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RESEARCH ARTICLE

A Study on Particle Size Effect of Polyurethane-Mica Composites

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ABSTRACT Nano-sized particles have a significant impact on the dielectric and mechanical properties of polyurethanes. In order to characterize its effects on solid insulators, different types of nanoparticles have been investigated in polymeric materials. One of the filler materials is nanometric mica in the polymer base. Therefore, the objective of this study is to investigate the dielectric properties of mica-filled thermoplastic polyurethane (TPU). Nanometer- and micrometer-size mica fillers with various mixing ratios were doped into TPU. The changes in such dielectric properties as relative permittivity, loss factor, dc conductivity, and breakdown strength have been evaluated in thermoplastic polyurethane composites filled with mica fillers of particle sizes 1 nm, 10 nm, and 5 μm. Physical changes have been observed through Scanning Electron Microscopy (SEM) analysis after adding nano-sized mica particles, while the addition of micron-sized mica particles resulted in samples with breakdown voltages at least 2.5 times higher than pure TPU. The loss factor of the composite, on the other hand, has been found to be the lowest with 3% mica content for 1 nm particle size, 2 % mica content for 10 nm particle size and 1 % mica content for 5 μm particle size.

INDEX TERMS Dielectric loss, dielectric properties, mica, nano particles, permittivity.

I. INTRODUCTION

Over the last three decades, composite polymeric materials filled with organic and inorganic nanometric fillers have become an important field of study to improve the properties of polymers, which have a variety of applications [1], [2]. When mixed with nanometric-size fillers, polymeric composites have exhibited remarkable improvement on mechanical, thermal, optical, physico-chemical and environmental properties as compared to the pure polymer essentially due to the dispersion of nanometric-size particles [3], [4], [5], [6], [7], [8]. Polyurethane (PU) has a variety of forms such as foams, adhesives, coatings, elastomers, etc. Although PU is one of the most widely used commercial polymeric materials for both industrial and daily life applications, one of its variants, thermoplastic polyurethane (TPU), has such specific applications as in automotive industry, in electrical systems, etc.

In recent years, TPU has found a place as a wire insulation. TPU has also been used as an insulating material in low voltage electric and electronic parts. Moreover, the elastomer structure of TPU enables its application in a broad range of high-voltage (HV) insulation systems. Because of its favorable mechanical properties, high insulation resistance, lightweight, recovery, large actuation strain, and cost-effectiveness, TPU is commonly used as a high-voltage insulator. Additionally, in high-voltage applications, TPU is employed as a sheathing compound in special purpose power cables and in high-voltage transformers because of its high strength, excellent abrasion resistance, chemical resistance as well as low smoke properties [9], [10].

The electrical properties of this polymeric material can be dramatically changed by incorporating a small amount of filler into the base polymer [11]. By doping TPU with different types of fillers, the relative permittivity of the new

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composite can be increased. Thus, this new TPU-based composite can be a good candidate in such applications as sensors, where high relative permittivity is needed. By implementing the technique of in situ polymerization of aniline in an aqueous dispersion of polyurethane, the resulting composite blend containing 17% (wt) aniline, the relative permittivity was obtained 1,120 while the pure polyurethane has a relative permittivity of 5.68 at 1 kHz frequency [12]. By increasing the ceramic phase in a Pb(Mg1/3Nb2/3)O_3-$PbTiO_3$/polyurethane composite from a ratio of 70:30 to a ratio of 90:10, an increase in relative permittivity from 20 to 70 has been observed at 1,100°C and 1 kHz [13]. To improve electrical properties, blending TPU with other thermoplastics has been of interest in the last several years. Polyurethane/poly(styrene-co-acrylonitrile) blends show a good miscibility. Addition of poly (styrene-co- acrylonitrile) to PU decreased the specific heat increment at the glass transition temperature of TPU, so, the rapid increase in relative permittivity of PU at glass transition temperature is lowered [14]. The dielectric behavior of two and three component polyurethane has been also studied along with the effect of temperature on its relative permittivity [15]. Moreover, the chain dynamics and ionic conductivity of polyurethane have been discussed in [16].

The micas are complex hydrous, potassium-aluminum silicate minerals. Biotite ($KMg_{2.5}Fe^{2+}_{0.5}AlSi_3O_{10}(OH)_{1.75}F_{0.25}$) is the most common form of the micas, containing iron and/or magnesium impurities substituting for octahedral aluminum. Mica is not affected by fire, water, acid, alkalis and is widely used in the industrial applications when a material with elasticity and tenacity as heat insulator is desired. Synthetic mica is commonly used as clay material, its applications and developments in clay-based nanocomposites have been reviewed by several studies [17].

The total area of resin/nanofiller interfaces is quite large in nanocomposite samples [18], [19]. Thus, the comparison of permittivities has indicated that there is a strong interaction between the resin and nanofiller, which restricts the molecular motion against the partial discharges [20], [21], [22]. When the experimental studies ~~out~~ so far are examined, it is observed that the dielectric performance has been evaluated by adding oxide-based materials to the PU material in general [11]. As a result of the addition of oxide structures to the PU material, it is aimed to improve both chemical and electrical properties. However, in previous studies, ZnO with a size range of 650 nm to 1.2 μm has been used as a filler [26], [27], [28]. Because of the large size of this metal oxide the effect of smaller particle sizes, such as 1 nm, 5 nm etc. could not be observed. Therefore, the objective of this study is to investigate the influence of mica particles with various sizes on the dielectric properties of TPU composites.

Within the scope of this study, the changes are investigated on dielectric characteristics of mica-doped TPU composite samples by measuring the relative permittivity, loss factor, dc conductivity, and breakdown strength. The results suggest that the use of nanometric size and micro-size mica can enhance the efficiency and effectiveness of the TPU composite in various applications.

II. MATERIALS AND EXPERIMENTAL SETUP

A. PREPARATION OF MICA FILLERS

Three sets of composites were prepared by mixing TPU with mica particles having sizes of 1 nm, 10 nm and 5 μm. As the mica filler Biotite ($KMg_{2.5}Fe^{2+}_{0.5}AlSi_3O_{10}(OH)_{1.75}F_{0.25}$) with a density of 2.9 g/cm^3 was used in the TPU composites. The particle size and diameter of mica were measured by employing a 2000 master sizer. For 1 nm mica, the length of particle was measured between 15 nm and 75 nm while for 10 nm size mica the length of particle was measured between 30 nm and 120 nm. For 5 micrometer size mica the length of particle size was measured between 1 μm and 1 μm. Size measurements of micas were made by special sieving method. Some of the micas passed through these sieves have semi-oval and some cylindrical geometries. For example, when a mica passes through a sieve with 1 nm apertures, it is assumed to be 1 nm. However, the lengths of cylindrical and semi-oval micas vary as stated in the article. The length of the mica with a diameter of 1 nm varies between 15 nm and 75 nm, while the length of the mica with a diameter of 10 nm varies between 30 nm - 120 nm. The length of the particle sizes for 1 nm and 10 nm size micas were also measured by using Transmission Electron Microscopy (TEM) analyses. TEM pictures for 1 nm and 10 nm particle size mica particles are shown in Figure 1.

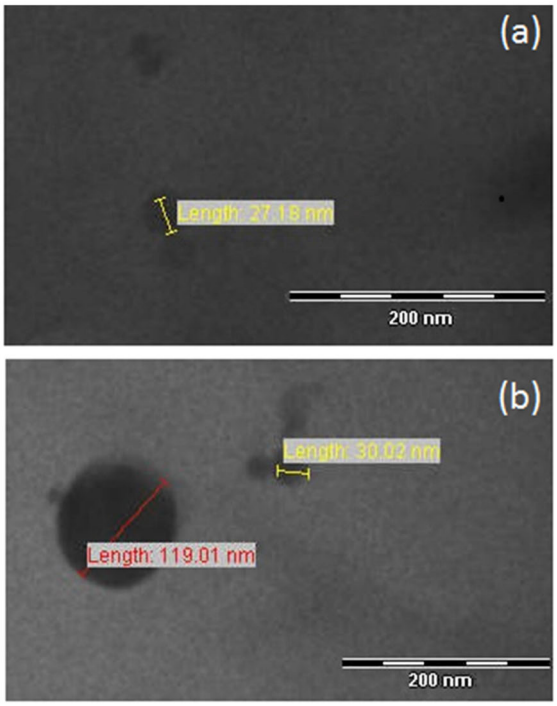

FIGURE 1. TEM pictures for (a) 1 nm and (b) 10 nm size mica particles.

The mica samples used in this study were modified with aminolauric acid and the preparation procedure is as follows: To a suspension of aminolauric acid (8.61 g, 40 mmol) in 1,000 mL distilled water concentrated HCl (4.17 g, 40 mmol) was added. The mixture was stirred at 80°C until getting a clear solution indicating the formation of ammonium salt. A suspension of 20 g of mica in 1,000 mL of distilled water was added into this solution and stirred using a mechanical stirring over night at 80°C. The final white precipitate was collected by suction filtration. Later the precipitate was suspended in hot distilled water with mechanical stirring for 1 h to remove the adsorbed salts. This process was repeated several times until no chloride ions were detected in the filtrate when adding 0.1 M $AgNO_3$. Finally, the precipitate was dried in a ventilated oven at 60°C for 3 days and finally at a temperature of 80°C and a pressure of 1.0133 kPa for 24 hours.

B. PREPARATION OF TPU/MICA NANOCOMPOSITES

The desired weights of polyurethane, mica and 0.01% Di butyltin dilaurate as catalyst were mixed for 5 minutes. Then the mixture was heated to a temperature of 100 °C and polymeric methylenediphenylene diisocyanate (MDI) with a concentration of 25% was added into the mixture. The new blend was poured into the mould and pressed for 10 minutes using clamps. Mould had been kept for 24 hours in a degasser under high vacuum in order to remove any air and potential water vapor from the system. After opening the mould samples were cut in the dimensions of 1 mm by 50 mm by 50 mm to evaluate their dielectric properties. All composite samples used in this study were prepared under the same laboratory conditions.

The TPU composites were prepared in such a way that the effect of the filler concentration and the sizes of mica filler was studied.

The highest content of mica was limited to 5% (wt) in the mixtures due to the dispersion and processing problems. Increasing the mica content in TPU-mica composites not only resulted in much harder and fragile specimens, but also caused an abnormal increase in the number and the size of the voids in the composite specimen. TPU composite sample doped with 10 nm particle size with 5% (wt) mica content is shown in Figure 2 under TEM at 200 nm scale.

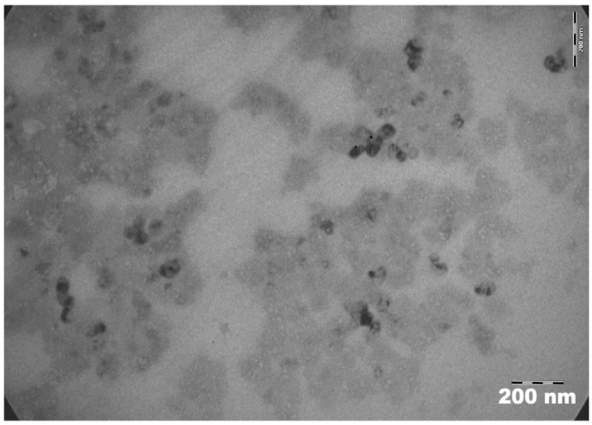

FIGURE 2. TEM picture of nano size mica distribution for 5 % 10 nm particle size mica added TPU composite sample.

III. EXPERIMENTAL SETUP

A high-voltage test equipment along with a set of appropriate instrumentation was used for the purpose of measuring the dielectric properties of TPU-mica composites. During the experiments DC conductivity, loss factor, relative permittivity and breakdown voltage of TPU-mica composites were measured.

High voltage DC source was used for evaluating the conductivity of the material, while in determining the relative permittivity and the breakdown voltage, a high voltage AC source operating at 60 Hz was employed. To calculate the relative permittivity of samples, the electric field between the electrodes was limited to a specific range from 1 kV/mm to 5 kV/mm according to previous studies and standards [13], [23], [24], [25]. During the experiments the applied voltage was raised at a rate of 200 V/s. The schematic of high voltage AC set up is illustrated in Figure 3. The test transformer used in this study has a transformation ratio of 220V/100kV with a rated output power of 5 kVA. A capacitive voltage divider was used in order to measure the applied voltage on TPU composite samples. A 1-kΩ, precision resistor with a ± 0.01% tolerance was connected between the ground electrode and the ground as a shunt resistor in order to evaluate the current through the composite sample by using a class 1 accuracy multimeter. For getting breakdown voltage of TPU composite samples, a voltage was applied and raised at a rate of 200 V/s up to the level of breakdown.

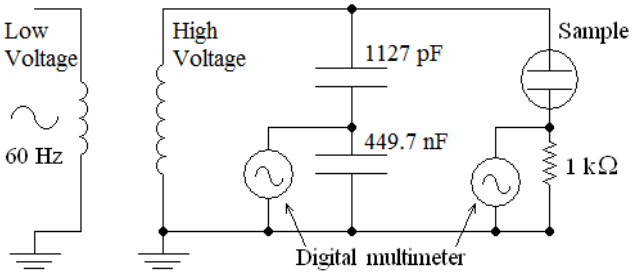

FIGURE 3. AC test set-up for measuring the relative permittivity and breakdown voltage.

A DC test set up was established as presented in Figure 4 with a view to evaluating the DC conductivity and also the real and the imaginary parts of the relative permittivity. In this set up, the applied voltage was measured with the help of a resistive voltage divider and a true rms digital multimeter. It is natural to have measurement uncertainty in measurements made from certain points in experimental studies. In our experimental study, Keithley GIT measuring device was used to minimize this uncertainty. Thus, the current which is flowing from positive terminal side of the sample to the

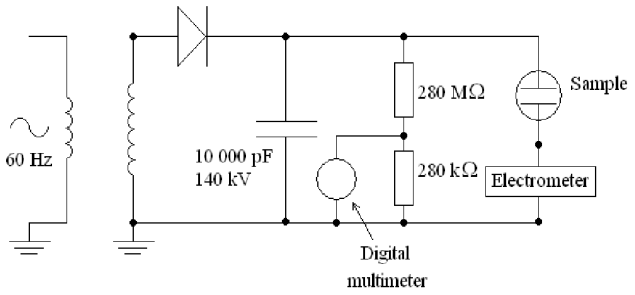

FIGURE 4. DC test set-up for measuring dc conductivity and loss factor.

ground electrode was measured using a precision electrometer (Keithley GIT) with a capable of measuring 10^{-14} A.

In order to prevent surface discharges on the composite sample, the experiments were carried out in a test vessel filled with refined mineral oil. Preliminary tests were carried out for each mica content and particle size to determine whether the mineral oil penetrated the polyurethane samples. The results revealed that there was no significant penetration of mineral oil into the composite samples. The high voltage and ground electrodes were both in circular shape with a diameter of 25 mm. The vessel and electrodes were made of stainless-steel material as shown in Figure 5. After the polyurethane sample sandwiched between the two electrodes, its thickness was also measured with a micrometer having a resolution of 10 μm.

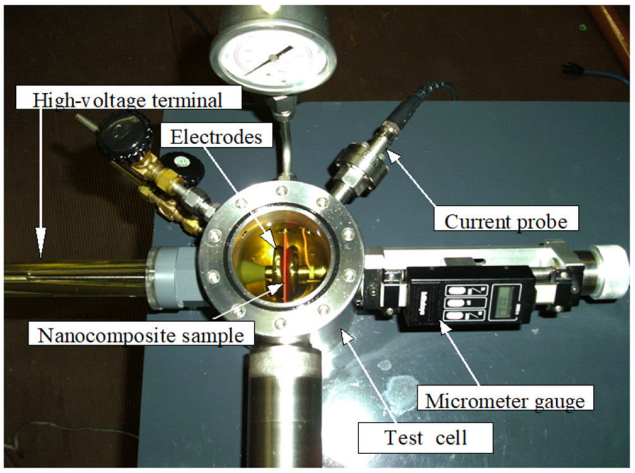

FIGURE 5. A photograph of the test cell with electrodes and a sample.

IV. RESULTS AND DISCUSSIONS

In this study, relative permittivity (dielectric constant), dc conductivity, loss factor and breakdown voltage values were experimentally determined for TPU composites mixed with 1% (wt), 2% (wt), 3% (wt), 4% (wt) and 5% (wt) of mica content having particle sizes of 1 nm, 10 nm and 5 μm. The relative permittivity as a function of the content of mica filler in TPU are presented in Figure 6 with the particle size of mica being a parameter. As can be seen from Figure 6,

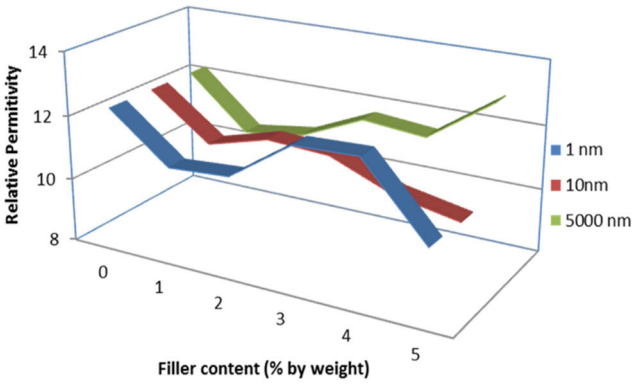

FIGURE 6. Dependence of mica content on relative permittivity in TPU composite sample.

relative permittivity revealed a non-linear relationship with mica content in TPU. For all sizes of mica fillers, the relative permittivity decreased when adding 1% (wt) of mica to pure TPU. However, a slight increase was observed on the relative permittivity when increasing the mica content in the TPU composite. But, after an optimum value of mica content in TPU, there was again a sharp decrease as can be seen in Figure 6. With a particle size of 1 nm, the addition of 1% (wt) mica to TPU decreased the relative permittivity, while 4% (wt) of mica content exhibited a slight increase on the relative permittivity. Addition of 5% (wt) of mica fillers to TPU, the relative permittivity once again diminished for particles with 1 nm and 10 nm size, but increased with 5 μm size.

As mentioned in Section II, Part B, the TPU composite samples having 5% (wt) mica fillers with particle sizes of 1 nm and 10 nm resulted in observable voids on the surface of the sample, which could possibly cause the decrease in the relative permittivity. For micro size filler addition surface properties were similar for each concentration levels rather than pure polyurethane sample. Indeed, the relative permittivity behavior for micro size mica added TPU samples is firstly decreased as the air impurities get smaller than pure TPU. However, with the increasing the micro size of mica concentration in TPU composite samples, a linear increase with mica concentration is measured.

Obtained results from 1 nm and 10 nm particle size experiments, relative permittivity values showed improvement by decreasing for 1%, 2% and 5% concentration levels when it is compared to pure TPU. The lower dielectric constants of solid insulating materials provide an advantage in terms of insulation performance. In the experiments, it was observed that the dielectric constant did not decrease as expected for the 1 nm and 5 μm particle size application, however dielectric behavior improved by generally decreasing and having less value when mica with 10 nm particle size doped to TPU.

For all particle sizes and concentrations of mica a lower dc conductivity was observed than that of the pure polyurethane sample. The experimental results are given in Figure 7. For all

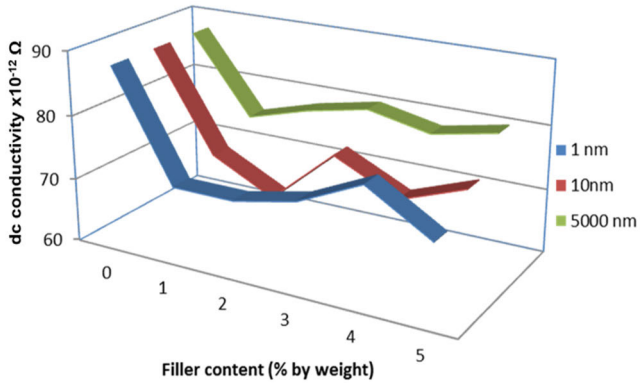

FIGURE 7. Dependence of mica content on dc conductivity in TPU composite sample.

micro size filler concentration levels measured dc conductivity values are greater than that for 1 nm and 10 nm particle size concentration levels. For nanometer size filler particles measured dc conductivity values are similar to each other and lower than pure TPU sample.

DC conductivity was generally measured lower values with doped condition than pure TPU state. This indicates that the insulation resistance of the material has increased. When the DC conductivity of the doped TPU material is examined, the insulation performance is observed in the most positive sense when mica is added with a particle size of 1 nm. It has also been clearly demonstrated that micro-sized additives have the worst performance in DC conductivity measurements.

The effects of particle-size mica on the loss-factor of polyurethane composites are summarized in Figure 8. Using 1 nm and 10 nm mica particle in TPU samples resulted in a decrease in loss factor of the composite. Further increase in the filler content lowers the loss factor slightly. However, more than 4 % of 1 nm and 3 % of 10 nm particle size filler content resulted in an increase in the loss factor when compared with the lower concentration levels rather than those. This behavior can be attributed to the voids and possible

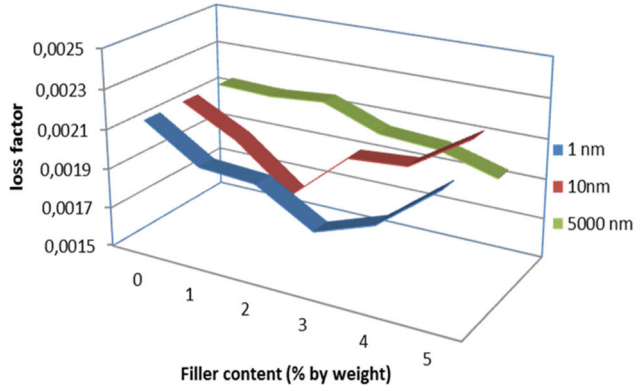

FIGURE 8. Dependence of mica content on loss factor in TPU composite sample.

dispersion of the nano size filler in the sample. For 5 μm particle size of mica, the measured loss factor values were almost the same as pure polyurethane sample, but increasing the concentration level 3% and above measured loss factor values were lower than that of the pure polyurethane. For 5% concentration level measured loss factor value for micrometer size filler content is lower than 1 nm and 10 nm particle size levels.

The low loss factor of the material means that the dielectric properties of the insulator are superior. When mica with 1 nm particle size is doped on pure TPU, the best dielectric performance loss factor was found at all doping ratios except 5% concentration level.

The breakdown voltages of polyurethane-mica composite samples are presented in Figure 9. From this experimental study it was noted that the composite which were prepared with micrometer size particles at least double of the value measured for pure TPU sample. The peak value is measured as 25 kV /mm for 1% mica added TPU composites. For other concentration levels measured breakdown voltages resembles each other and doubles the pure polyurethane sample. For 1 nm size particles revealed breakdown voltages higher than those of with polyurethane samples with 10 nm size mica particles except 2 % concentration level. For micron size mica addition to thermoplastic polyurethane resulted 2.5 times higher breakdown voltages than pure TPU. The highest breakdown voltage level is measured as 2.45×10^5 V/cm at 1% mica concentration level and the lowest breakdown voltage level is measured as 1.89×10^5 V/cm at 5 % mica concentration level. Both breakdown voltage levels were higher than any concentration level recorded for 1 nm and 10 nm particle size mica addition.

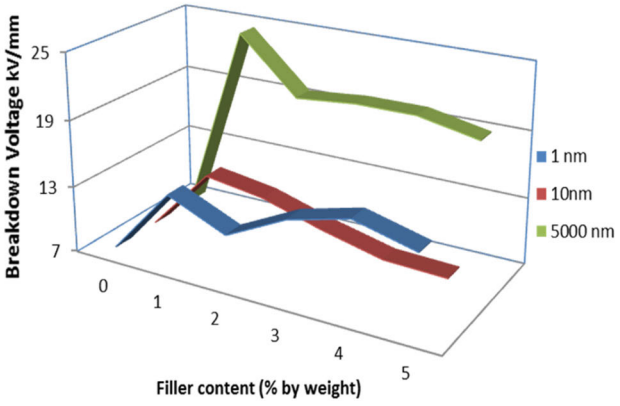

FIGURE 9. Dependence of mica content on breakdown voltage in TPU composite sample.

Also, it was observed that during the breakdown tests, the breakdown usually occurred in regions closer to the edges of the electrodes, which was similar to the observations of other investigators with pure polyurethane samples [7].

In Table 1, Table 2 and Table 3 measured dielectric parameters for 1 nm, 10 nm and 5 μm particle size mica added TPU composite samples were summarized.

TABLE 1. Electrical properties of TPU mixed with various concentrations of mica 1 nm particle size.

Filler Content (% by weight)	Relative Permittivity	DC Conductivity ($x10^{-12}$ 1/Ω)	Loss Factor	Breakdown Voltage ($x10^5$ V/cm)
0	12.25	87.774	0.002147	0.74
1	10.75	70.672	0.001970	1.35
2	10.88	70.659	0.001951	1.12
3	12.21	72.734	0.001785	1.39
4	12.28	77.362	0.001887	1.53
5	10.09	71.308	0.002117	1.39

TABLE 2. Electrical properties of TPU mixed with various concentrations of mica 10 nm particle size.

Filler Content (% by weight)	Relative Permittivity	DC Conductivity ($x10^{-12}$ 1/Ω)	Loss Factor	Breakdown Voltage ($x10^5$ V/cm)
0	12.25	87.774	0.002147	0.74
1	10.83	72.359	0.002002	1.31
2	11.35	67.494	0.001782	1.23
3	11.24	76.203	0.002031	1.07
4	10.43	71.460	0.002053	0.94
5	10.04	75.137	0.002242	0.92

TABLE 3. Electrical properties of TPU mixed with various concentrations of mica 5 μm particle size.

Filler Content (% by weight)	Relative Permittivity	DC Conductivity ($x10^{-12}$ 1/Ω)	Loss Factor	Breakdown Voltage ($x10^5$ V/cm)
0	12.25	87.774	0.002147	0.74
1	10.58	75.439	0.002136	2.45
2	10.85	78.206	0.002159	1.95
3	11.71	80.162	0.002051	2.00
4	11.52	78.094	0.002031	2.00
5	12.92	80.069	0.001947	1.89

V. SEM ANALYSIS

Polyurethane has a more porous in their inherent character than other polymers. Therefore, in this study, as it is mentioned in the ''Preparation Of TPU/Mica Nanocomposites'' section of mica added to our base/neat material, which has the character of this hollow structure, it was mixed at high speed in a vacuum environment to ensure an equal and uniform distribution within the structure as much as possible. In this way, mica was distributed homogeneously in the PO spaces and the most accurate experimental data was obtained. This situation has been tried to be shown as much as possible in the SEM photos using space propagation. Upon the lateral surface of the pure TPU samples, it is clear that the void distribution is not proper. There are few big voids and numerous small voids are all through the sample (Figure 10.a). After electrical breakdown analysis, a black smoke area is observed. When this area is fractured and enlarged 150 times, the explosion in the void can be seen clearly (Figure 10.b). The picture taken from the fractured area (Figure 10.c) and nearby this area (Figure 10.d) shows no difference.

The SEM pictures at the filler content of 1%, 3%, 5% and 10% added TPU composites for 1 nm mica particle size are shown in Figure 11. In this figure the letter (a), (b) and (c) indicates that the sample surface is enlarged 35 times, 1000 times and 5000 times respectively. After electrical breakdown occurred, lateral surface of TPU samples when the filler level is 1 % with 1 nm mica particle size is illustrated in Figure 11 (1a). As the related of this figure is detailed examined, it is clearly seen that the voids all through the sample get smaller compared to pure TPU sample. The fractured area (void) which occurred after electrical breakdown is enlarged 1000 times Figure 11 (1b) and 5000 times Figure 11 (1c). The picture taken upon the fractured area shows that there are numerous pores through the surface and they are discrete when it is compared with pure TPU sample.

When it comes to examine of TPU samples which are filled with the content of 3 % for 1 nm particle size of mica, the lateral surface situation of this type of specimen after the electrical breakdown is shown in Figure 11 (3a), (3b) and (3c). Here the voids all through the sample get smaller compared to pure TPU sample Figure 11 (3a). The fractured area which occurred after electrical breakdown is enlarged 1000 times in Figure 11 (3b) and 5000 times in Figure 11 (3c). From these two pictures it can be clearly stated that the pores on the fractured surface are masked with a glass like structure.

For 5 % filler content of 1 nm mica added TPU samples, voids all through the sample get smaller compared to pure TPU sample. However, the diameter of the voids is bigger than filler content of 1% with 1 nm mica added or filler content of 3% with 1 nm mica added polyurethane samples Figure 11 (5a). In Figure 11 (5b), the bridge like area between the two fractured areas is enlarged 1000 times, voids diameters are bigger than filler content of 3% with 1 nm mica added samples Figure 11 (3b) and filler content of 1% with 1 nm mica added samples Figure 11 (1b). Enlarging this area for 5000 times shows the glassy like structure as given in Figure 11 (5b) after the electrical breakdown test. This is attributed to the increase in mica concentration through the TPU composite.

Figure 11 (10a) gives the lateral surface of the 10 % 1 nm mica added TPU samples after electrical breakdown. With this concentration the voids in the polyurethane composite sample are similar to pure TPU sample, visible voids are clear in Figure 11 (10a). In (10b) and (10c) the void occurred after electrical breakdown is enlarged for 1000 times and 5000 times respectively. In this fractured area the spongy structure which is seen in (5b) for filler content of 5% with 1nm mica added samples is not seen but the glassy like structure upon the pores is thicker than the other concentrations for 1nm mica filler addition.

In Figure 12, filler content of 1%, 3%, 5% and 10% with 10 nm mica particle size added TPU composite's

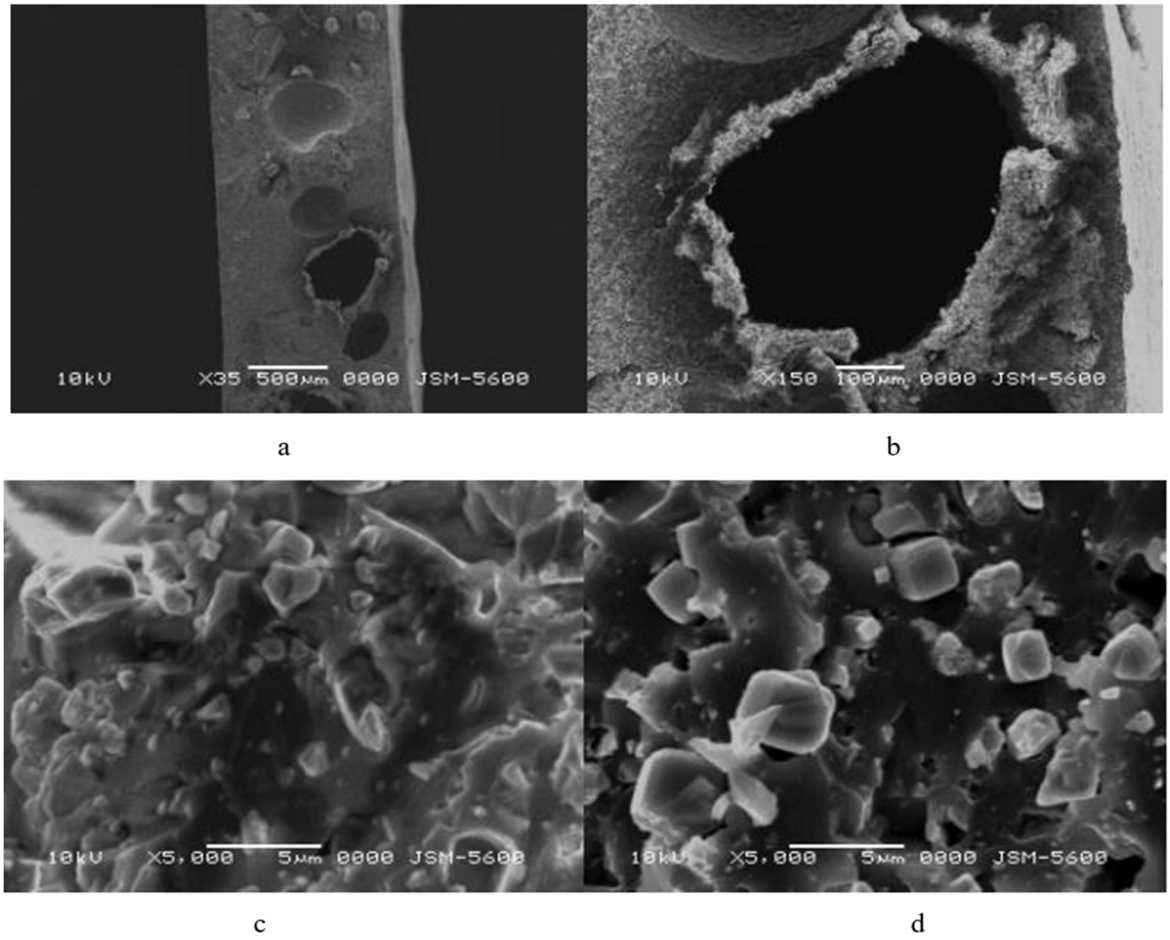

FIGURE 10. SEM pictures for pure Thermoplastic Polyurethane (TPU) samples lateral picture of the fractured area after breakdown analysis. (a) 35 times enlarged, (b) 150 times enlarged, (c) 5000 times enlarged near by the fractured area, (d) 5000 times enlarged upon the fractured area.

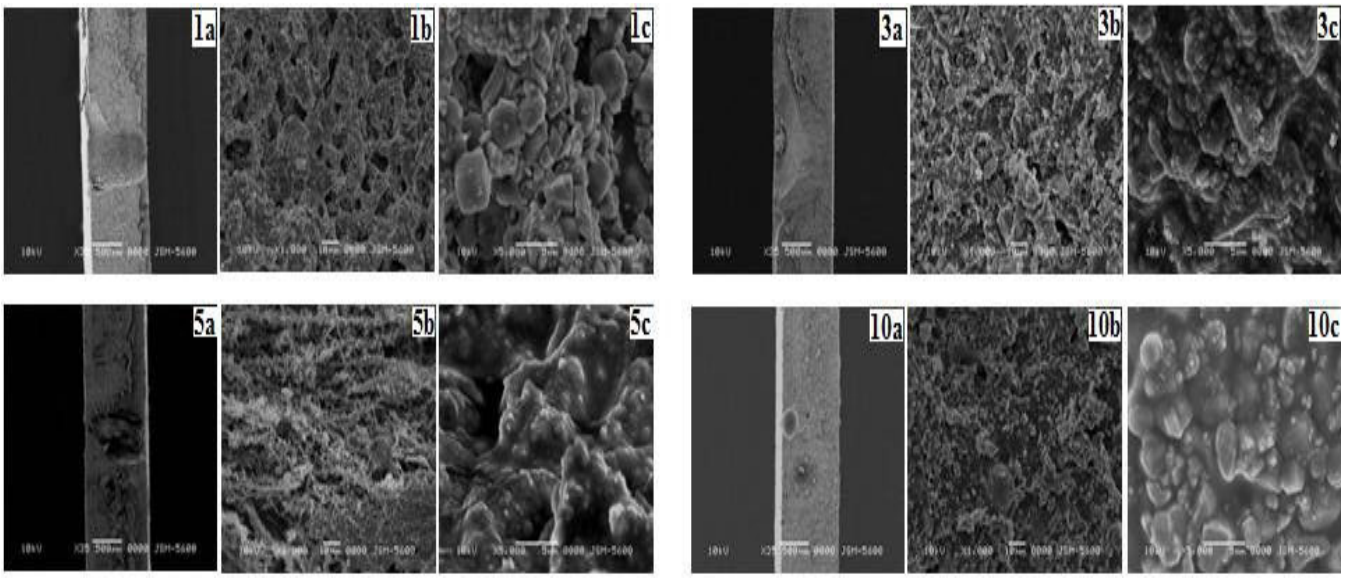

FIGURE 11. SEM pictures for 1 %, 3%, 5% and 10 %, 1 nm mica added TPU samples, lateral picture of the fractured area after breakdown analysis. (a) 35 times enlarged, (b) 1000 times enlarged and (c) 5000 times enlarged.

SEM pictures were summarized. In this figure the letter (a), (b) and (c) indicates that the sample surface is enlarged 50 times, 500 times and 1000 times respectively. Here the enlargement scale has to be lowered to make the difference in void diameters and surface mutation clearer than 1 nm mica added samples. For 10 nm mica added TPU samples

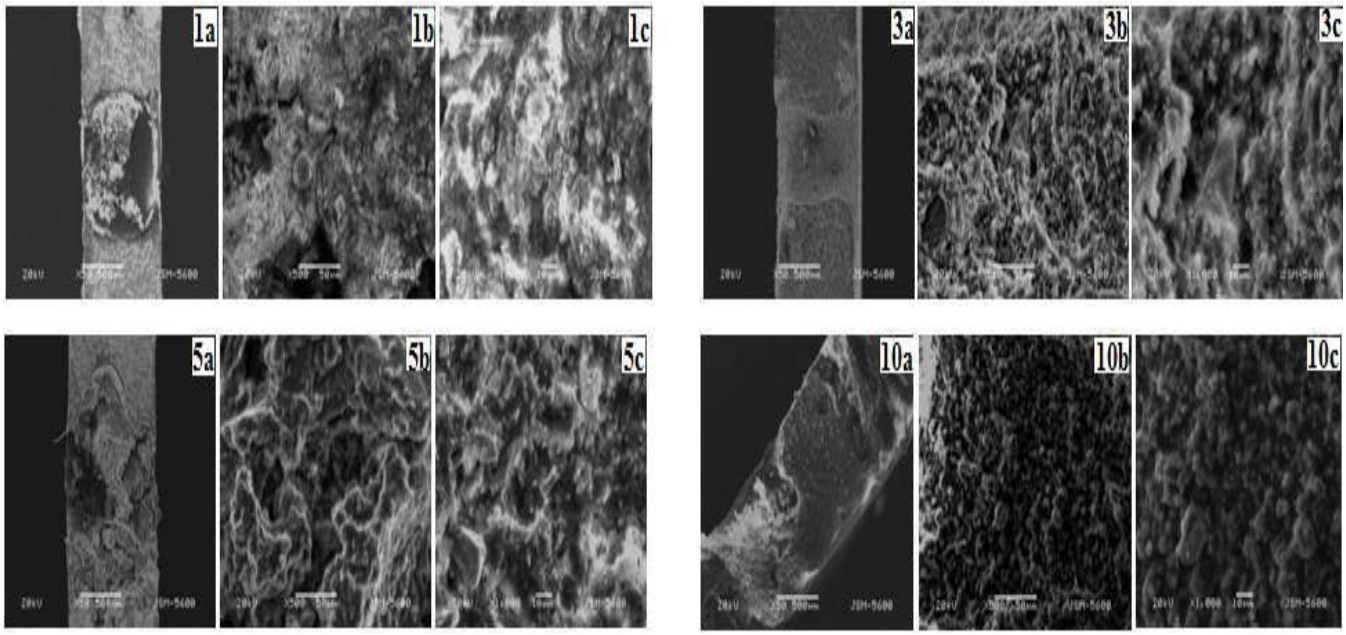

FIGURE 12. SEM pictures for 1%, 3%, 5% and 10% 10 nm mica added TPU samples, lateral picture of the fractured area after breakdown analysis. (a) 50 times enlarged, (b) 500 times enlarged and (c) 1000 times enlarged.

increasing the filler concentration in the composite let the TPU sample density higher (Figure 12 (1a) and (3a)) and lower the void size (Figure 12 (1b) and (3b)) for 1% and 3% filler content of mica added samples. However different from the 1 nm particle size mica addition the number of the voids through the sample is very high compared to pure polyurethane sample. Increasing the filler concentration in TPU composites to 5% and 10 % levels increases the void number and diameter dramatically as it is clearly seen in Figure 12 (5a) and (10a).

VI. CONCLUSION

It is known that the nano additive of mica improves the mechanical and physical properties of polymers and there are many studies on this subject. However, detailed information about how it affects the electrical properties is analyzed and explained with experimental results in this study. Thus, an important contribution has been made to the literature and the effect of mica on TPU at nanoscale has been made. The electrical properties of the additive have been shown to improve the effect. In this study, it has been tried to show that how addition of mica mineral to pure thermoplastic polyurethane sample at some different percentages enhances the dielectric properties of TPU by indicating the test results obtained from electrical tests. It was observed that the relative permittivity of TPU composites were the lowest for 1 nm and 10 nm particle size with 5% mica content and 1% mica content for 5 μm particle size. Whereas, the lowest conductivity of the composite was found to be with 2% mica content of size 1 nm and 10 nm and 1% mica content of size 5 μm.

The loss factor of the composite, on the other hand, was the lowest with 3% mica content for 1 nm particle size, 2 % mica content for 10 nm particle size and 1 % mica content for 5 μm particle size.

When the DC conductivity of the doped TPU material is examined, the insulation performance is observed in the most positive sense when mica is added with a particle size of 1 nm.

The breakdown voltages at 60 Hz were found to be the lowest for pure TPU. The peak value is measured as 25 kV /mm for 1% mica added TPU composites. For other concentration levels measured breakdown voltages resembles each other and doubles the pure polyurethane sample. The highest breakdown voltages were measured at any concentration level for micron size mica added samples rather than nano size mica added composites. The micron size mica added samples measured breakdown voltages were at least 2.5 time higher than the pure TPU. Although measured breakdown voltages for nanometer size mica added composite samples higher than the pure TPU but not as high as the 5 μm size mica added thermoplastic polyurethane. The breakdown voltages taken from the experiments for nano size mica added samples 1 nm particle size mica addition to polyurethane shows a better performance than 10 nm particle size mica content for any concentration level. However, addition of mica content to thermoplastic polyurethane for any concentration level and any particle size improves the electrical properties of pure TPU.

Therefore, from the experimental results it can be clearly indicated that usage of mica in thermoplastic polyurethane to improve the electrical properties is an appropriate choice.

Because, the price of mica has more advantage when compared with other additives used in electrical insulation materials such as Aluminum trihydrate etc. As a consequence of this experimental study, it is also shown that micro size mica addition to polyurethane indicated a better performance than nano size mica addition.

In the evaluation of a dielectric material, the parameters measured experimentally in this study should be considered together. It is seen that an evaluation based on a single parameter is insufficient. Where and under what conditions the material will be used is also an important factor when evaluating the parameters. In this respect, the evaluations made here are the results observed under ideal conditions in the laboratory environment. The thickness of the material used in the experiments was 1 mm and the evaluations were made according to this material.

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