same amount of filler.
4. The investigation of the thermal properties and crystallinity of conductive polymers, influenced by the injection molding process.
5. The improvement of processability of highly filled polymers.
6. The development of a model to predict the thermal conductivity of composites as a function of filler concentration.

### **3. Materials and methods**

#### **3.1. Materials**

In my research composites were prepared with the use of different matrices and fillers. The names, manufacturers and abbreviations (used in my research) of the applied materials are presented in Table 1 and Table 2. Talc, boron nitride and graphite have plate like shape which show anisotropic behaviors. The titanium dioxide has spherical shape. The matrices can be processed directly, only polyamide 6 and polylactic acid need to be dried at 80°C for 4 hours.

The melt flow of the polypropylene homopolymer matrix was enhanced with CBT 100 cyclic butylene terephthalate oligomer (CBT) (Cyclics Europe GmbH (Germany)). Cyclic butylene terephthalate is the cyclic form of polybutylene terephthalate (PBT). For the surface treatment of boron nitride silane coupling agent was used. The Geniosil GF 56 vinyltriethoxysilane coupling agent was purchased from Wacker Chemie AG (Germany). For the thermal conductivity measurements to decrease the thermal contact resistance between the samples and the measurement unit, ceramic powder filled thermal interface silicone grease was applied. The conductive grease was purchased from T-Silox Kft., (Hungary).

Name	Trade name	Manufacturer	Abbreviation in the dissertation
Polypropylene homopolymer	Tipplen H 145 F	Tisza Chemical Group Public Limited Company	PP
Polypropylene copolymer	Tipplen K 693	Tisza Chemical Group Public Limited Company	cPP
Polyamide 6	Schulamid 6 MV 13	A. Schulman, Inc.	PA6
Polylactic acid	PLA AI-1001	Shenzhen eSUN Industrial Co., Ltd.	PLA

Table 1. Matrix polymers used in the dissertation

Name	Trade name	Manufacturer /distributor	Particle size (D50)	Abbreviation in the dissertation
Talc	Talc Powder 325 mesh coating grade	QualChem Zrt.	24.4 $\mu\text{m}$	talc
Boron nitride	HeBoFil 482	Henze BNP GmbH	3-5 $\mu\text{m}$	BN
Titanium dioxide	Titanium dioxide KTR 600	QualChem Zrt.	n.a.	TiO <sub>2</sub>
Graphite	Timrex C-Therm 011	Timcal Ltd.	n.a. (soft granules)	Graphite

Table 2. Fillers used in the dissertation

## 3.2. Processing methods

### *Compounding methods*

The components of the composites were compounded with two different methods. In the first case the composites were prepared with a Brabender Plastograph internal mixer. The components were mixed at 230°C for 20 minutes at a rotational speed of 25 1/min to achieve the desired homogeneity. In the second case the materials were compounded with a Labtech Scientific LTE 26-44 twin screw extruder (L/D ratio is 44; D=26 mm) at 230°C (zone temperatures from 230°C to 210°C) at a rotational speed of 30 1/min. Not only the composites but the unfilled matrices were also processed with these technologies to have the same thermal history. The proper amounts of matrix and filler materials were calculated with Equation (1):

$$m_f = \frac{m_c}{\frac{\varphi_m \cdot \rho_m}{\varphi_f \cdot \rho_f} + 1}, \quad m_m = m_c - m_f, \quad (1)$$

where  $m_c$ ,  $m_f$  and  $m_m$  [g] are the mass of the composite, the filler and the matrix material,  $\varphi_f$  and  $\varphi_m$  [vol%] are the volume fraction of the filler and the matrix material, and finally  $\rho_f$  and  $\rho_m$  [g/cm<sup>3</sup>] are the density of the filler and the matrix material.

### *The preparation of samples*

From the compounds 2 mm thick plate-like samples were compression molded and injection molded. Compression molding was performed with a Collin Teach-Line Platen Press 200E machine at 230°C for 15 minutes. The injection molded samples were produced with an Arburg Allrounder Advance 370S 700-290 machine. The main technological parameters can be seen in Table 3.

Parameter	Unit	PP/cPP	PA6	PLA
Volume	[cm <sup>3</sup> ]	49	49	49
Injection rate	[cm <sup>3</sup> /s]	50	50	50
Holding	[bar]	80% of injection pressure	80% of injection pressure	80% of injection pressure
Clamping force	[kN]	700	700	700
Residual cooling time	[s]	10	15	20
Zone temperatures	[°C]	200; 195; 190; 185; 180	230; 225; 220; 215; 210	210; 195; 190; 185; 180
Mold temperature	[°C]	50	50	50

**Table 3. Injection molding parameters**

Injection-compression molding technology was also applied to produce samples. During the process first the polymer melt was injected into the partially open mold. In the second step the mold was closed. This clamping forced the melt to fill completely the cavity and acts as holding pressure. The injection-compression molded samples were produced with an Arburg Allrounder Advance 370S 700-290 injection molding machine. The main molding parameters can be seen in Table 4.

Parameter	Unit	Value
Injected volume	[cm <sup>3</sup> ]	56
Injection rate	[cm <sup>3</sup> /s]	50
Compression stroke	[mm]	1.5
Compression force	[kN]	700
Compression speed	[mm/s]	25
Residual cooling time	[s]	10
Zone temperatures	[°C]	200; 195; 190; 185; 180
Mold temperature	[°C]	50

**Table 4. Injection molding parameters**

### **3.3. Testing methods**

The samples for thermal, mechanical and morphological investigation were cut from the 2 mm thick plates with a water jet cutter machine. On these specimens mechanical, thermal and morphological analyses were performed. The details of the testing methods are presented in this section.

## ***Mechanical tests***

### *Tensile testing*

The tensile tests were carried out according to the recommendation of the ISO 527-1:2012 standard with a Zwick Z020 universal testing machine. The type of the standard specimen was 5A (length: 75 mm, width: 4 mm, thickness: 2 mm, grips length: 50 mm). The testing speed was 2 mm/min. The tests were performed at room temperature (25°C). From the force-displacement curves the tensile strength ( $\sigma$  [MPa]) and tensile modulus ( $E$  [MPa]) of the samples were calculated. The tensile strength was determined from the maximum developed force. The tensile modulus was calculated between 0.0005 and 0.0025 strain. The tensile properties were determined from five measurements in each case.

### *Charpy impact testing*

The Charpy tests were carried out according to the recommendation of the ISO 179-2:1997 standard with a Ceast Resil Impactor Junior machine. For the tests unnotched specimens with a 2x6 mm cross-section were used with a 40 mm span distance. The tests were performed at room temperature with a 2 J pendulum. From the absorbed energy the Charpy impact strength ( $a_{cU}$  [kJ/m<sup>2</sup>]) could be calculated. The impact properties were determined from ten measurements in each case.

## ***Thermal analysis***

### *Thermal conductivity*

To measure the thermal conductivity of the composite samples, two different thermal conductometers were developed, a hot plate and a linear heat flow apparatus. In this section the basic theory and layout of these units are presented.

In this research a ***single-specimen hot plate apparatus*** was developed where the heat flows in a single direction between the hot plate and the cold plate through the specimen. Figure 1/a shows the main components of the designed measurement system. The main task is to maintain the temperature difference between the cold and the hot plates. The calculation of thermal conductivity is based on Fourier's law

A further thermal conductivity meter, a ***linear heat flow apparatus*** was designed and built (Figure 1/b), based on the comparative longitudinal heat flow method. In this method the unknown sample is compressed between the known reference samples and a heat flux passes through the measurement unit as a temperature difference is created between the two sides of

the unit. The thermal conductivities of the sample and the reference sample are inversely proportional to their thermal gradients.

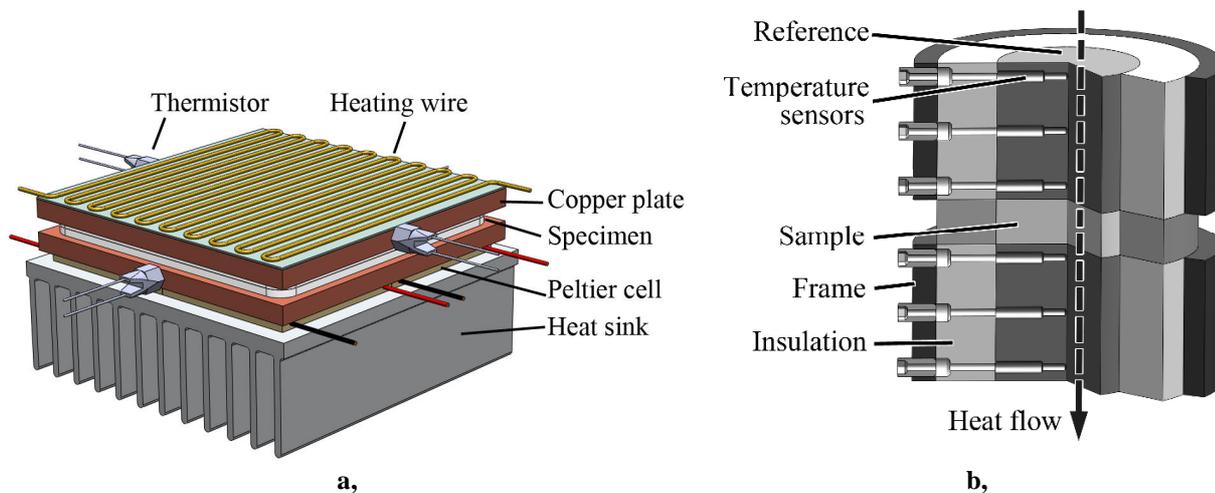


Figure 1. Hot plate (a) and linear heat flow (b) measurement unit

### DSC analysis

A DSC Q2000 (TA Instruments) differential scanning calorimeter was used to analyze the specific heat, crystallization temperature and crystallinity of the samples. 3-5 mg samples were cut off from the center of the injection molded plates and placed into pans. The measurements consisted of three phases: heating to 225°C from 25°C, cooling back to 25°C and heating to 225°C again. The first heating is used to measure the effect of the injection molding process, as in the next two phases crystals are created and melted during a controlled process (at a heating and cooling rate of 10°C/min). The degree of crystallinity ( $X$ ) was determined from the exothermic and the endothermic peaks with Equation (2), which takes into account the filler fraction of the compound:

$$X = \frac{\Delta H_m - \Delta H_{cc}}{\Delta H_f \cdot (1 - \varphi)}, \quad (2)$$

where  $\Delta H_m$  is the enthalpy of melting,  $\Delta H_{cc}$  is the enthalpy of cold crystallization,  $\Delta H_f$  is the melting enthalpy of a theoretically fully crystalline polymer and  $\varphi$  is the mass fraction of the filler.

### Microscopy

The fracture surface of the samples was analyzed with a Jeol JSM 6380LA Scanning Electron Microscope. The samples were first coated with an Au/Pd alloy with a Jeol JFC-1200 fine coater apparatus to avoid electric charging.

### ***Segregation investigation***

To determine filler distribution in the injection molded samples, they were cut into 16 identical parts. Next, the density of the samples was measured based on Archimedes' principle. Knowing the density of the matrix, the filler and the composite, the filler and matrix concentration can be calculated according to the Equations (3):

$$\varphi_f = \frac{\rho_c - \rho_m}{\rho_f - \rho_m} \cdot 100, \quad \varphi_m = 100 - \varphi_f \quad (3)$$

### ***Flow properties***

#### *Melt volume rate measurements*

To characterize the flow properties of the materials, the melt volume rate (MVR) was determined according to the ISO 1133-1:2013 standard at 230°C, with a load of 2.16 kg using CEAST Modular Melt Flow (7027.000) apparatus. In each case 6 measurements were performed. The measurement procedure consists of the following steps: 60 seconds preheating; compacting with 375 N to the position of 75 mm; compacting with the standard (2.16 kg) weight; and performing a measurement at 40, 30 and 20 mm.

#### *Viscosity measurement*

The viscosity of the CBT modified polypropylene was measured with an Instron capillary rheometer, installed on a Zwick Z050 tensile-testing machine. Measurements were made at four different temperatures: 190, 200, 220 and 240°C, with three capillaries of different length (Table 5) and at seven different crosshead speeds: 5, 10, 20, 50, 100, 200 and 500 mm/min.

Nr.	Sizes of the capillaries	
	Diameter [mm]	Length [mm]
1	1.23	24.45
2	1.20	49.17
3	1.20	73.55

**Table 5. Sizes of the capillaries used for the viscosity measurements**

## 4. Theses

Based on the results of this PhD dissertation the following theses have been deduced:

### *Thesis 1/a*

I proved that there is a significant difference between the effective thermal conductivity of injection molded and compression molded polymer composites containing plate-like fillers. The differences in the orientation of the particles lead to decreased thermal conductivity in injection molded parts. This statement was confirmed by measurements of boron nitride and talc filled polypropylene homopolymer. The thermal conductivity of injection molded samples were 16-39% and 30-39% lower than that of compression molded samples in the 10-30 vol% filler concentration range [1-3, 7, 10].

### *Thesis 1/b*

I showed that the injection-compression molded 20-30 vol% boron nitride filled polypropylene homopolymer samples have 20-23% higher through plane thermal conductivity than that of the injection molded samples. The difference can be originated from the proportion of layers with different particle orientation (core and shell layers). While the core layer of the 2 mm thick injection molded samples is only 300-400  $\mu\text{m}$  thick, the core of the injection-compression molded samples is higher than 600  $\mu\text{m}$ . As the particles in the core layer are near parallel to the heat flow direction (through thickness direction), the thickness of the core has a great effect on the achievable effective thermal conductivity. My statements were proved with scanning electron microscopy and thermal conductivity measurements.

### *Thesis 2*

I proved that the thermal conductivity of polypropylene/boron nitride composites can be improved with the surface modification of the boron nitride filler and the efficiency can be further improved with sodium hydroxide pretreatment of the filler and increasing the acidity of the silane solution. With sodium hydroxide treatment more hydroxide ions can be attached onto the surfaces of the boron nitride particles for chemical bonding. By increasing the acidity of the silane solution the hydrolysis can be promoted. This statement was proved with measurements on compression molded 30 vol% boron nitride filled polypropylene homopolymer composites, where the improvement of thermal conductivity was 4-30%.

**Thesis 3/a**

I proved that there is a positive hybrid effect on thermal conductivity between the fillers when the matrix is a polypropylene homopolymer and the fillers are boron nitride and talc. As a result, using a mixture of these two fillers leads to better thermal conductivity than that predicted by the rule of mixtures. At 30 vol% total filler concentration 30-33% higher through plane thermal conductivity can be achieved with the use of boron nitride and talc in the ratio of 1:2 and 2:1 respectively. This effect can be attributed to the difference in particle sizes of fillers [3, 8, 11, 12].

**Thesis 3/b**

I confirmed that the hybrid effect of boron nitride powder and talc does not only affect thermal conductivity but viscosity and quasistatic and dynamic mechanical properties as well. While the hybrid effect decreases flowability and impact strength, it increases tensile strength and modulus, which can be attributed to the different particle sizes [8, 12, 13].

**Thesis 4**

I proved that a filler concentration upper limit exists in the case of boron nitride filled thermally conductive composites with semi-crystalline polymer matrices. Above this filler content the effect of fillers on crystallinity is minimal, the crystal fraction of the semi-crystalline matrix starts to decrease. Because of increased thermal conductivity and intensive cooling crystallinity decreases. I proved this statement for polypropylene homopolymer and polylactic acid matrices with boron nitride and talc fillers. With boron nitride the filler content limit in the case of a PP and PLA matrix was about 10 and 20 vol%, respectively [4, 5].

**Thesis 5/a**

I worked out new measurement methods to determine the achievable maximum filler concentration in composites and the effective thermal conductivity of fillers. To determine the achievable filler concentration, powders were compressed between two steel reference cylinders and the relative density was determined in the function of the compacting pressure. The maximum filler concentration was calculated from the saturation curve fitted to the measured values:

$$RD_p = [2 \cdot RD_0 - RD_\infty] + 2 \cdot \left[ \frac{RD_0 - RD_\infty}{1 + e^{-a \cdot p^b}} \right], \quad (0 \leq p \leq \infty),$$

where  $RD_0$  [-] is the relative density without compression,  $RD_\infty$  [-] is the relative density at infinite pressure,  $p$  [bar] is the pressure on the sample and  $a$  and  $b$  [-] are the data fitting

constants. The effective thermal conductivity of the compacted filler was calculated from the saturation curve fitted to the thermal conductivities measured at different pressure:

$$\lambda'(p) = \lambda'_\infty \frac{1 - e^{-g \cdot p^h}}{1 + e^{-g \cdot p^h}}, \quad (0 \leq p \leq \infty),$$

where  $\lambda'_\infty$  [W/mK] is the thermal conductivity at infinite pressure,  $p$  [bar] is the pressure on the sample,  $g$  and  $h$  [-] are data fitting parameters.

### **Thesis 5/b**

I worked out a mathematical model to predict the thermal conductivity of polymer composites in function of filler concentration. The relationship is as follows:

$$\lambda_c = \lambda'_m \cdot \left[ 1 - \left( \frac{\varphi}{\varphi_{\max}} \right)^C \right] + \lambda'_f \cdot \left( \frac{\varphi}{\varphi_{\max}} \right)^C, \quad (0 \leq \varphi \leq \varphi_{\max}),$$

where  $\lambda_c$  [W/mK] is the thermal conductivity of the composite,  $\lambda'_m$  and  $\lambda'_f$  [W/mK] are the effective thermal conductivities of the matrix and the filler,  $\varphi$  and  $\varphi_{\max}$  [vol%] are filler content and maximum achievable filler content, and  $C$  [-] is a constant describing the conductive chain formation capability and shape factor of the material. The applicability of the model was proved for boron nitride, talc and graphite-filled composites with a polypropylene homopolymer matrix, where factor  $C$  was 1.4 in all cases.

## 5. List of the own publication

### *Journal articles (English)*

1. Kovács J. G., Körtélyesi G., Kovács N. K., **Suplicz A.**: Evaluation of measured and calculated thermal parameters of a photopolymer. *International Communications in Heat and Mass Transfer*, 38, 863-867 (2011). (*IF*<sub>2011</sub>=1,892)
2. **Suplicz A.**, Kovács J. G.: Development of thermally conductive polymer materials and their investigation. *Material Science Forum*, 729, 80-84 (2013).
3. Kovács J. G., **Suplicz A.**: Thermally conductive polymer compounds for injection moulding: The synergetic effect of hexagonal boron nitride and talc. *Journal of Reinforced Plastics and Composites*, 32, 1234-1240 (2013). (*IF*<sub>2013</sub>=1,188)
4. **Suplicz A.**, Szabó F., Kovács J. G.: Injection molding of ceramic filled polypropylene: The effect of thermal conductivity and cooling rate on crystallinity. *Thermochimica Acta*, 574, 145-150 (2013). (*IF*<sub>2013</sub>=2,105)
5. Tábi T., **Suplicz A.**, Czigány T., Kovács J. G.: Thermal and mechanical analysis of injection moulded poly(lactic acid) filled with poly(ethylene glycol) and talc. *Journal of Thermal Analysis and Calorimetry*, 118, 1419-1430 (2014). (*IF*<sub>2013</sub>=2,206)
6. Zsíros L., **Suplicz A.**, Romhány G., Tábi T., Kovács J.G.: Development of a novel color inhomogeneity test method for injection molded parts. *Polymer Testing*, 37, 112-116 (2014). (*IF*<sub>2013</sub>=1,816)

### *Journal articles (Hungarian)*

7. **Suplicz A.**, Szabó F., Kovács J. G.: Anyagvizsgálati módszerek fejlesztése fröccsöntési alkalmazáshoz. *Műanyagipari Évkönyv*, 11, 34-41 (2013).
8. **Suplicz A.**, Kovács J. G.: Hővezető polimerek az elektrotechnikában – Hibrid rendszerű töltőanyagok alkalmazásának előnyei. *Műanyag és Gumi*, 4, 156-160 (2014).
9. Kovács N K, **Suplicz A.**, Kovács J G: Gyors prototípusgyártás, mint újszerű fröccsöntő szerszámozási technológia. *Műanyagipari Évkönyv*, 9, 45-53 (2011).

### *Conference proceedings*

10. **Suplicz A.**, Kovács J. G.: Analysing the thermal properties of the PolyJet photopolymer. in 'Proceedings of the Seventh Conference on Mechanical Engineering, Budapest, Hungary' 153-159 (2010).

11. **Suplicz A.**, Kovács J. G.: Development of thermal conductive hybrid composites. in 'Proceedings of the 15th European Conference on Composite Materials, Italy' 1-6 (2012).
12. Kovács J. G., **Suplicz A.**: Improved thermal properties with hybridization of the fillers for thermoplastic materials. in 'Proceedings of the 19th International Conference on Composite Materials, Canada' 4011-4018 (2013).
13. **Suplicz A.**, Szabó F., Kovács J. G.: Development possibilities and analyzing methods of thermally conductive polymers. International Conference on Mechanical Engineering, Romania, 346-349 (2013).
14. Szabó F., **Suplicz A.**, Kovács J. G.: Novel methods for material properties measurements. International Conference on Mechanical Engineering, Romania, 350-353. (2013).

*Conference lectures*

15. **Suplicz A.**, Kovacs J. G.: Analysing the thermal properties of the PolyJet photopolymer. *Gépészet 2010: Seventh Conference on Mechanical Engineering*. Budapest, Hungary, 25-26 May 2010.
16. **Suplicz A.**, Kovacs J. G.: Development and investigation of thermally conductive polymers. International Summer School on Polymers, Smolenice, Slovakia, 22-26 August 2011.
17. **Suplicz A.**, Kovacs J. G.: Hővezető polimer anyagok fejlesztése és vizsgálata. 8th Hungarian Conference on Material Science, Balatonkenese, Hungary, 9-11 October 2011.
18. **Suplicz A.**, Kovacs J. G.: Development of thermal conductive hybrid composites. 15th European Conference on Composite Materials (ECCM15). Venice, Italy, 24-28 June 2012.
19. **Suplicz A.**, Szabó F., Kovács J. G.: Hővezető polimerek fejlesztési lehetőségei és vizsgálati módszerei. International Conference on Mechanical Engineering (OGÉT), Arad, Romania, 25-28 April 2013.