Research Article

Thermoplastic Polyurethane/ZnO Composites Simply Prepared from Solution Casting and Proposed as Thermally Conductive Gaskets for Energy Storage Technology and Energy Applications

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Abstract
In the study, a thermoplastic polyurethane composite is formulated and proposed as a gasket used in energy storage technology and energy applications. Due to the high preparation cost of thermally conductive composite gaskets, the composite materials were prepared through inexpensive solution casting and monitored in their thermal conductivity, mechanical properties and morphology. The specimens were also tested in a fluid resistance test and a hot water immersion test. The thermal conductivity of the proposed composite gaskets is in the range of 0.1–0.2 $Wm^{-1}K^{-1}$. An increase in ZnO loading enhances shore A hardness and Young's modulus whereas it decreases in %elongation at break. However, tensile strength and tear strength remain unaffected. Scanning electron microscope (SEM) images and SEM combined with Energy Dispersive X-ray analysis (EDX) reveal that the prepared composites demonstrate enhanced thermal conductivity, attributed to a higher filler content and minimized distances between conductive particles. With thicknesses ranging from 1.40 to 1.85 mm, their physical appearance, weight loss and thermal conductivity were not significantly changed after fluid immersion and water immersion at 70 °C. Consequently, the composite samples developed in the study are proposed as promising candidates for use in energy storage technologies and related applications.

Keywords: Energy applications, Energy storage technology, Thermally conductive gasket, Thermoplastic polyurethane/ZnO composite

1 Introduction

Gaskets are essential components that serve a critical function in sealing the junction between two surfaces, effectively preventing the escape of fluids and gases. Their development has evolved significantly over time, adapting to meet the needs of diverse industries such as food processing, automotive, and petrochemicals. Common materials used for gasket production include engineering polymers, ethylene propylene diene monomer (EPDM) rubber, thermoplastic vulcanizate (TPV), acrylonitrile butadiene styrene (ABS), nitrile rubber, silicone, polytetrafluoroethylene (PTFE), and butyl rubber. [1]–[4]. Thermal interface materials (TIMs), sometimes known as gaskets, are crucial for one of the main components of fuel cells and electrolytic cells typically run at least 70 °C [5]–[9]. Consequently, heat management of the TIMs has been a concern. The use of thermally conductive fillers in polymer matrix composites presents a valuable solution for enhancing the thermal properties of gaskets or TIMs at high working temperatures and performing as intended [10].

As mentioned previously, TIMs are significantly necessary to thermal management because of how their heat transfer property affects device performance, longevity, and stability [11], [12]. In general, TIMs can be categorized into four types including greases, phase change materials, carbon-based materials and polymer composites. Polymer composites are defined as minor phase or fillers dispersed in major phase or polymer matrix and their properties can be adjusted as type, shape, content and network of fillers. Furthermore, the polymeric material has been interestingly considered as a candidate for TIMs preparation due to its excellent insulation, lightweight, mechanical properties, ease of processing and inexpensive cost [13], [14]. Even though intrinsic thermally conductive polymer either containing conjugated or crystalline structures with high thermal conductivity can be synthesized, its undesirable disadvantages are difficult, costly and only conducted in the laboratory. Thermally conductive fillers in the polymer matrix have been interesting since these fillers significantly enhance thermal conductivity for the thermally conductive polymer composites in which channels or networks of these fillers are formed [15].

Thermal conductivity of TIMs can be improved by increasing the amount of thermally conductive fillers by phonons as carriers [14]. In the beginning, well-dispersed 0D particles in the matrix can enhance the thermal conductivity of the composites. However, the size of the thermal filler results in heat transfer property, in which the thermal conductivity of the thermally conductive particles decreases as decreasing in their size. Additionally, the shape of the thermal conductive filler importantly affects thermal conductivity [16]–[19]. Higher thermal conductivity of silicon carbide (SiC) nanowires in nanofluids than the one of cylinder-SiC and sphere-SiC in nanofluids were reported. At the same volume fraction, the heat conduction of composites was significantly enhanced by the addition of the tetrapod-shaped ZnO when compared to the sphere-shaped ZnO or 0D thermally conductive filler since thermal conductive networks of the tetrapod-shaped ZnO favorably formed. In certain systems, hybrid thermally conductive fillers with different filler sizes or filler shapes were applied. The effect of filler shape on the thermal conductivity of thermal functional composites was reported the unique-shaped filler such as tripod-shaped filler was easier to form a thermal conductivity chain or network, resulting in greater thermal conductivity. In a three-dimensional scheme, a strong synergistic effect is derived from the small-size filler of 2D or 3D fillers located between larger thermally conductive particles. Thermal conductivity channels or networks take place and significantly increase thermal conductivity for the composites [20]. For the system of the filled thermally conductive polymeric composites, significant mechanisms, thermally conductive path theory and thermally conductive percolation theory, have been reported. In the thermally conductive path theory, heat can transfer via thermal conductive channels in which the filler networks from the contact of the thermally conductive fillers in the polymeric matrix are established. Thermally conductive percolation theory is also used to explain the thermally conductive behavior of the filled thermally conductive polymeric composites. However, the thermal conductivity of these composites is still controversial [15].

Additionally, composite gaskets can be processed including compression molding, solution casting, etc. Good dispersion of thermally conductive fillers is crucially essential in the composite gasket industry whereas filler agglomeration including the other defects is avoided. To obtain the shape of the composite gasket as designed, viscoelastic behavior of the polymer matrix plays an important role in the processing method for the composite gasket [21]–[27]. The preparation method is one of the challenging problems for the composite gasket industry due to several parameters related as mentioned previously.

Therefore, thermal conductivity of TIM applications can be tailored by cooperation of thermally conductive additives. The research aims to propose a polymer composite formulation. In the study, ZnO, which is an electrical insulator and thermal conductor, is chosen as the filler due to its availability and cost. Thermoplastic polyurethane or TPU is selected as a polymer matrix due to its elasticity, chemical and fluid resistance [23]. The prepared ZnO-filled TPU composites are characterized in their quality, reliability, and performance to be potentially used as a gasket in energy storage technology and energy applications. This proposed composite is simply tested in coolant and hot water immersion for monitoring fluid and thermal resistance performance.

2 Materials and Methods

Polyester based thermoplastic polyurethane (TPU) (Grade Estane ® S160D) from Global Connections

Public Company Limited, Thailand was used as purchased. Dimethylformamide (DMF) (Analytical .reagent grade) was obtained from Chem-Supply company, Thailand. Zinc oxide (ZnO) particles in the size range 0.1–16.2 micron. (See Supplement) (Analytical reagent Grade) from Univar Solutions Inc., Thailand was utilized as purchased Corsair hydro X series XL8 performance coolant, a commercial coolant, was purchased from Compute and more, Thailand and used as received.

2.1 Sample preparation

For TPU solution preparation, TPU was dissolved in DMF with 15% (w/v). ZnO quantity was varied from 5, 10, 15, and 20% and added to 25 mL of the prepared TPU solution [3]. Each sample was mixed homogeneously before being poured into a petri dish with 90 mm in diameter. All the samples were dried at room temperature for 72 h before the further sample characterization. The pure TPU sample and the composite samples prepared in the study are approximately 1 mm in thick.

2.2 Sample characterization

2.2.1 Physical appearance

After adding ZnO as thermal conductive fillers at various quantities to TPU solution, physical appearance of the prepared samples was observed. Their filler sedimentation or phase separation were monitored and avoided. Afterwards, physical appearance of the dried composite samples was also followed.

2.2.2 Thickness measurement

Thickness measurement was conducted using a vernier caliper. The pure TPU and the composite samples in the study were measured in their thicknesses from three different points. The average and standard deviation (SD) of their thicknesses were calculated and reported.

2.2.3 Density determination

The density of all samples was determined by an electronic densimeter (AlfaMirage, Model: MDS-300). The samples were cut into pieces, approximately

1×1 cm^2 in size. Afterwards, they were weighed in the air and in the water. Their weights and densities were collected.

2.2.4 Thermal conductivity measurement

In the study, thermal properties including specific heat capacity, thermal diffusivity and thermal conductivity of the neat polymer and the composite samples varied in thermal conductive fillers were determined by a thermal conductivity analyzer (NETZSCH, Model: LFA 467 Hyper Flash). All the samples were cut into squares of 1×1 cm^2. Before the measurement, graphite spraying was applied on the top and the bottom surfaces of their samples twice and then the samples were dried for 1 hour. Afterwards, thermal properties of the samples at 25 °C were tested and recorded.

2.2.5 Morphology characterization

Before being added to polymeric solution, morphology of ZnO used in the study was investigated by SEM technique as well as the composite samples varied in the amount of additional ZnO fillers. They all were characterized using FEI Quanta 450 with thermal field emission 10 kV. Furthermore, SEM with energy dispersive X-Ray spectroscopy (EDX) was used to scrutinize surface, elemental analysis, chemical composition and distribution of elements of the samples.

2.2.6 Determination of mechanical properties

The Rex Durometer, OS-1 Operating Stand, was used to investigate hardness Shore A for all the samples at room temperature and their hardness was reported. For determination of tensile strength, %elongation at break and Young's modulus, the samples were cut in the dumbbell shape V as mentioned in ASTM-D638. Each sample was subjected to Cometech, QC-506M1 with load cell at 2 kN and testing speeding at 5 mm/min. Then, tensile strength, %elongation at break and Young's modulus of each prepared sample were collected. Type C Tear strength of the specimens was followed. All the samples were cut with the dimensions and tested as ASTM D624. Type C tear strength test sample was installed to Zwick/Roell, Z010 with load cell at 1 kN and speed of testing at 500 mm/min.

2.2.7 Fluid resistance test

According to fluid resistance test as ASTM F146, all samples were cut with the dimension of 1 cm × 1 cm and placed in the small test tubes. Then 10 mL of the commercial coolant was poured into the test tube. The immersion time was varied from 3, 5, and 7 days, respectively. After the coolant immersion, the samples were monitored for their changes in physical appearance, weight change and thermal conductivity.

Additionally, a hot water immersion test, in which the commercial coolant fluid was replaced by water heated at 70 °C, was applied and examined for all the samples cut with the same dimension for the fluid resistance test. Also, the immersion time for the test was studied from 3, 5, and 7 days. All samples were followed and compared in their physical appearance, weight change and thermal conductivity before and after hot water immersion test.

3 Results and Discussion

3.1 Morphology of the thermal conductive filler

The morphology of ZnO before being added to TPU solution is monitored by SEM. Figure 1 displays an SEM micrograph of ZnO at magnification 10,000 times. An individual ZnO particle is not found but these ZnO particles tend to form loose agglomerates (Refer to a blue arrow).
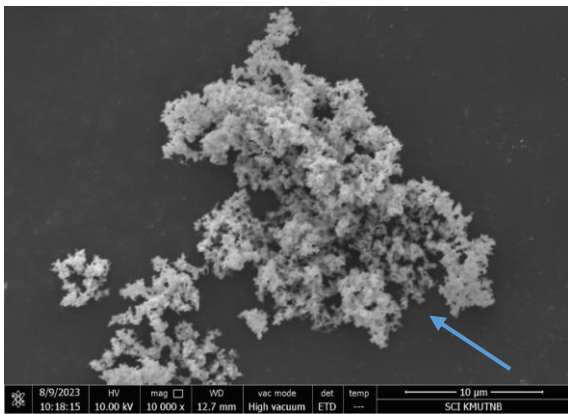

Figure 1: SEM image of ZnO particles magnified 10,000 times.

3.2 Physical appearance of the composite solutions

Polymeric solutions before and after adding ZnO as the thermally conductive particles were monitored and their physical appearance is demonstrated in Figure 2 (a)–(e).
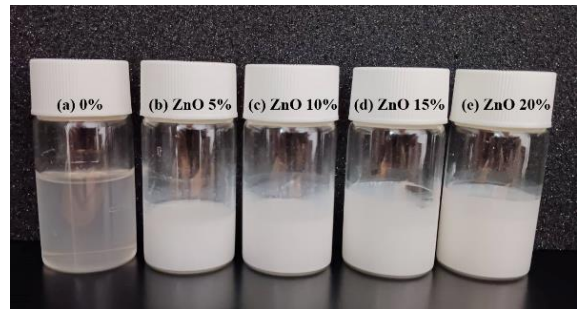

Figure 2: Physical appearance of polymer solutions without and with ZnO at various quantities.

In the study, sedimentation of the thermally conductive filler is not detected in any resulting TPU composites with amount of ZnO content varied from 5, 10, 15, and 20%wt. In other words, their phase separation is also not found in any prepared samples. Thus, they are suitable for solution casting and sample preparation, respectively.

3.3 Thickness, density and thermal properties

In the study, thickness, density and thermal characteristics including specific heat capacity, thermal diffusivity and thermal conductivity of all specimens are listed in Table 1 and compared to the commercial silicone TIM. The thickness of the samples with 0, 5, 10, 15 and 20 wt% of ZnO is 1.72, 1.37, 1.85, 1.70, and 1.45 mm, respectively. The thickness of the prepared samples is thicker than that of commercial TIM whose thickness is 1.10 mm. The densities of the composite samples are 0.44, 0.49, 0.70, 0.920, and 1.05 g cm^{-3} in 0, 5, 10, 15, and 20 wt% of ZnO, respectively. Composite density is increased as increasing ZnO quantity.

Specific heat capacity obtained from thermal conductivity measurement is 1.07, 1.04, 1.02, 1.00, 1.01 and 1.02 J g^{-1} K^{-1} for the TPU, 5 wt%ZnO, 10 wt%ZnO, 15 wt%ZnO, 20 wt%ZnO, and the commercial TIM samples, respectively. There is no significant difference in their specific heat capacity. This indicates the indifferent amount of heat required to change the temperature of the prepared samples and the commercial TIM sample by 1 °C. Without any thermally conductive fillers, thermal diffusivity of the TPU sample is 0.129 mm^{2}s^{-1}. When the ZnO filler is added to the polymer matrix at 5 wt%ZnO, its thermal

diffusivity is increased to 0.154 mm^{2}s^{-1}. The thermal diffusivity of the commercial TIM specimen is 0.155 mm^{2}s^{-1}. This thermal characteristic of the sample with 5 wt%ZnO is comparable to that of the commercial TIM. Furthermore, thermal diffusivity of 10 wt%ZnO, 15 wt%ZnO and 20 wt%ZnO composite samples are 0.173, 0.192 and 0.202 mm2^{s-1}, respectively. An increase in ZnO loading in the composite samples results in increasing thermal diffusivity which heat

conduction and heat propagation are expected to be fast.

For thermal conductivity, polymer matrix is considered as the thermal insulator and its thermal conductivity is 0.057 Wm-1K-1. With the presence of thermally conductive fillers, thermal conductivity of the composite samples with 5 wt%ZnO, 10 wt%ZnO, 15 wt%ZnO, and 20 wt%ZnO is 0.092, 0.127, 0.165 and 0.207 Wm^{-1}K^{-1}, respectively.

Table 1: Thickness, density, specific heat capacity, thermal diffusivity and thermal conductivity of the neat TPU and the composite samples at several ZnO contents compared to the ones of the commercial silicone TIM.

Sample	Thickness	Density	Specific Heat Capacity	Thermal Diffusivity	Thermal Conductivity
	(mm)	ρ *(g cm^{-3})*	C_p *(J g^{-1} K^{-1})*	α *(mm^2 s^{-1})*	κ *(W m^{-1} K^{-1})*
TPU	1.72 ± 0.00	0.44 ± 0.00	1.07 ± 0.05	0.13 ± 0.01	0.057 ± 0.053
5wt%ZnO	1.37 ± 0.00	0.49 ± 0.01	1.04 ± 0.07	0.15 ± 0.01	0.092 ± 0.003
10wt%ZnO	1.85 ± 0.00	0.70 ± 0.06	1.02 ± 0.02	0.17 ± 0.02	0.127 ± 0.014
15wt%ZnO	1.70 ± 0.00	0.92 ± 0.04	1.00 ± 0.01	0.19 ± 0.01	0.165 ± 0.010
20wt%ZnO	1.45 ± 0.00	1.05 ± 0.01	1.01 ± 0.02	0.20 ± 0.01	0.207 ± 0.016
Commercial silicone TIM	1.10 ± 0.00	1.21 ± 0.02	1.02 ± 0.04	0.16 ± 0.01	0.205 ± 0.008

Table 2: Mechanical properties of ZnO-filled polymer composites at several ZnO contents.

ZnO Loading (wt%)	Hardness (Shore A)	Tensile Strength (MPa)	Elongation at Break (%)	Young's modulus (MPa)	Tear Strength (kN/m)
0	72.0 ± 1.2	4.12 ± 0.40	286.05 ± 24.63	1.29 ± 0.07	24.77 ± 3.60
5	73.8 ± 1.6	5.29 ± 0.37	259.04 ± 12.31	1.77 ± 0.06	24.58 ± 2.23
10	74.7 ± 1.8	3.55 ± 0.35	170.43 ± 19.91	1.89 ± 0.23	23.57 ± 4.86
15	76.5 ± 1.7	2.96 ± 0.10	144.34 ± 5.89	1.98 ± 0.02	24.67 ± 3.10
20	80.2 ± 1.8	3.81 ± 1.39	151.30 ± 60.82	2.54 ± 0.63	22.16 ± 8.37

It is clear that the greater ZnO quantity, the higher thermal conductivity of the composites. Furthermore, thermal conductivity of the composite with 20 wt%ZnO is comparable to that of the commercial sample whose thermal conductivity is 0.205 Wm^{-1}K^{-1}.

$$\kappa/(C_p \times \rho) = \alpha \quad (1)$$

In general, thermal conductivity (κ) can be calculated from Equation (1) in which thermal parameters are specific heat capacity (C_p), thermal diffusivity (α), and density (ρ). Since specific heat capacity of the samples prepared in the study is not significantly different, their thermal conductivity is potentially dominated by density and thermal diffusivity.

3.4 *Mechanical properties*

Shore A hardness of TPU and TPU-ZnO composite samples are listed in Table 2. Without ZnO fillers, shore A hardness of TPU sample is 72.0. Shore A hardness of the composite samples with 5 wt%ZnO,

10 wt%ZnO, 15 wt%ZnO, and 20 wt%ZnO is 73.8, 74.7, 76.5 and 80.2, respectively. This can be explained by ZnO fillers significantly contributing and increasing Shore A hardness. Therefore, hardness can be increased by increasing filler concentration.

Table 2 also shows tensile properties as maximum tensile strength, elongation at break and Young's modulus of the TPU sample and ZnO-TPU composites. Tensile strength detected is 4.12, 5.23, 3.55, 2.96 and 3.81 MPa of the samples with 0, 5, 10, 15, and 20 wt%ZnO, respectively. Thermally conductive filler, ZnO, at various concentrations, slightly changes in tensile strength of the composites in the study. Elongation at break for the samples with 0, 5, 10, 15, and 20 wt%ZnO are 286, 259, 170, 144, and 151%, respectively. An increase in ZnO filler content in the matrix reduces elongation at the break of the composites. This might be due to the presence of ceramic ZnO fillers resulting in restricted mobility of the polymer chain mobility [3]. Young's modulus is 1.29, 1.77, 1.89, 1.98, and 2.54 MPa for the prepared composite samples with 0, 5, 10, 15, and 20 wt%ZnO, respectively. It is found that Young's modulus can be promoted by adding ZnO fillers to the matrix.

Furthermore, Young's modulus increases as increasing thermally conductive particles in the study. The tear strength of the pure TPU polymer is 24.77 kN/m. When ZnO fillers added to the polymer matrix were varied from 5, 10, 15, and 20 wt%ZnO, tear strength of the samples is 24.58, 23.57, 24.67, and 22.16 kN/m, respectively. In general, tensile strength and tear strength can be enhanced and derived by strong interaction between fillers and matrix. However, tensile strength and tear strength of the composites prepared are still in the same range as their TPU sample. Tensile strength and tear strength are independent on the amount of thermally conductive filler or ZnO added to the composite samples.

3.5 *Morphology*

SEM images of the samples with 0, 5, 10, 15, and 20 wt% ZnO filler are demonstrated in Figure 3(a)–(e), respectively. In the SEM micrographs, the light and the dark areas are filler (Refer to yellow arrows) and matrix regions, respectively. Figure 3(b)–(e) display ZnO filler particles well-dispersed in the polymer matrix. This confirms no formation of filler agglomeration.

According to SEM and SEM-EDX results for carbon and zinc, an attempt was also made to present the distribution of the ZnO fillers in the TPU matrix. All Figures 4 show the mapping for the reference TPU matrix and the composite systems in the study. Mappings obtained for the reference matrix sample as shown in Figure 4(a), (d), (h), (l) and (p) SEM images and Figure 4(b)-(c), (e)-(g), (i)-(k), (m)-(o) and (q)-(s) elemental composition derived from EDX for C and Zn, C and Zn the prepared samples at various ZnO loadings were collected and compared. As displayed in Figure 4(g), (k), (o), and (s), an increasing number of red points indicating the greater concentration of zinc can be observed as an increase in ZnO concentration from 5% to 20 %wt. Figure 4(g) and (k) for the composite samples with 5% and 10%wt ZnO particles demonstrate individual particles distributed in the matrix. Evidence of no contact between ZnO particles suggests that ZnO concentration is still below the percolation threshold.

Significantly, quantities of ZnO particles are increased to 15 and 20% wt in the study, network formation of ZnO particles detected and shown in Figure 4(o) and (s), respectively. At these two filler concentrations, distance or gaps between ZnO particles seems shorter and some gaps can be filled. So, concentration of ZnO above percolation threshold can be implied [12].

Thus, percolation concepts of composite systems in the study are proposed and depicted in Figure 5(a) and (b) for ZnO concentration below and greater than percolation threshold, respectively. Light grey circle and dark area are represented by the ZnO thermally conductive filler and TPU matrix, respectively. Separate islands or individual fillers can be seen at filler concentrations below percolation threshold. (See Figure 5(a)) Meanwhile, an emergence of the filler network formation can be detected at filler concentration above percolation threshold. Therefore, ZnO network shortens the distance between fillers, avoids heat passing through the TPU matrix with low thermal conductivity, and promotes thermal conductivity as illustrated in Figure 5 (b). As evidence obtained from SEM and SEM-EDX indicates that thermally conductive fillers well dispersed in TPU matrix and located at shorter distances enhance fast thermal dissipation. Furthermore, the heat transfer corresponds to the heat diffusivity increased as measured (Table 1).
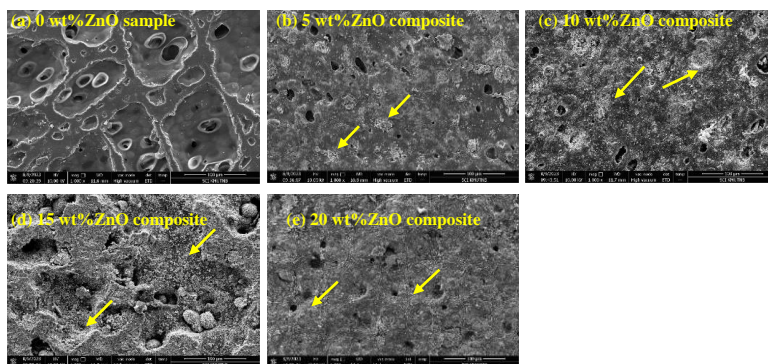

Figure 3: SEM micrographs of the prepared samples varied in ZnO loadings. (scale bar 100 μm and ZnO dispersed in the samples (yellow arrows)).
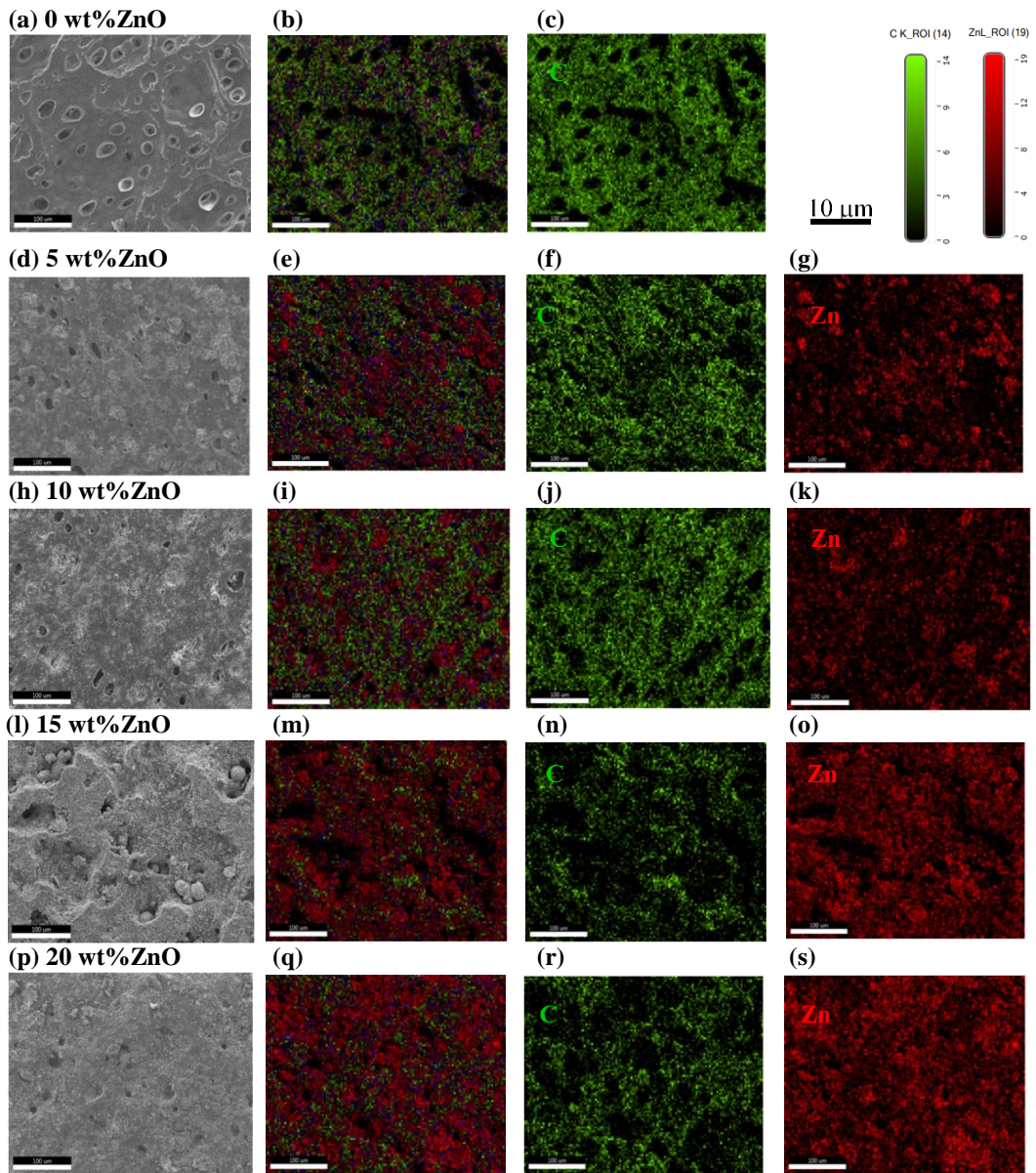
Figure 4: (a), (d), (h), (l) and (p) SEM images and (b)-(c), (e)-(g), (i)-(k), (m)-(o) and (q)-(s) elemental composition derived from EDX for C and Zn the prepared samples at various ZnO loadings.
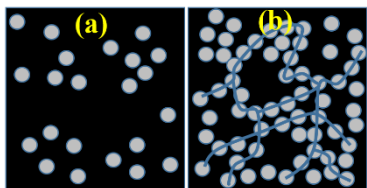

Figure 5: Schematic percolation concepts proposed (a) below and (b) above percolation threshold, respectively. (ZnO particles shown in light grey circles).

3.6 *Fluid resistance*

Fluid resistance of all the composite samples with different ZnO concentrations was tested in the commercial coolant as ASTM F146. Their physical appearance, weight change and thermal conductivity were monitored after 3, 5 and 7 immersion days. Change in physical appearance of the composite samples varied in ZnO particles is collected in Table 3.

Before being immersed in the commercial coolant fluid, the samples with 0, 5, 10, 15 and 20 wt%ZnO were white and appeared as the white pad. The sample without ZnO is still white pad. With additional ZnO, the composite samples are light pink after the coolant immersion.

According to fluid resistance test, thermal conductivity and weight change of the samples prepared in the study are monitored and plotted as a function of immersion time (See Figure 6(a)). As reported earlier, thermal conductivity of the composites in the range of 0.1–0.2 $Wm^{-1}K^{-1}$ is enhanced by increasing thermally conductive filler before the coolant immersion. Interestingly, when all the samples were immersed in the commercial coolant fluid, it was found that a slight change of thermal conductivity was detected at 3, 5, and 7 days. Weight change of the composite samples with 0, 5, 10, 15 and 20 wt%ZnO did not changed significantly when they were immersed in the fluid for 3 and 5 days. After 7 days of fluid immersion, a slight weight change is observed but it is less than 2.5%.

Furthermore, all the samples were immersed in the hot water at 70 °C as an operational temperature at different periods of time (Table 3). Before the hot water immersion, physical appearance of the sample with 0, 5, 10, 15, and 20%wt of ZnO particles is white pad. After in the hot water immersion for 3 days, 5 days, and 7 days, their physical appearance remains the same as before water immersion. Their thermal conductivity and weight change after hot water immersion test were followed and plotted in Figure 6(b). Thermal conductivity of the prepared samples changes insignificantly. Furthermore, weight changes measured after the immersion test are less than 2%.

The slight change in weight observed after immersing composite samples in commercial coolants or hot water indicates that the thermally conductive fillers remain embedded within the polymer matrix. This stability ensures that the thermal conductivity of the composite is still consistent during immersion testing, as confirmed by the results. The retention of fillers within the matrix is crucial for maintaining the desired thermal performance, highlighting the effectiveness of the polymer in protecting the fillers from leaching or degradation.

Table 3: Physical appearance of the samples immersed in commercial coolant and hot water (70 °C) at different immersion days.

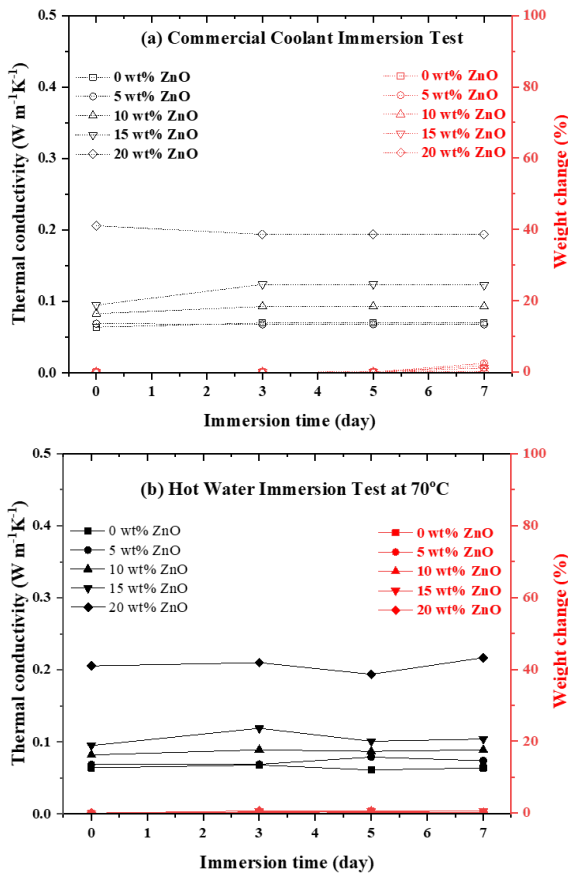| Sample Name	Before Immersion	Physical Appearance after Commercial Coolant Immersion (day)			Physical Appearance after Hot Water Immersion at 70 °C (day)		
	0	3	5	7	3	5	7
0 %wt ZnO							
5 %wt ZnO							
10 %wt ZnO							
15 %wt ZnO							
20 %wt ZnO							

Figure 6: Thermal conductivity (black y-axis) and weight change (red y-axis) of all prepared samples at 0, 3, 5 and 7 days after (a) the commercial coolant immersion and (b) the hot water immersion at 70 °C.

In the study, the thermal dissipation composites prepared through a simple solution casting method demonstrate promising stability for use in commercial coolants and at operational temperatures of up to 70 °C. These composites exhibit insignificant changes in both thermal conductivity and weight during testing, indicating their robustness. As a result, they show potential for applications in energy storage technologies and other energy-related applications.

4 Conclusions

In the study, composites composed of inexpensive ZnO as the thermally conductive filler and TPU as polymer matrix can be successfully prepared by solution casting. The prepared ZnO-filled polymer composites are characterized in their performance such as thermal conductivity, mechanical properties, morphology and fluid resistance. Increase in ZnO loading plays an important role of enhanced thermal conductivity and thermal diffusivity whereas it does not effect on specific heat capacity. Morphological evidence suggests good dispersion of the fillers and short distance between fillers as the filler loading is increased. For mechanical properties, tensile strength and tear strength are not changed when the filler loading is increased. Young's modulus and shore A hardness increase when %ZnO cooperation is increased. However, increasing thermally conductive fillers reduces %elongation at break. Furthermore, physical appearance, weight change and thermal conductivity of the prepared composites remain constant when they are immersed in the coolant fluid and the hot water. According to filler cost, simple preparation method, and performance, composites in the study can be potentially proposed, and challengingly used as the thermal dispersion composites in the future.

Acknowledgments

Author Contributions

S.C.: conceptualization, investigation, methodology, data curation, writing—reviewing and editing, funding acquisition, project administration.; R.Y.: conceptualization; T.U.: conceptualization, research design, sample preparation, data analysis. All authors have read and agreed to the published version of the manuscript

Conflicts of Interest

The authors declare no conflict of interest.

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