

**ANTAL KERPELY DOCTORAL SCHOOL OF  
MATERIALS SCIENCE & TECHNOLOGY**



**Polymer Composites for Energy Applications  
(Polyurethanes of Increased Heat Conductivity)**

Thesis Booklet

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## **1. Introduction**

Polymers are usually electrical and thermal insulating materials; they display unusual electronic properties such as low energy optical transition, low ionization potentials and high electron affinities. Furthermore, they have some defects which can lead phonon scattering and a significant reduction in phonon mean free path, both factors contribute to the thermal conductivity of polymer [1]. However, they have several advantages such as lightweight, low cost, easy processability, and so on. The lightweight polymer with good thermal conductivity can be applied in heat management and processability are highly required for the construction of miniaturized electronic devices to smoothly transfer the heat generated from various sources integrated in its limited space. Besides, only few polymers have high thermal conductivity to fulfill these requirements, but their processability and properties are insufficient. Therefore, polymer composites are absolutely essential for modern electronic applications.

Polyurethane (PU) is versatile polymeric material that has been used in a wide range of applications such as elastomers, coatings, footwear, furniture, foams, packaging, adhesives, automotive finishes and electronics. Polyurethane elastomers (PUR) are a very important group of urethane products although their consumption is much lower than urethane foams. Structure and properties of PU can be improved by varying diisocyanate, polyol and chain extender. A chain extender may increase the hard segment length to allow hard segment segregation which results in good mechanical properties such as an increase in the modulus as well as an increase in the hard segment glass transition temperature of the polymer. Therefore, the chain extender may also increase the value of thermal conductivity of PUR. Furthermore, PU composites and blends have wide applications in electronics and optoelectronics.

The conductive polymer composites are usually fabricated by incorporating conductive fillers such as carbon black, graphite flakes, fibers, metal powder and ceramic powders into the insulating polymer matrices. The degree of conductivity of the polymer is decided by the volume fraction of the filler. If the filler volume is high enough, the thermal conductivity will increase from high conductivity fillers form thermally conductive networks. The filler type, loading level, filler size, filler shape and the interaction between the filler and the matrix have a strong influence on the thermal conductivity of polymer composites [2]. High thermal conductivity ceramic such as carbonous and metallic materials with different filler content, size and shape were added to enhance thermal conductivity of polymer composites such as aluminum oxide ( $\text{Al}_2\text{O}_3$ ), zinc oxide (ZnO), boron nitride (BN), silicon carbide (SiC), beryllium oxide (BeO), magnesium oxide (MgO), copper (Cu), silver (Ag), etc. Various fillers including carbon black (CB), carbon nanotubes (CNT), metal, and graphene have been studied to improve the electrical properties of the PU. Although much work has been done on the improvement of electrical properties of PU, there are barely any works focusing on thermal conductivity of thermosetting polyurethane elastomer composites with inorganic and metallic fillers.

The main goal of this dissertation is to enhance the thermal conductivity of polyurethane elastomers by synthesis new thermosetting polyurethane elastomers with varying the chain extender content and preparing new composites by varying the content of the high thermal conductive fillers for application of thermal conductive polymer.

## **2. Summary of literature**

The aim of the literature is to show the possibility of development of thermal conductive polymer composites. At the beginning of this work, the thermal conductivity of polymer was

reviewed. Next, four types of high thermal conductive fillers with polymer matrix were also investigated that consists of SiC, MgO, ZnO and Cu.

The thermal conductivity of a polymer depends greatly on its morphology. When amorphous domains are dominant, vibrational modes in the polymer tend to be localized, resulting in a low thermal conductivity. This is because thermal energy transports more efficiently along the polymer chain. Crystalline polymers have ordered structure, and therefore have higher thermal conductivity than amorphous polymers [3]. These lead to phonon scattering and significant reduction in the mean of the phonon's free path. Phonons are usually considered to be the thermal carriers in polymers because there is a free electron. When the surface of the polymer makes contact with the heat source, heat transfers to the first atom of the molecular chain in the form of a vibration and then transfer to the nearest atom. Heat transfer in a molecular chain will also cause the disordered vibration and rotation of atoms which significantly reduces the thermal conductivity of the polymer. A good conductor has a complete lattice structure and atoms accumulate closely. When the heat reaches the first atom, it will quickly transfer to the last one. However, heat transfer in a bad conductor causes the vibration and rotation of atoms, which will significantly reduce the thermal conductivity [4].

Presently, the thermal conductivity of polymer composites is widely investigated. However, there is a few polymer composites have high thermal conductivity but it is still needy for electronic devices. There are many kinds of polymer which can be used as matrix materials. For example, polypropylene (PP), polystyrene (PS), low- and high-density polyethylene (LDPE and HDPE), epoxy, polyurethane (PU), etc. PU is one important polymer to developing for thermal conductivity applications. PU structure and its properties can be improved by varying diisocyanate, polyol and chain extender. For basic knowledge of PU, the chain extender may increase the hard segment length to allow hard segment segregation which results in good properties [5]. Therefore, the chain extender factor may also increase the value of thermal conductivity of PU. The effective thermal conductivity of polymer composite composed of particles of one material embedded in a polymer matrix. It is a function of the thermal conductivity of the constituents, the particle loading, the particle size and shape, the particle dispersion and the thermal interfacial resistance [6]. Many research works focused on adding various types of high thermal conductivity fillers to improve the thermal conductivity and mechanical properties of polymer composites. In this study, we have a focus on SiC, MgO, ZnO, and Cu fillers because they have high thermal conductivity, not too expensive and have some good mechanical properties.

In case of SiC composites, there are several works which deal with incorporating SiC, silicon carbide nanowires into epoxy matrix to improve thermal conductivity and mechanical properties of the composites. Some work can enhance thermal conductivity of 406% per 1 v/v% loading SiC [7]. Furthermore, polyurethane reinforced with SiC were synthesized, which can improve tensile strength and tensile modulus of nanocomposites with different loading. An increase of about 21.4 times and 2.2 times in tensile modulus and strength, respectively [8]. However, previous PU and SiC work did not focus on thermal conductive applications but only studied mechanical and thermal properties.

One kind of high thermal conductive filler is MgO. Mechanical properties of polystyrene were improved by adding MgO powder [9]. The difference in the diameter of MgO fillers added in low-density polyethylene show a decreasing in the conductivity this decrease is observed only in the nanocomposites and not observed in the microcomposites [10]. Thermal conductivity of

MgO-ethylene glycol nanocomposites was also investigated. The obtained results show that the thermal conductivity increases with increasing fraction of MgO nanoparticles in suspensions [11].

The number of publications concerning the thermal conductivity of the materials based on ZnO is limited. The thermal conductivity of the composite materials based on the ZnO powders with different average particle sizes dispersed in the polymethylsiloxane (silicone oil) was measured using the radial heat flow method [12], while nano zinc oxide with high density polyethylene (HDPE) composites show a decrease in the elasticity modulus, yield strength, tensile strength, elongation, Izod impact strength and hardness of composites with increasing particle loading [13]. Furthermore, the incorporation of nano ZnO particles can improve crystallinity and thermal conductivity in polypropylene [14]. With the increase of ZnO particles content in silicone rubber, the amount of formed conductive chains increases and the conductive chains trend linearly to increase the thermal conductivity of the composite. The tensile strength and elongation at break of silicone rubber increased initially with increasing volume content of ZnO. When ZnO particles were added with large volume content, the tensile strength and elongation at break decreased [15].

The last one is Cu fillers, Cu powder was used as filler in polymer matrix because it has excellent electrical and thermal conductivities, good strength and formability, and so on. Thermal and electrical conductivity of unsaturated polyester resin with Cu filler composite material are investigated. It has also been observed that both thermal and electrical conductivity increase with increasing filler particles size. The tensile strength values were found to increase with increasing Cu loading. The maximum tensile strength value shows an improvement. On the other hand, a gradual decrease in the elongation at break of the composites was observed with increasing Cu content [16]. Thermal conductivity of copper filled polyamide composites depends on several factors including the thermal conductivity of the filler particles, filler particle shape, size and the volume fraction and spatial arrangement of the filler particles in the polymer matrix [17]. The electrical and thermal conductivity of systems based on epoxy resin and poly(vinyl chloride) filled with copper powders have been studied [18].

From the foregoing discussion, polymer composites with SiC, MgO, ZnO and Cu fillers can give evidence that there is no work had focused on improving thermal conductivity of thermosetting polyurethane elastomers with these filler types. Some works carried out using other polymer matrices was aiming to improve thermal conductivity while some works used these fillers to improved only mechanical properties of the thermoplastic polyurethane composites. Therefore, thermosetting polyurethane elastomer with high thermal conductive fillers is still an undeveloped filed of interest for electronic applications.

### **3. Knowledge gaps and goal**

From the literature overview, we found that there are a few work studies on polyurethane and high thermally conductive filler composites. However, there is no work studied polyurethane elastomers (PUR) with different chain extender content and incorporates with high thermal conductive filler (silicon carbide, magnesium oxide, zinc oxide and copper). Moreover, we found the knowledge gap of different used high thermal conductive filler content and particle size.

From the discussion above, the main goal of this study is to enhance the thermal conductivity of polyurethane elastomers for application of thermal conductive polymer by

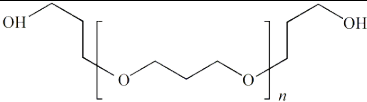
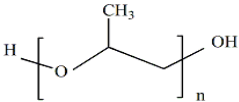
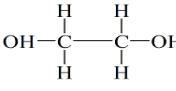

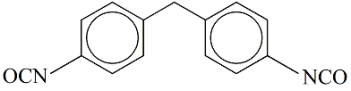
synthesis new thermosetting polyurethane elastomers with varying the chain extender content and preparing new composites via varying the content of each of silicon carbide, magnesium oxide, zinc oxide, and copper fillers. Effect of the chain extender content, filler types, and filler contents on thermal conductivity, mechanical properties, thermal properties, and morphology of new thermosetting polyurethane elastomer composites are investigated to support their usability in electrical applications.

## 4. Experimental

### 4.1 Materials

In this research, PUR composites with a newly synthesized formula matrix and the high thermal conductive filler composites were prepared by adjusting the chain extender content, filler types and contents. All the components with trade name and amount for synthesis are presented in Table 1. The main components were supplied by BorsodChem Zrt. (Hungary). There are some fillers were purchased from Minerals Water, United Kingdom, and Subolab GmbH company, Germany, such as SiC and ZnO, respectively. Four types of fillers have different shapes and sizes, which SiC has a flake-like shape while MgO has a spherical-like shape, ZnO has a cube-like or flake-like shape and Cu has a dendritic shape.

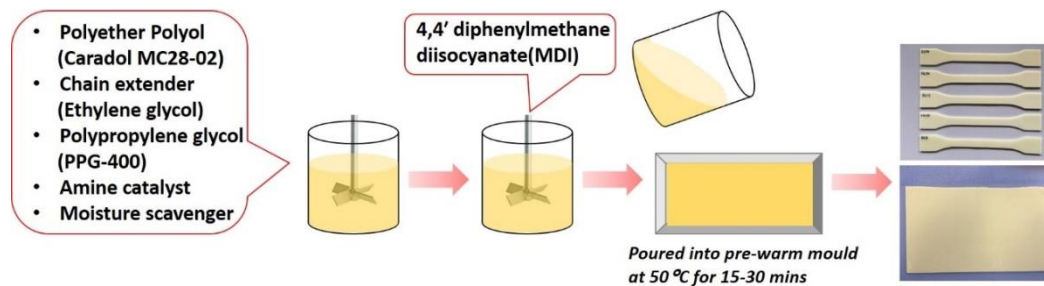
**Table 1** Components of polyurethane elastomer composites formula

Components	Trade Name	Formula	Amount (phr)
Polyether polyol	Caradol MC28-02		100
Polypropylene glycol (PPG-400)	ALCUPOL D411		5
Monoethylene glycol (chain extender)	mEG		7, 10, 22, 30, 34
Amine Catalyst	Dabco 33-LV		0.3 to 2.4
Moisture scavenger	Finmasorb 430 PR	N/A	5
4,4' diphenylmethane diisocyanate (MDI)	ONGRONAT XP 1117		22 to 52
Silicon carbide	Silicon Carbide	SiC (6.587 $\mu\text{m}$ )	0 to 121 (0 to 14 <sup>*</sup> )
Magnesium oxide	n.a.	MgO (3.505 $\mu\text{m}$ )	0 to 100 (0 to 12 <sup>*</sup> )
Zinc oxide	Zinc Oxide	ZnO (1.367 $\mu\text{m}$ )	0 to 100 (0 to 8 <sup>*</sup> )
Copper	n.a.	Cu (28.084 $\mu\text{m}$ )	0 to 39 (0 to 2 <sup>*</sup> )

\* percent by volume

## 4.2 Preparation methods

A stoichiometric amount of polyether polyol (PEP), monoethylene glycol, polypropylene glycol (PPG 400), amine catalyst and moisture scavengers were prepared with part per hundred resin and mixed by using sheared stirrer machine as shown in Figure 1. The chain extender content was varied from 7 to 34 phr while the other additives were kept at constant values to prepare flexible and rigid polyurethane elastomer matrices. All of the components were solution mixed. The mixture was homogenized by using a stirrer machine at around 1000 rpm for 10 mins. Then, the air bubbles were removed by using a vacuum pump machine for 60 mins before mixing with diisocyanate. The diisocyanate was mixed with the pre-polyol blend by shear stirrer again for 8-15 secs at around 1000 rpm and suddenly poured into the pre-warm mould at 50 °C. Polyurethane elastomer sheet remains on the warm mould for 15-30 mins. Then, it was removed off the mould. The dimension of polyurethane sheet is 1 mm and 4 mm in thickness, 150 mm in width and 220 mm in length. Polyurethane sheet was left at the room temperature at least 3 days before cut the specimen test by following the standard testing.



**Figure 1** Preparation diagram of polyurethane elastomers sheet

In case of PUR composites, we had already selected two formulas from five to prepared PUR composites with high thermal conductive fillers. One formula was prepared for flexible PUR at the chain extender content of 10 phr and the others for rigid PUR at the chain extender content of 30 phr. The high thermally conductive fillers such as SiC, MgO, ZnO, and Cu were added and mixed in the pre-polyol blend step as shown in Figure 2. All of the fillers were dried at 90 °C for at least 3 days before adding into the pre-polyol blend. Polyether polyol, monoethylene glycol, polypropylene glycol, amine catalyst and moisture scavengers were weighted (as shown in Table 1) and poured into a plastic bottle. After that, fillers were added to the pre-polyol mixture. The mixture was homogenized by using a stirrer machine at around 1000 rpm for at least 10 mins. Then, the air bubbles inside the mixture also were removed by using a vacuum pump machine for 60 mins. The MDI was mixed with the mixture by shear stirrer again for 8-15 secs at around 1000 rpm and also suddenly poured into the pre-heated mould. Then, the specimen testing was prepared similar to PUR without fillers as represented in Figure 2. Both flexible and rigid polyurethane elastomers with different filler types and contents were prepared with the same method.



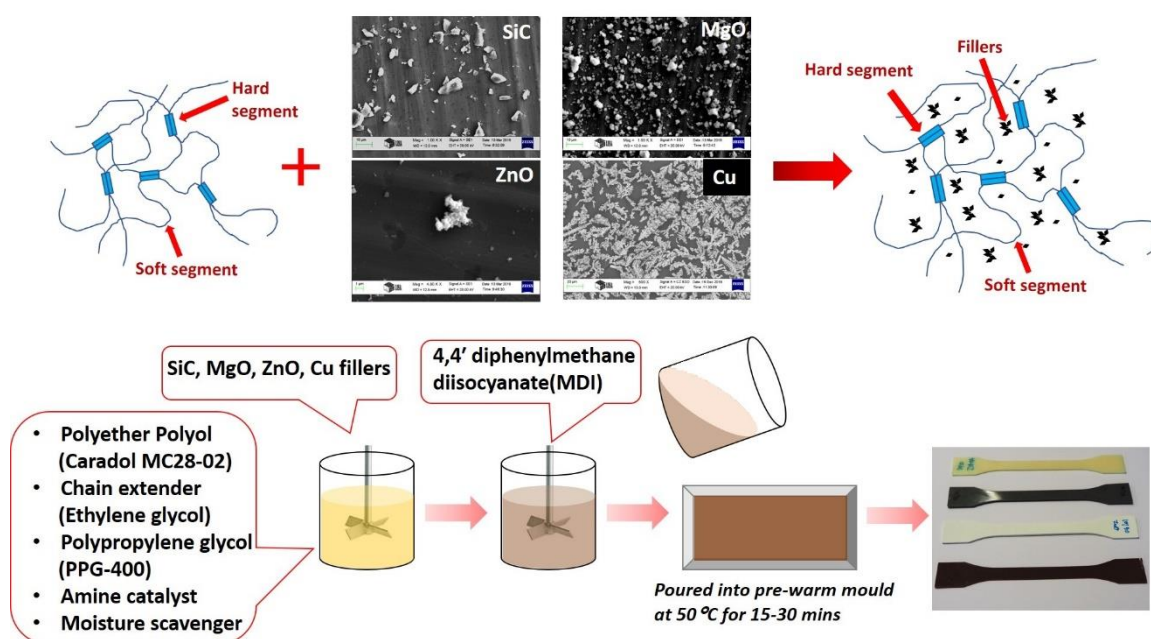


Figure 2 Preparation diagram of polyurethane elastomer composites sheet

### 4.3 Testing methods

Thermal conductivity was measured by the C-THERM thermal conductivity analyzer (TCi) at the Institute of Ceramic and Polymer Engineering, University of Miskolc. The density was measured at the room temperature by the density tester at BorsodChem Company, Kazincbarcika, Hungary. The specimen test for thermal conductivity testing should be thicker than 5 mm. In case of density measuring following ISO 1183, density is the mass per unit volume of a material. Specific gravity is a measure of the ratio of the mass of at given volume of material at room temperature to the same volume of deionized water. The specimen is weighed in the air then weighed when immersed in distilled water at room temperature using a sinker and wire to hold the specimen completely submerged as required.

Mechanical properties were investigated by measuring of Shore A and Shore D hardness according to ISO 868 standard and operated at BorsodChem Company. The loading forces of Shore A are 822 g and Shore D is 4536 g. Shore hardness value may vary in the range from 0 to 100. Tensile properties have been measured according to ISO 527 and tensile specimens have been also prepared according to the same standard. Tensile specimens test was prepared by die cutting from 1 mm sheet both PUR without fillers and with fillers. The samples were prepared of 5-10 specimens in every condition. The cross-head speed of the tensile test is 100 mm/min at room temperature measured by using Instron Universal Testing Machine.

Thermal properties were characterized by differential scanning calorimetry (DSC) technique. DSC of pure PUR and its composites were performed on METTER TOLEDO model DSC823e with a heating rate of 10 °C/min from -100 to 250 °C. Viscoelastic properties were investigated by a dynamic mechanical thermal analyzer, DMA 8000 (PerkinElmer), at BorsodChem company. Storage modulus and  $\tan\delta$  were analyzed from -80 to 150 °C with bending mode at 1 Hz and a heating rate of 2 °C/min.

The infrared (IR) spectra of pure PUR and its composites were recorded on a Bruker Tensor 27 FTIR instrument at the Institute of Ceramic and Polymer Engineering, the University of Miskolc. The spectra were recorded in the range of 400 – 4000  $\text{cm}^{-1}$  with a nominal resolution



of  $4 \text{ cm}^{-1}$ . The swelling degree of pure flexible and rigid polyurethane was measured at room temperature using ten different solvents. The test samples are disks 1 cm in diameter and 1 mm in thickness, cut from the cast thin sheet. The samples were immersed in each solvent for 1 week. After that, these samples were removed from the solvent and weighted after removal of the excess solvent from the samples. Thermally stimulated discharge (TSD) technique was used to investigate the structure of both flexible and rigid PUR without fillers by thermally stimulated discharge machine, model TSC II. Sample disks of 26 mm diameter were cut by die-cutting. The polarizing field at 500 V/mm was operated in the temperature range of  $-120$  to  $10 \text{ }^\circ\text{C}$  while cooling and heating rates of  $5 \text{ }^\circ\text{C}/\text{min}$  were used.

Besides, morphology and element of fillers and PUR composites were investigated by scanning electron microscopy technique (SEM; ZEISS EVO-MA10) and energy-dispersive X-ray spectroscopy (EDS) at the University of Miskolc. Every sample was coated by gold before the examination. SEM image of the composites are captured on fractured tensile sample surface. To obtain particle size distribution of the high thermal conductive fillers, all fillers used were measured using a laser scattering particle size distribution analyzer (HORIBA LA-950).

## 5. Results and discussion

### 5.1 Polyurethane elastomers with different chain extender contents

Increasing the chain extender content in polyurethane elastomers (PUR) formula from 7 to 34 phr can enhance the thermal conductivity by 1.3 times. The density, Shore A and D hardness, tensile strength and tensile modulus were also improved when the chain extender content was increased as presented in Table 2-4. Increasing the chain extender content has provided high reactivity with MDI and polyol that leads to high physical cross-linking within the structure and the formation of phase-separated hard segment. Adjusting the chain extender content has no influence on  $T_{g,SS}$  and  $T_{endo}$  of PUR while  $T_{g,HS}$  slightly decreased as shown in Table 5.  $E'$  was improved with increasing the chain extender content, especially in the rubbery region.  $T_{g,SS}$  slightly decreases which did not significantly change while  $T_{g,HS}$  increases with increasing the chain extender content by DMA technique as shown in Table 6. This increase is due to increase in the number of higher length hard segment chains in the hard segment domains that occur as the hard segment content of the polymer increased and attributed to increasing hard segment crystallinity and phase separation. The intensity peak of all chemical band groups from IR spectra decrease with raising chain extender content which means the chemical structure of PUR shows more aggregated hard segments to form domains in the PUR block copolymer. Thermally stimulated discharge spectroscopic and swelling degree results can confirm affect increasing of the chain extender content in PUR structure.

**Table 2** Thermal conductivity and density of polyurethane elastomers with different chain extender contents

Chain extender content (phr)	Thermal conductivity (W / mK)	Density ( $\text{g}/\text{cm}^3$ )
7	$0.230 \pm 0.003$	$1.117 \pm 0.000$
10	$0.253 \pm 0.003$	$1.137 \pm 0.002$
22	$0.278 \pm 0.002$	$1.178 \pm 0.002$
30	$0.290 \pm 0.002$	$1.194 \pm 0.001$
34	$0.310 \pm 0.004$	$1.202 \pm 0.002$

**Table 3** Shore A and D hardness of polyurethane elastomers with different chain extender contents

Chain extender content (phr)	Hardness	
	Shore A	Shore D
7	66 ± 0.4	19 ± 2.3
10	81 ± 0.7	26 ± 0.7
22	95 ± 0.6	52 ± 0.7
30	95 ± 0.7	65 ± 0.5
34	96 ± 0.7	64 ± 1.1

**Table 4** Tensile strength, elongation at break and tensile modulus of polyurethane elastomers with different chain extender contents

Chain extender content (phr)	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
7	4 ± 0.2	191 ± 9	10 ± 2
10	7 ± 0.3	185 ± 14	18 ± 1
22	17 ± 0.2	123 ± 7	293 ± 10
30	22 ± 0.2	31 ± 6	771 ± 38
34	20 ± 0.4	10 ± 1	791 ± 26

**Table 5** Thermal properties of polyurethane elastomers with different chain extender contents

Chain extender content (phr)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)
7	-60	N/A	N/A
10	-60	45	68
22	-60	46	68
30	-60	44	67
34	-60	48	66

**Table 6** The glass transition temperature of the soft and hard segment of polyurethane elastomers with different chain extender contents from DMA technique

Chain extender content (phr)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)
7	-45	-12
10	-46	11
22	-47	78
30	-48	83
34	-49	90

## 5.2 Flexible and rigid polyurethane elastomers with silicon carbide composites

We found out that the former model describes a constant temperature gradient and the latter a constant heat flow according to equations (1) and (2), respectively.

$$\lambda_u = \phi_1 \lambda_1 + \phi_2 \lambda_2 \quad (1)$$

$$\lambda_l = \left( \frac{\phi_1}{\lambda_1} + \frac{\phi_2}{\lambda_2} \right)^{-1} \quad (2)$$

Where  $\lambda_u$ ,  $\lambda_l$ ,  $\lambda_1$ ,  $\lambda_2$  are the thermal conductivities of composite, the upper limit of thermal conductivity, the lower limit of thermal conductivity, thermal conductivity of components 1 and 2, respectively, while  $\phi_1$  and  $\phi_2$  are the volume fraction of components 1 and 2, respectively. This applied model has estimated thermal conductivity in parallel and serial arrangement. The model of equal temperature gradient model results the upper limit of thermal conductivity while the model of equal heat flow model results the lower limit. This is formally identical to the mechanical properties, namely the modulus of elasticity used by Coran and Patel [19] replacing the  $M$  modulus values by  $\lambda$  thermal conductivity in the following equations (3) and (4).

$$M_u = \phi_H M_H + \phi_S M_S \quad (3)$$

$$M_l = \left( \frac{\phi_H}{M_H} + \frac{\phi_S}{M_S} \right)^{-1} \quad (4)$$

Where  $M_u$ ,  $M_l$ ,  $M_H$  and  $M_S$  are the modulus of the upper limit of modulus, the lower limit of modulus, the modulus of the pure hard and soft phases, respectively.  $\phi_H$  and  $\phi_S$  are the volume fractions of the hard phase and the soft phase. For real, mixed systems the equation (5) is valid equation. Where  $M$ , is the modulus of the composite and  $n$  is the adjustable parameter since the upper and lower bound modulus.

$$M = M_l + \phi_H^n (n\phi_S + 1)(M_u - M_l) \quad (5)$$

Because of the similarity, it can be used for thermal conductivity as well as described in equation (6).

$$\lambda_c = \lambda_l + \phi_1^n (n\phi_2 + 1)(\lambda_u - \lambda_l) \quad (6)$$

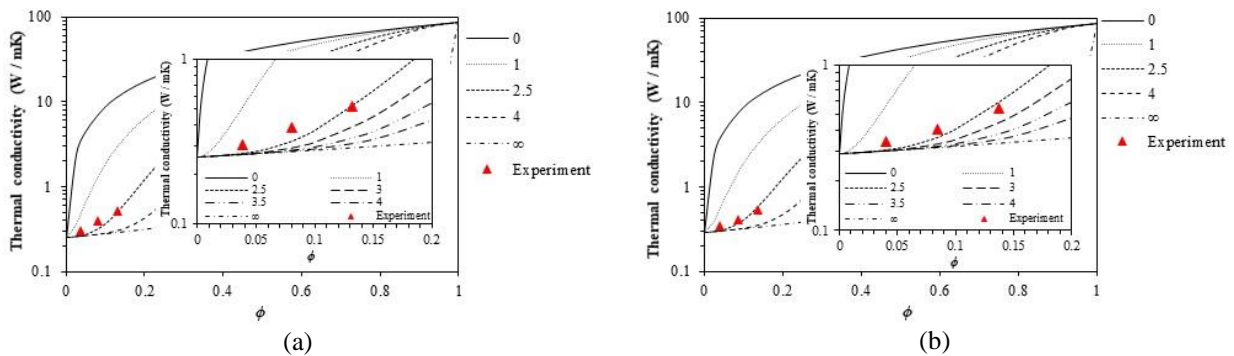
Where  $\lambda_c$ ,  $\lambda_u$ ,  $\lambda_l$  are the thermal conductivity of composite, the upper limit of thermal conductivity and the lower limit of thermal conductivity, respectively,  $\phi_1$  and  $\phi_2$  are the volume fractions of components 1 and 2, respectively. Besides,  $n$  is the characteristic exponent. If  $n = 0$  means that the heat conductivity of composite is at the upper limit and  $n = 100$  means the lower limit [19]. For the calculations, a short computer program was compiled,  $n = 100$  was used instead of  $\infty$  because the error is less than 0.01%. From the applied model, we had expected that the thermal conductive value from the experiment can be predicted using the applied mechanical model which was not used before. Moreover, we expected that this applied model could be properly used to predicting the thermal conductivity of the composites at high filler content.

Adding SiC fillers from 0 to 14 v/v% into flexible and rigid PUR composites can improve the thermal conductivity of both flexible and rigid PUR composites when compared to pure PUR by 2 and 1.9 times, respectively (Table 7). Applied mechanical model provided good prediction on thermal conductivity both PUR matrices as present in Figure 3. Besides, increasing Shore A and D hardness, tensile strength, modulus, and  $E'$  of the composites can indicate that good dispersion of SiC and it is acting as active and reinforcement fillers in both matrices (Table 8 and 9). SiC did not influence on polyol segment motion in PUR matrix and thermal properties as presented in Table 10. At high amount of SiC obstructed the molecular chain movement in the physical cross-linking structure. The crystalline phase was increased with increasing SiC content

and improved the hard segment phase separation in flexible PUR.  $E'$  was increased with adding SiC in flexible PUR because of effect of reinforcement fillers. Decreasing amplitude of  $\tan\delta$  peak implied that SiC content and its dispersion influence the degree of polyol segment motion. The shift to low temperature of  $T_{g,HS}$  indicated the decreasing level of cross-linking in both PUR matrices (Table 11). Loading SiC particles did not significantly affect thermal properties but it affects the hard segment cross-linking. IR spectra show that SiC content has no significant effect in the main PUR structure while increasing SiC content might be affect degradation both PUR matrices. Furthermore, SiC particles show evenly dispersed and embedded into both flexible and rigid PUR matrices.

**Table 7** Thermal conductivity and density of flexible and rigid polyurethane elastomers with different SiC contents

SiC content (v/v%)	Flexible PUR		SiC content (v/v%)	Rigid PUR	
	Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )		Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )
0.00	0.253±0.003	1.137±0.002	0.00	0.290±0.002	1.194±0.001
3.79	0.302±0.003	1.219±0.002	3.97	0.344±0.004	1.218±0.002
8.13	0.389±0.002	1.302±0.000	8.51	0.410±0.002	1.292±0.008
13.18	0.521±0.003	1.369±0.000	13.75	0.542±0.002	1.441±0.002



**Figure 3** Thermal conductivity modelling of flexible (a) and rigid (b) polyurethane elastomers with different SiC contents

**Table 8** Mechanical properties of flexible PUR with different SiC contents

SiC content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	81±0.7	26±0.7	7±0.3	185±14	18±1
3.79	84±0.4	32±0.8	9±0.3	203±7	22±1
8.13	85±0.7	34±0.5	8±0.8	153±20	27±2
13.18	88±0.5	37±0.6	9±0.5	131±16	31±2

**Table 9** Mechanical properties of rigid PUR with different SiC contents

SiC content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	95±0.7	65±0.5	22±0.2	31±6	771±38
3.97	97±0.2	61±1.6	12±0.2	21±2	514±38
8.51	97±0.3	68±0.9	12±1.4	11±1	648±91
13.75	97±0.5	72±1.0	20±1.1	11±2	1073±58

**Table 10** Thermal properties of flexible and rigid polyurethane elastomers with different SiC contents

Flexible Polyurethane				Rigid Polyurethane			
SiC content (v/v%)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)	SiC content (v/v%)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)
0.00	-60	45	68	0.00	-60	44	67
3.79	-60	45	67	3.97	N/A	42	60
8.13	-61	43	70	8.51	N/A	42	58
13.18	-61	44	66	13.75	N/A	39	60

**Table 11** The glass transition temperature of the soft and hard segment of polyurethane elastomers with different SiC contents from DMA technique

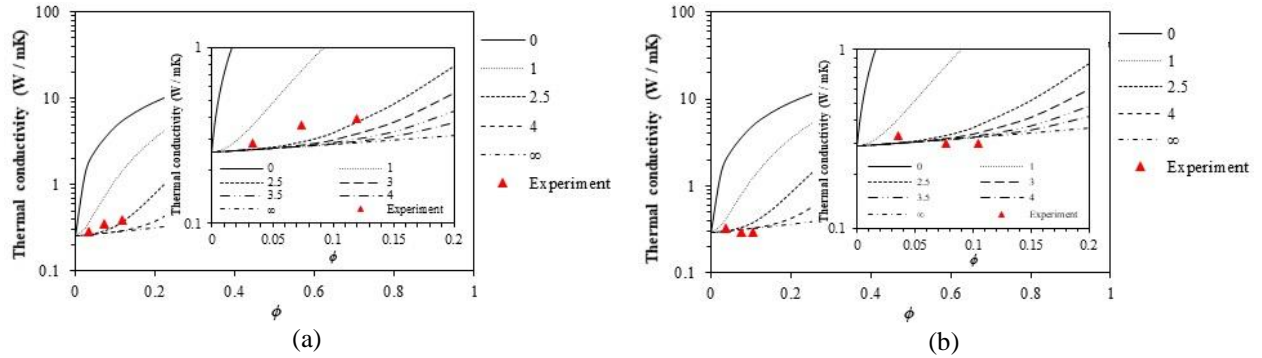
SiC content (v/v%)	Flexible PUR		SiC content (v/v%)	Rigid PUR	
	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)		T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)
0.00	-46	11	0.00	-48	83
3.79	-45	1	3.97	-48	55
8.13	-47	2	8.51	-48	72
13.18	-48	2	13.75	-49	122

### 5.3 Flexible and rigid polyurethane elastomer with magnesium oxide composites

Thermal conductivity can improve only by adding magnesium oxide (MgO) fillers in flexible PUR matrix by 1.6 times as shown in Table 12. Uniform dispersion of MgO fillers might be acting as network fillers that the phonon can easily cross the PUR matrix. Moreover, applied model reveal fairly good fitting to thermal conductivity as exhibited in Figure 4. MgO is acting as active fillers in flexible PUR matrix. Loading MgO created some foaming within the rigid PUR matrix which decreasing thermal conductivity and mechanical properties (Table 13 and 14). MgO particles did not influence the polyol segment motion. A small degree of ordering in hard segment in both PUR matrices were exhibited with adding MgO fillers. Furthermore, loading MgO did not significantly change T<sub>g,SS</sub>, T<sub>g,HS</sub>, and T<sub>endo</sub> in both PUR matrices as shown in Table 15. Adding MgO filler can obstruct the physical cross-linking level in PUR matrix by the shifting of T<sub>g,HS</sub> to lower temperature from DMA curve (Table 16). IR spectra show that MgO content affects the increase in the intensity peak of IR spectra that might increase the rate of degradation in PUR matrix. MgO particles can disperse and embedded inside flexible and rigid PUR matrices. However, the agglomeration of MgO particles and cavities clearly seen in rigid PUR matrix with addition of 3.57 v/v% MgO content.

**Table 12** Thermal conductivity and density of flexible and rigid polyurethane elastomers with different MgO contents

MgO content (v/v%)	Flexible PUR		MgO content (v/v%)	Rigid PUR	
	Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )		Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )
0.00	0.253±0.003	1.137±0.002	0.00	0.290±0.002	1.194±0.001
3.41	0.285±0.004	1.203±0.001	3.57	0.329±0.008	0.892±0.014
7.36	0.360±0.003	1.240±0.001	7.70	0.299±0.005	0.803±0.010
11.98	0.396±0.008	1.237±0.001	10.49	0.297±0.006	0.712±0.015



**Figure 4** Thermal conductivity modelling of flexible (a) and rigid (b) polyurethane elastomers with different MgO contents

**Table 13** Mechanical properties of flexible PUR with different MgO contents

MgO content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	81±0.7	26±0.7	7±0.3	185±14	18±1
3.41	83±1.1	31±0.2	7±0.3	168±9	26±3
7.36	85±0.5	32±1.1	8±0.3	155±14	29±2
11.98	87±0.8	35±0.8	8±0.3	111±8	31±1

**Table 14** Mechanical properties of rigid PUR with different MgO contents

MgO content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	95±0.7	65±0.5	22±0.2	31±5.6	771±38
3.57	92±1.7	46±1.4	6±0.3	55±9.6	128±7
7.70	94±1.1	57±1.9	14±1.3	11±1.8	622±32
10.49	88±1.5	48±1.5	8±0.5	7±0.5	478±34

**Table 15** Thermal properties of flexible and rigid polyurethane elastomers with different MgO contents

Flexible Polyurethane				Rigid Polyurethane			
MgO content (v/v%)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)	MgO content (v/v%)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)
0.00	-60	45	68	0.00	-60	44	67
3.41	-60	40	63	3.57	N/A	40	61
7.36	-59	40	61	7.70	N/A	41	59
11.98	-58	39	65	10.49	N/A	41	63

**Table 16** The glass transition temperature of soft and hard segment of polyurethane elastomers with different MgO contents from DMA technique

MgO content (v/v%)	Flexible PUR		MgO content (v/v%)	Rigid PUR	
	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)		T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)
0.00	-46	11	0.00	-48	83
3.41	-45	-2	3.57	-50	82
7.36	-44	1	7.70	-50	71
11.98	-46	1	10.49	-51	75

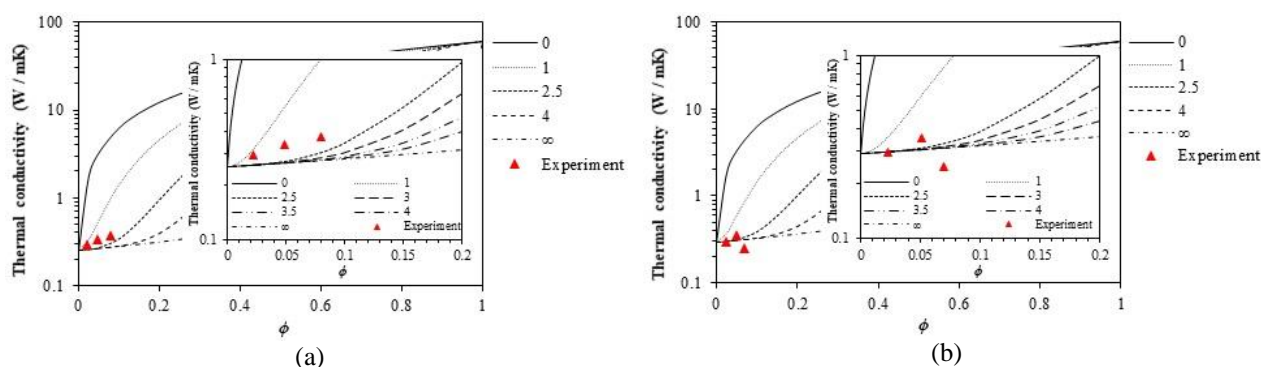


### 5.4 Flexible and rigid polyurethane elastomer with zinc oxide composites

Thermal conductivity is also improved with loading zinc oxide (ZnO) fillers from 0 to 7.99 v/v% into flexible matrix, by 1.5 times as shown in Table 17. Adding ZnO in flexible PUR matrix exhibited a little better fitting to applied model than SiC and MgO as exhibited in Figure 5. Smaller particle size of ZnO can create more network fillers that result in faster phonon transportation. Foam structure of rigid composites decrease thermal conductive value. On the other hand, ZnO filler did not improve the mechanical properties of both PUR matrices (Table 18 and 19). This result proved that ZnO fillers are inactive fillers and non-reinforcement. From DSC result, loading ZnO fillers did not influence on thermal properties of both flexible and rigid PUR matrices as presented in Table 20. However, ZnO content affects the cross-linking of hard segment.  $T_{g,SS}$  from DMA result has no significant change with adding ZnO fillers into both PUR matrices while  $T_{g,HS}$  is decreased with loading ZnO fillers in rigid matrix (Table 21). IR spectra show similar effect to adding MgO fillers. SEM images reveal some agglomeration of ZnO particles and cavities in rigid PUR matrix.

**Table 17** Thermal conductivity and density of flexible and rigid polyurethane elastomers with different ZnO contents

ZnO content (v/v%)	Flexible PUR		ZnO content (v/v%)	Rigid PUR	
	Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )		Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )
0.00	0.253±0.003	1.137±0.002	0.00	0.290±0.002	1.194±0.001
2.20	0.296±0.004	1.237±0.001	2.31	0.296±0.004	0.691±0.013
4.82	0.335±0.007	1.279±0.003	5.05	0.357±0.003	0.976±0.011
7.99	0.372±0.005	1.370±0.001	6.96	0.249±0.003	0.720±0.016



**Figure 5** Thermal conductivity modelling of flexible (a) and rigid (b) polyurethane elastomers with different ZnO contents

**Table 18** Mechanical properties of flexible PUR with different ZnO contents

ZnO content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	81±0.7	26±0.7	7±0.3	185±14	18±1.1
2.20	81±0.7	28±0.8	6±0.4	169±11	19±0.6
4.82	82±0.6	31±0.8	5±0.2	109±5	25±1.9
7.99	82±1.3	30±1.1	4±0.1	104±3	21±1.8

**Table 19** Mechanical properties of rigid PUR with different ZnO contents

ZnO content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	95±0.7	65±0.5	22±0.2	31±6	771±38
2.31	92±0.8	40±1.5	4±0.2	40±4	108±3
5.05	95±0.8	62±1.6	9±0.5	15±1	293±9
6.96	92±1.3	46±1.9	5±0.2	13±2	203±9

**Table 20** Thermal properties of flexible and rigid polyurethane elastomers with different ZnO contents

Flexible Polyurethane				Rigid Polyurethane			
ZnO content (v/v%)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)	ZnO content (v/v%)	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)	T <sub>endo</sub> (°C)
0.00	-60	45	68	0.00	-60	44	67
2.20	-60	44	72	2.31	N/A	45	62
4.82	-61	43	67	5.05	N/A	45	59
7.99	-60	45	63	6.96	N/A	44	58

**Table 21** The glass transition temperature of soft and hard segment of polyurethane elastomers with different ZnO contents from DMA technique

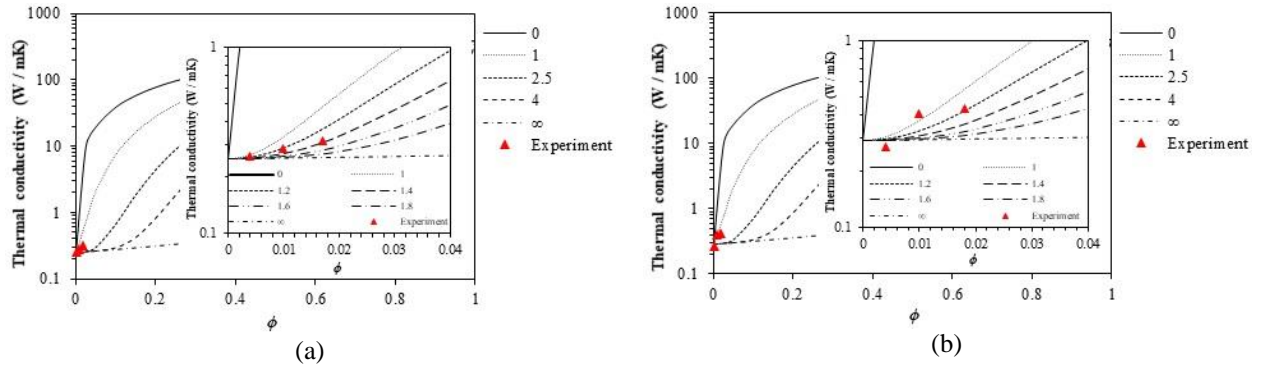
ZnO content (v/v%)	Flexible PUR		ZnO content (v/v%)	Rigid PUR	
	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)		T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)
0.00	-46	11	0.00	-48	83
2.20	-45	-5	2.31	-52	87
4.82	-47	1	5.05	-52	78
7.99	-49	14	6.96	-52	77

## 5.5 Flexible and rigid polyurethane elastomer with copper composites

Electrolytic copper (Cu) was incorporated into both flexible and rigid PUR matrices from 0 to 2 v/v%. Results show that the thermal conductivity of flexible PUR and rigid PUR composites were enhanced by 1.2 and 1.5 times, respectively (Table 22). Applied model reveals a very good predicted value for both PUR matrices by getting close the upper limit line as shown in Figure 6. Good dispersion and dendritic shape of Cu can easily create filler networks that can accelerate the phonon transportation. Electrolytic Cu fillers is acting as an active and reinforcement filler in flexible PUR matrix (Table 23). Loading Cu filler has no influence on the thermal properties of the composites as confirmed by DSC curves as exhibited in Table 25.  $E'$  of the composites improves with raising Cu content in flexible PUR matrix.  $T_{g,SS}$  did not significantly change both PUR matrices while  $T_{g,HS}$  tends to decrease in case of flexible composites as presented in Table 26. The  $\tan\delta$  peak shows a shoulder on the transition for rigid PUR matrix. This may be due to the Cu filler's content, size and shape influences the cross-linking segment motion of the hard segment. As was expected, loading Cu has no significant influence on the main chemical structure of PUR. However, increasing Cu content may be causing degradation in both PUR matrices. SEM images show the dendritic shape of Cu particles and it can be dispersed inside both flexible and rigid PUR matrices. Dendritic shape like of electrolytic Cu can be a clue that it has improved the thermal conductivity of the composites more than the other fillers.

**Table 22** Thermal conductivity and density of flexible and rigid polyurethane elastomers with different Cu contents

Cu content (v/v%)	Flexible PUR		Cu content (v/v%)	Rigid PUR	
	Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )		Thermal conductivity (W / mK)	Density (g/cm <sup>3</sup> )
0.00	0.253±0.003	1.137±0.002	0.00	0.290±0.002	1.194±0.001
0.39	0.260±0.006	1.171±0.001	0.41	0.269±0.002	1.179±0.004
0.95	0.285±0.002	1.210±0.000	1.00	0.408±0.001	1.281±0.003
1.71	0.314±0.003	1.269±0.004	1.79	0.429±0.005	1.349±0.002



**Figure 6** Thermal conductivity modelling of flexible (a) and rigid (b) polyurethane elastomers with different electrolytic Cu contents

**Table 23** Mechanical properties of flexible PUR with different Cu contents

Cu content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	81±0.7	26±0.7	7±0.3	185±14	18±1.1
0.39	82±0.8	30±0.6	8±0.5	264±28	20±1.3
0.95	84±0.7	32±0.5	8±1.0	212±28	23±0.8
1.71	86±0.4	33±0.0	10±1.0	191±35	38±7.4

**Table 24** Mechanical properties of rigid PUR with different Cu contents

Cu content (v/v%)	Shore A hardness	Shore D hardness	Tensile strength (MPa)	Elongation at break (%)	Tensile modulus (MPa)
0.00	95±0.7	65±0.5	22±0.2	31±6	771±38
0.41	93±1.1	61±0.8	21±0.8	81±13	508±21
1.00	96±0.7	65±1.0	17±0.9	59±5	477±10
1.79	98±0.5	68±0.6	17±2.8	63±5	524±8

**Table 25** Thermal properties of flexible and rigid polyurethane elastomers with different Cu contents

Flexible Polyurethane				Rigid Polyurethane			
Cu content (v/v%)	T <sub>g, SS</sub> (°C)	T <sub>g, HS</sub> (°C)	T <sub>endo</sub> (°C)	Cu content (v/v%)	T <sub>g, SS</sub> (°C)	T <sub>g, HS</sub> (°C)	T <sub>endo</sub> (°C)
0.00	-60	45	68	0.00	-60	44	67
0.39	-60	45	77	0.41	N/A	42	60
0.95	-58	43	65	1.00	N/A	43	64
1.71	-60	41	66	1.79	N/A	44	60

**Table 26** The glass transition temperature of soft and hard segment of polyurethane elastomers with different Cu contents from DMA technique

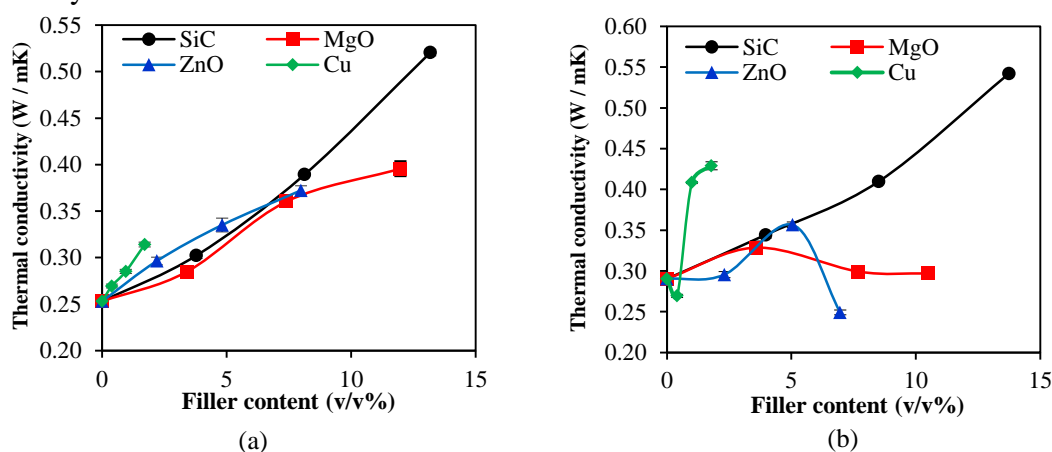
Cu content (v/v%)	Flexible PUR		Cu content (v/v%)	Rigid PUR	
	T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)		T <sub>g,SS</sub> (°C)	T <sub>g,HS</sub> (°C)
0.00	-46	11	0.00	-48	83
0.39	-49	-8	0.41	-50	N/A
0.95	-47	-2	1.00	-52	N/A
1.71	-48	3	1.79	-52	N/A

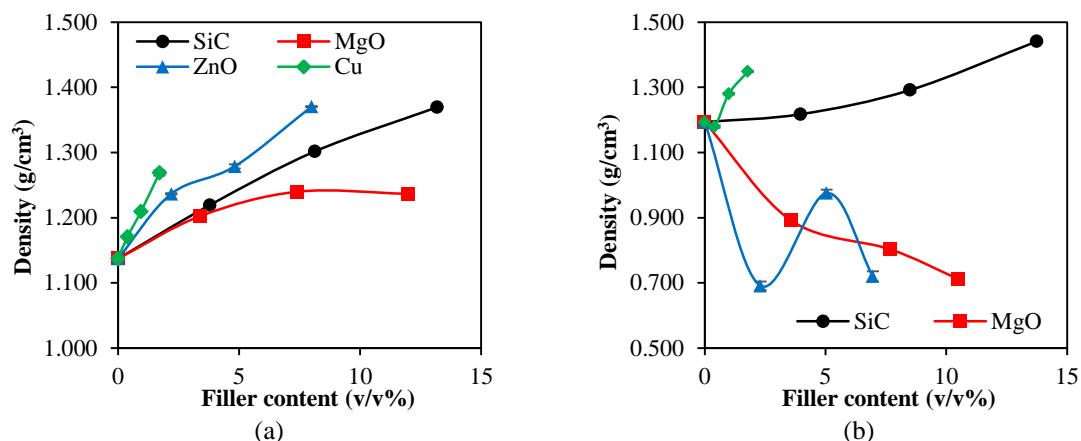
## 5.6 Comparing properties of polyurethane elastomers with different types and contents of fillers

Properties of both flexible and rigid PUR with different filler types and contents were compared in this topic that consists of results based on measurement of thermal conductivity, density, Shore A and D hardness, tensile strength, modulus and elongation at break.

Thermal conductivity as a function of filler types and contents are presented in Figure 7. In case of flexible PUR matrix, loading SiC, MgO, ZnO, and Cu fillers can improve the thermal conductivity of all composites. The result indicates that increasing SiC content increases the thermal conductivity higher than MgO and ZnO fillers when same loadings were compared. In similar trend, raising Cu content also increased thermal conductivity of the composites. Moreover, the value of thermal conductivity changed more significantly by adding Cu fillers than the other fillers. This result is due to the inherent high thermal conductivity of the Cu and SiC fillers and because the uniform dispersion of these fillers inside the flexible PUR matrix. The other reasons may be that the dendritic shape of Cu can easy form filler networks. Filler bridges can be used by the phonons in order to cross the polymer matrix faster. Unfortunately, presence of moisture is not following strictly increase thermal conductive value.

In case of density, the trends found in the results are correlating with the thermal conductivity of both flexible and rigid PUR matrices. It is clearly seen that the increase of density value for the flexible PUR composite with the increase of Cu filler is higher than the other filler. This can be because of the effect of the density value of these fillers (Cu>ZnO>MgO>SiC). Furthermore, decreasing of density found for the rigid PUR composites can be correlated to decreasing thermal conductivity of the composites with adding MgO and ZnO fillers as exhibited in Figure 8. This can confirm influence of foam formation on thermal conductivity result.

**Figure 7** Comparing thermal conductivity of flexible PUR (a) and rigid PUR (b) with different the high thermal conductive fillers

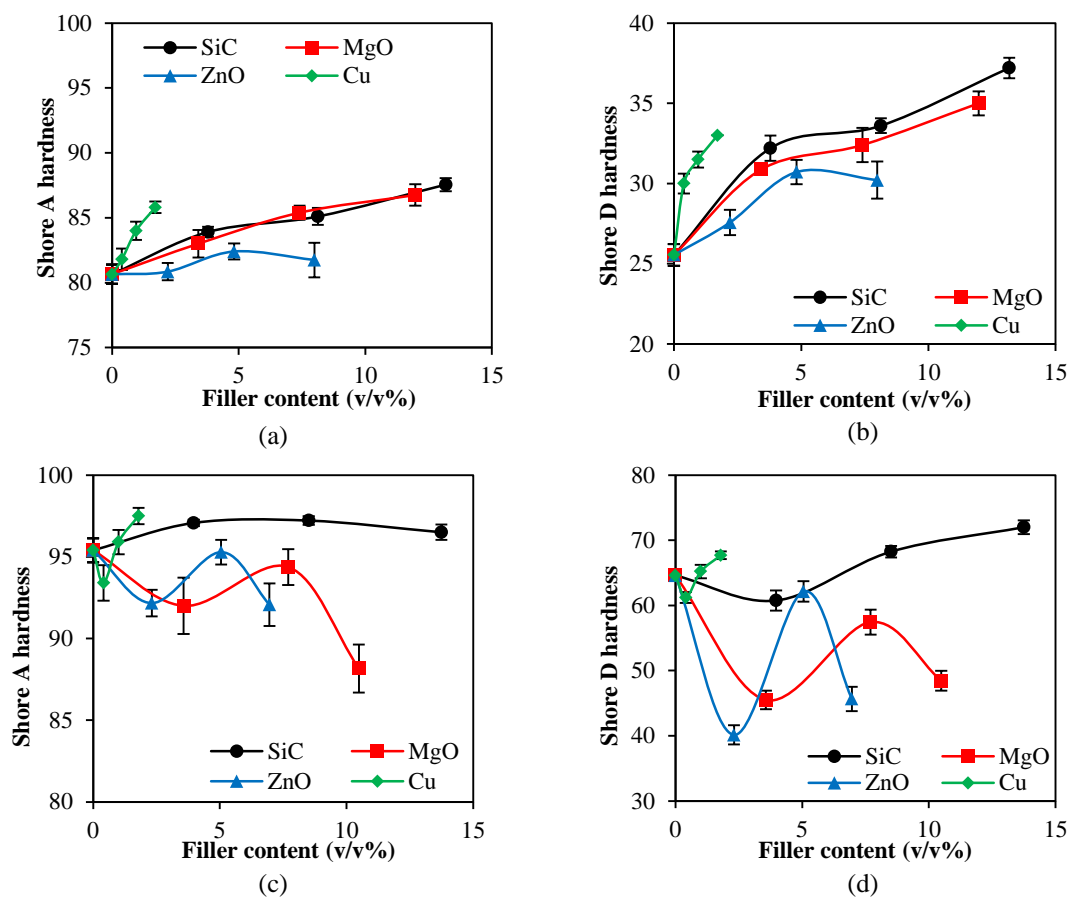


**Figure 8** Comparing density of flexible PUR (a) and rigid PUR (b) with different the high thermal conductive fillers

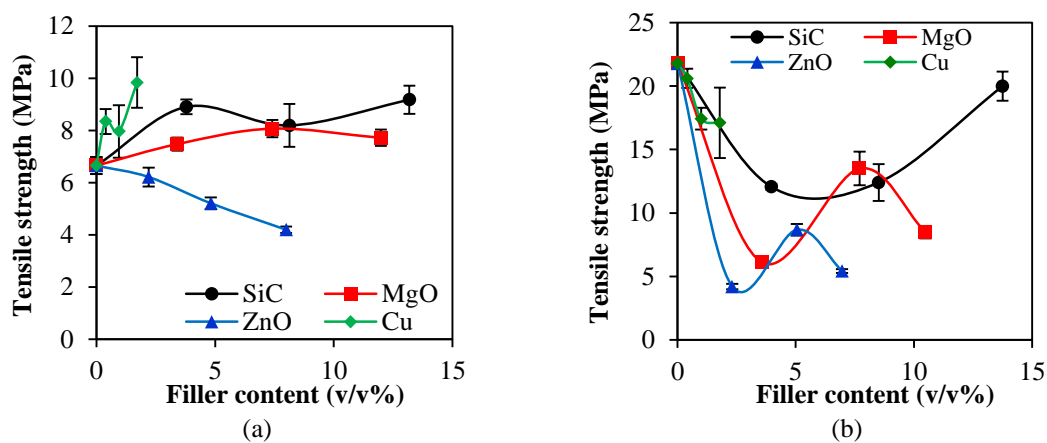
Shore A and D hardness clearly shown that SiC, MgO, and Cu fillers are acting as active fillers in flexible PUR matrix by improving of Shore A and D hardness when these filler's content were increased, especially, adding Cu filler as presented in Figure 9 (a) and (b). This result is due to good dispersion of fillers in flexible PUR matrix even at high content of fillers. For rigid PUR matrix, Shore A and D hardness did not significant change when the content of fillers was increased as shown in Figure 9 (c) and (d). The cause for this result is that the high viscosity of rigid PUR matrix affect the dispersion of fillers and because of their incompatibility between these fillers and rigid PUR matrix and foam formation with adding MgO and ZnO rigid PUR matrix.

For tensile properties, Figure 10 shows increasing of tensile strength with rising SiC, MgO, and Cu content in flexible PUR matrix. The fillers might help the molecular chain of PUR against the deformation when the composites were forced. As a result of rigid PUR matrix, tensile strength did not significant changed with increasing filler content. This result occurs due to presence fillers agglomeration in the high viscosity matrix and the poor adhesion between the fillers and rigid PUR matrix.

Tensile modulus was enhanced with increasing SiC, MgO and Cu contents as presented in Figure 11. It can be improved by 1.7 times (SiC and MgO) and 2.1 times (Cu) for flexible PUR composites. This increasing can be demonstrated that these fillers act as reinforcement fillers in flexible PUR matrix. This also can be assumed that filler can dissipate applied force to matrix. For rigid PUR matrix, tensile modulus did not significant change with increasing filler content except adding SiC filler. As expected the elongation at break, results reveal that elongation of all composites was decreased with raising filler contents (Figure 12). Main reason is PUR composites indicates hindrance by these fillers to molecular mobility of PUR chain or deformability of composites which causes the matrix to lose its elastic deformation ability.

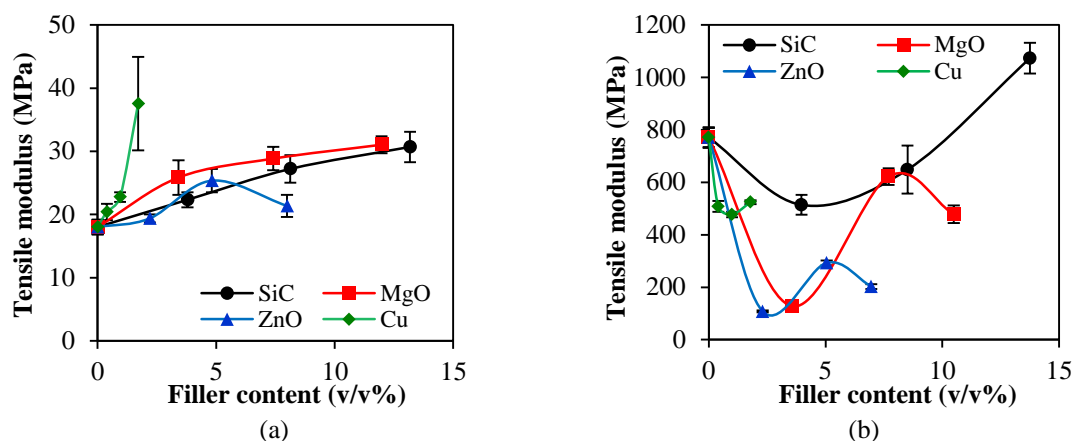


**Figure 9** Comparing Shore A (a), Shore D hardness of flexible PUR and Shore A (c) and Shore D (d) of rigid PUR with different the high thermal conductive fillers

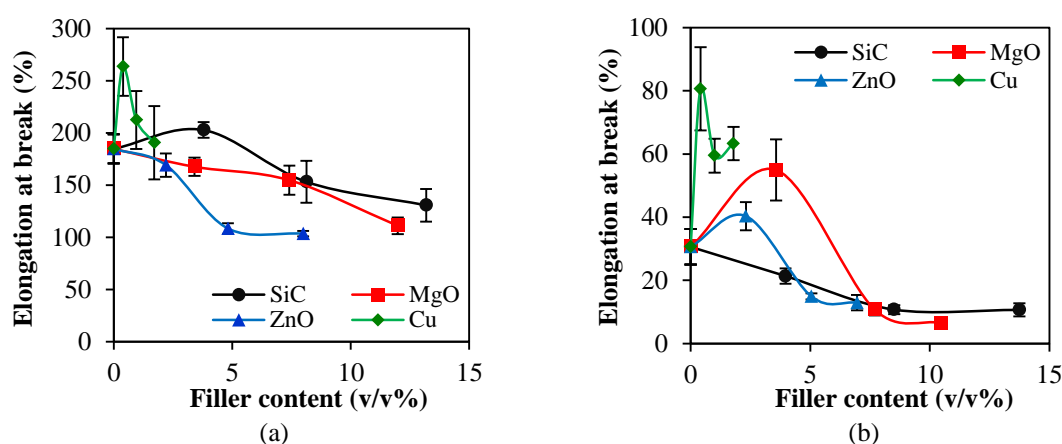


**Figure 10** Comparing tensile strength of flexible PUR (a) and rigid PUR (b) with different the high thermal conductive fillers





**Figure 11** Comparing tensile modulus of flexible PUR (a) and rigid PUR (b) with different the high thermal conductive fillers



**Figure 12** Comparing elongation at break of flexible PUR (a) and rigid PUR (b) with different the high thermal conductive fillers

## 6. New scientific results

**Thesis 1.** It has been revealed that increasing the chain extender content in the range of 7 to 34 phr can provide higher thermal conductivity and improve the mechanical properties of polyurethane elastomers. Adjusting the chain extender content can enhance thermal conductivity, Shore A and Shore D hardness, tensile strength, and tensile modulus of polyurethane elastomers by 1.3, 1.5, 3.4, 5.5, and 79.1 times, respectively.

**Thesis 2.** I showed that the thermal conductivity of flexible polyurethane elastomers can be enhanced by preparing a new composition of the chain extender content at 10 phr and different filler types and content. I have examined this new composition and provided a quantitative description of the changing of the thermal conductivity as a function of the applied filler and its content. The thermal conductivity of the composites resulted in different improvements such as 2.1 times by loading 13.18 v/v% silicon carbide, 1.6 times by loading 11.98 v/v% magnesium oxide, 1.5 times by loading 7.99 v/v% zinc oxide, and 1.2 times by loading 1.71 v/v% copper.

**Thesis 3.** I demonstrate that new flexible polyurethane elastomer composites of the chain extender content at 10 phr and all of the tested high thermal conductive fillers by different composition that were not prepared before, but can improve the mechanical behavior, namely, increasing the Shore A and D hardness, tensile modulus, and storage modulus. I have also shown that the highest improvement of Shore A and D hardness are 1.1 and 1.5 times by loading 13.18 v/v% silicon carbide and the tensile modulus is 2.1 times by loading 1.71 v/v% copper.

**Thesis 4.** I proved that the thermal conductivity of polyurethane elastomer composites can be described using the equation below. Where  $\lambda_u$  and  $\lambda_l$  are the upper and lower limiting value of the thermal conductivity. This model is similar to the model developed for mechanical properties of the composites described by Coran and Patel (1976) but never used before for thermal conductivity.

$$\lambda_c = \lambda_l + \phi_2^n (n\phi_1 + 1)(\lambda_u - \lambda_l)$$

## 7. List of publications

### 7.1 International Journal articles

1. **Somdee P.**, Marossy K., Lassú-Kuknyó T. and Kónya C.: Polyurethane Elastomers with Improved Thermal Conductivity Part I: Elaborating Matrix Material for Thermal Conductive Composites. *International Journal of Mechanical and Production Engineering (IJMPE)*, 6(6), 1-5 (2018).
2. **Somdee P.**, Lassú-Kuknyó T., Kónya C., Szabó T. and Marossy K.: Thermal analysis of polyurethane elastomers matrix with different chain extender contents for thermal conductive application. *Journal of Thermal Analysis and Calorimetry*, 138, 1003-1010 (2019). doi : <https://doi.org/10.1007/s10973-019-08183-y>
3. **Somdee P.**, Lassú-Kuknyó T., Kónya C., Szabó T. and Marossy K.: Investigating the Properties and Structure of Polyurethane Elastomers with Monoethylene Glycol Chain Extender. *Materials Science Forum*, 986, 18-23 (2020). doi : <https://doi.org/10.4028/www.scientific.net/MSF.986.18>
4. **Somdee P.**, Lassú-Kuknyó T., Kónya C., Ibrahim J.F.M. and Marossy K.: Investigation of the rubber elasticity and properties of polyurethane elastomers with different silicon carbide contents. *Journal of Physics: Conference Series*, 1527, 012038 (2020). doi : [10.1088/1742-6596/1527/1/012038](https://doi.org/10.1088/1742-6596/1527/1/012038)

### 7.2 National Journal articles

1. **Somdee P.**, Lassú-Kuknyó T., Kónya C., Szabó T. and Marossy K.: Influence of Chain Extender on Soft and Hard Segment of Polyurethane Elastomers. *Materials Science and Engineering: A Publication of the University of Miskolc*, 43(1), 98-107 (2018).

### 7.3 Conference Proceeding

1. **Somdee P.**, Marossy K., Lassú-Kuknyó T. and Kónya C.: Polyurethane elastomers with improved thermal conductivity part I: Elaborating matrix material for thermal conductive composites. *ISER international conference, Poland* (2018).

## 7.4 Oral Presentations

1. **Somdee P.**, Polyurethane Elastomer Composites of Increased Thermal Conductivity Part I: Magnesium Oxide, DOKTORANDUSZOK FÓRUMA, Miskoci Egyetem, Miskolc, Hungary, 15 November 2017.
2. **Somdee P.**, Polyurethane elastomers with improved thermal conductivity part I: elaborating matrix material for thermal conductive composites, ISER international conference, Krakow, Poland, 15 April 2018.
3. **Somdee P.**, Effect of Chain Extender on Hard Segment in Polyurethane Elastomers Structure. 5th International Conference on Competitive Materials and Technology Processes, Miskolc, Hungary, 11 October 2018.
4. **Somdee P.**, Chemical structure and thermal properties of flexible polyurethanes with silicon carbide, 18 Österreichische Chemietage, Linz, Austria, 24-27 September 2019.
5. **Somdee P.**, Investigation of the rubber elasticity and properties of polyurethane elastomers with different silicon carbide contents. 4th International Conference on Rheology and Modeling of Materials (ic-rmm4), Miskolc, Hungary, 9 October 2019.

## 7.5 Poster Presentation

1. **Somdee P.**, Effect of Magnesium Oxide on Flexible and Rigid Polyurethanes, ANM2019 conference, Aveiro, Portugal, 17-19 July 2019.

## 8. Acknowledgements

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