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Research Article

Dependence of electrical resistance of polypropylene–mineral filler composites on temperature and ionizing radiation

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Abstract

The article studies the changes in the electrical properties of composite materials based on polypropylene (PP) modified with varying amounts of α-Al_2O_3 and mica under the influence of temperature and ionizing radiation. In the studies, along with the original polypropylene, composites containing 20 and 40 wt.% α-Al_2O_3, as well as 20 and 40 wt.% mica, were compared. The temperature dependence of the specific resistance was investigated in the temperature range of 298÷480 K in the coordinates lgρ=f(T), and the changes in the electrical resistance after irradiation of the samples at doses of 50 kGy and 80 kGy were analyzed. It was found that in all the studied samples, an increase in temperature is accompanied by a decrease in specific resistance. This behavior is associated with the thermal activation of charge carriers in the polymer matrix and the strengthening of the temperature dependence of electrical conductivity. The inclusion of mineral fillers significantly increases the sensitivity of the electrical resistance of composites to temperature changes. In particular, in samples modified with mica, a more intensive decrease in resistivity is observed as the temperature increases. Increasing the radiation dose causes additional changes in the electrical properties of the composites, which can be explained by radiation-induced structural changes and the formation of local energy levels at the polymer-filler interface.

Keywords: polypropylene, α-Al_2O_3, mica, polymer composite, resistivity, electrical conductivity, temperature dependence, ionizing radiation, radiation modification

1. Introduction

Polymer composite materials are widely used in modern electrical engineering, radio engineering, the cable industry, instrument manufacturing, and the development of radiation-resistant structural materials. The functional properties of these materials are determined not only by the nature of the polymer matrix but also by the type, concentration, and dispersity of the mineral fillers incorporated into it, as well as by the polymer–filler interfacial interaction [1], [2], [3].

Polypropylene (PP) is a thermoplastic polymer characterized by high electrical resistivity, low dielectric loss, reasonably high mechanical strength, and good processability. However, changes at the molecular level can occur in the structure of PP under the influence of rising temperatures and ionizing radiation [4], [5], [6], [7]. These changes affect the movement of charge carriers, the distribution of local energy levels, and, consequently, the electrical conductivity of the material.

The addition of mineral fillers to a polymer enables the targeted modification of the composite's electrical properties. α-Al_2O_3 is of particular interest as an oxide material with high electrical resistance, while mica is notable as a mineral filler distinguished by its layered structure and superior thermal and electrical insulation properties [8], [9], [10].

In such systems, the transport of electric charge depends not only on processes occurring within the bulk of the polymer matrix but also on those taking place at the interface between the polymer and filler phases. Therefore, studying the electrical resistance of the composite under temperature and irradiation conditions is of great importance for evaluating its structure and functional properties [11]. The aim of this work is to determine the effect of mineral filler concentration and ionizing radiation dose on the temperature dependence of the electrical resistivity of PP/α-Al_2O_3 and PP/mica composites.

2. Experimental Procedure

Composites based on a polypropylene matrix were used as the object of study. α-Al_2O_3 and mica were used as mineral fillers in the preparation of the composites [12].

The following compositions were considered for comparison:

- ilkin PP; initial PP
- PP + 20% α-Al_2O_3;
- PP + 40% α-Al_2O_3;
- PP + 20% mica;
- PP + 40% mica.

The electrical properties of the samples were investigated under various temperature conditions. As shown in the graphs, the temperature range was approximately 298÷480 K. The decimal logarithm of resistivity for evaluating the temperature dependence of electrical resistance:

$$lg\rho = f(T)$$

It is presented in the form of. Here, ρ is the electrical resistivity (Ω·m), and T is the absolute temperature (K). Radiation doses of 50 and 80 kGy were used to determine the effect of exposing the samples to ionizing radiation. The obtained results were compared with the initial PP sample, and the effect of the type and concentration of the mineral filler was evaluated separately [13-14].

Analysis of the results:

Electrical resistance of PP/α-Al_2O_3 and PP/mica composites after 50 kGy irradiation.

The lgρ=f(T) dependence for samples irradiated at a dose of 50 kGy is shown in Figure 1.

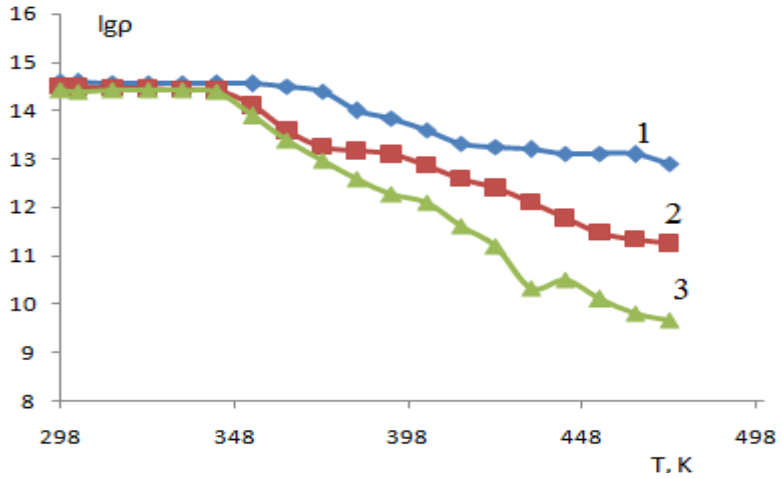


Figure 1. Temperature dependence of resistivity after 50 kGy irradiation, lgρ=f(T): 1 – pristine PP; 2 – PP + 20% α-Al_2O_3; 3 – PP + 20% mica.

As can be seen from Figure 1, lgρ decreases with increasing temperature in all the samples studied. However, the rate of this decrease varies depending on the composition of the samples. In the initial PP sample, the decrease in lgρ as the temperature rises from 298 K to approximately 480 K is relatively slight. In the initial

sample, the retention of a high resistivity value can be attributed to the preservation of the polypropylene matrix's high electrical insulation capability.

When 20% α-Al_2O_3 is added to PP, the temperature dependence of the resistivity becomes more pronounced. As the temperature rises, log ρ decreases from a level of approximately 14,4÷14,5 to 11,2÷11,3.

In the composite with 20% mica added, however, this change is more pronounced. As the temperature rises, lgρ decreases from a level of approximately 14,4 to a level of 9,6÷9,7. Thus, at the same filler concentration, the mica-modified PP sample exhibits higher sensitivity in terms of the change in specific resistance in response to temperature [15], [16].

This result can be attributed to the thermal activation of charge carriers within the polymer matrix and at the polymer–mineral interface. As the temperature rises, the increase in the kinetic energy of charge carriers facilitates their passage over local potential barriers; consequently, electrical conductivity increases while resistivity decreases.

Effect of α-Al_2O_3 concentration

To more clearly evaluate the effect of the α-Al_2O_3 concentration, the results for the composite containing 40% α-Al_2O_3 are presented in Figure 2.

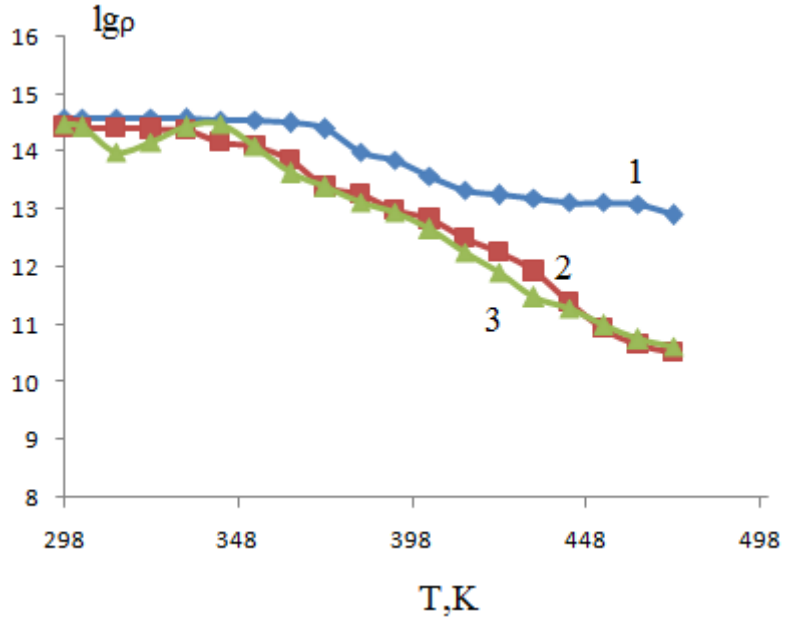


Figure 2. Temperature dependence of resistivity, lgρ=f(T), after 50 kGy irradiation: 1 – pristine PP; 2 – PP + 40% α-Al_2O_3; 3 – PP + 20% mica.

Figure 2 compares the temperature dependencies of virgin PP and composites containing 40% α-Al_2O_3 and 20% mica. With the incorporation of 40% α-Al_2O_3, the decrease in resistivity with rising temperature becomes more pronounced compared to the sample containing 20% α-Al_2O_3. This phenomenon can be explained by the expansion of the polymer–filler interfacial area resulting from the increased filler concentration, and by the formation of additional local energy levels within the composite's microstructure that influence the movement of charge carriers.

As is known, α-Al_2O_3 is a material with high electrical resistance. It is impossible to explain the effect of such a material—characterized by high electrical resistance—solely based on the principle of "increasing interphase conductivity." The principle of "enhancing interphase conductivity" in composites relates to the processes occurring within the system comprising the polymer matrix, mineral particles, and the interphase boundaries between them. Thus, it is based on the interaction at their interphase boundary [17]. Therefore, increasing the number of α-Al_2O_3 particles alters the temperature dependence of the new composite's electrical properties. As a result, a change in the temperature dependence can lead to an increase in the material's temperature sensitivity.

Processes occurring in the electrical properties of composites under 80 kGy irradiation

The results obtained for the composite after an irradiation dose of 80 kGy are shown graphically in Figure 3.

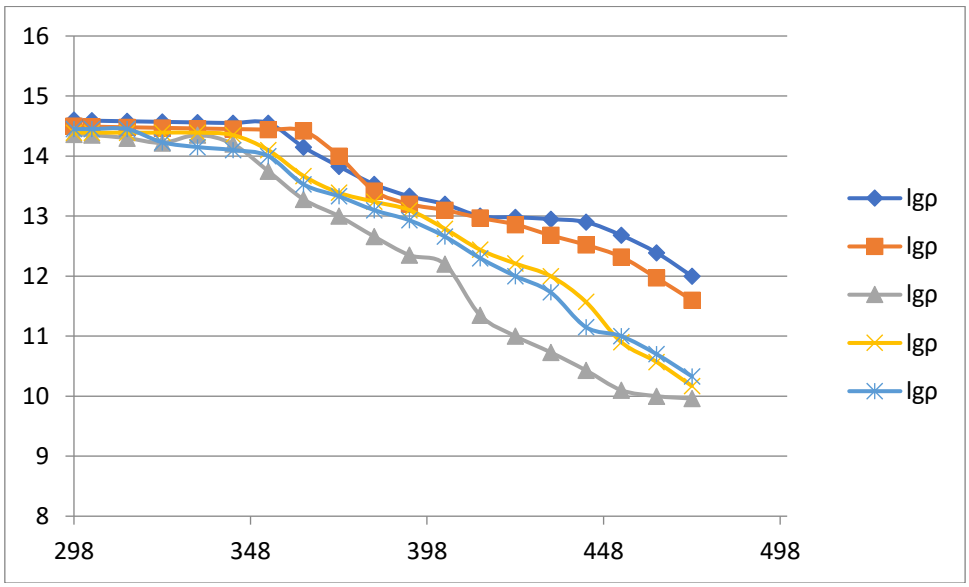


Figure 3. Temperature dependence of resistivity after 80 kGy irradiation, lgρ=f(T): 1 – pristine PP; 2 – PP + 20% α-Al_2O_3; 3 – PP + 20% mica; 4 – PP + 40% α-Al_2O_3; 5 – PP + 40% mica.

The temperature dependence of the electrical resistance of five composite samples with different compositions is shown in Figure 3. At the same time, the temperature dependence of the composite samples' electrical resistance is presented in the form of a comparative graph. The initial polypropylene sample exhibits higher lgρ values across all specified temperature ranges. Within the specified temperature range (450–470 K), the resistivity of polypropylene remains around 13 units. The obtained results confirm that polypropylene possesses high electrical insulation properties. After the incorporation of nanoparticles, the resistivity of the resulting composites decreases more rapidly with increasing temperature. A sudden increase in the specific resistance of the composite was observed in the composite containing 20% mica. In the samples examined, the value of resistivity approaches the level of approximately 10 units at very high temperatures. However, in composites containing 40% α-Al_2O_3 and 40% mica, a significant decrease in resistivity with increasing temperature is observed. Thus, by varying the concentration and composition of the nanoparticles, it is possible to significantly influence the temperature-electrical characteristics of the resulting composite [18].

The obtained composite sample was subsequently subjected to a radiation dose of 80 kGy. The results obtained and the changes observed in the graphs aroused considerable interest. So, it turns out that radiation can have a beneficial effect on the molecular structure of the polymer. Thus, it confirms the possibility of the formation of radical centers, structural defects, and new local energy states in the chain of the high-molecular-weight polymer as a result of 80 kGy of radioactive radiation. The radical centers that have formed can participate in the capture and release of charge carriers.

Now, let us look at the comparison of all composite systems after 50 kGy irradiation

The temperature dependencies of all the investigated composites mentioned above were determined following 50 kGy irradiation and are presented graphically in Figure 4.

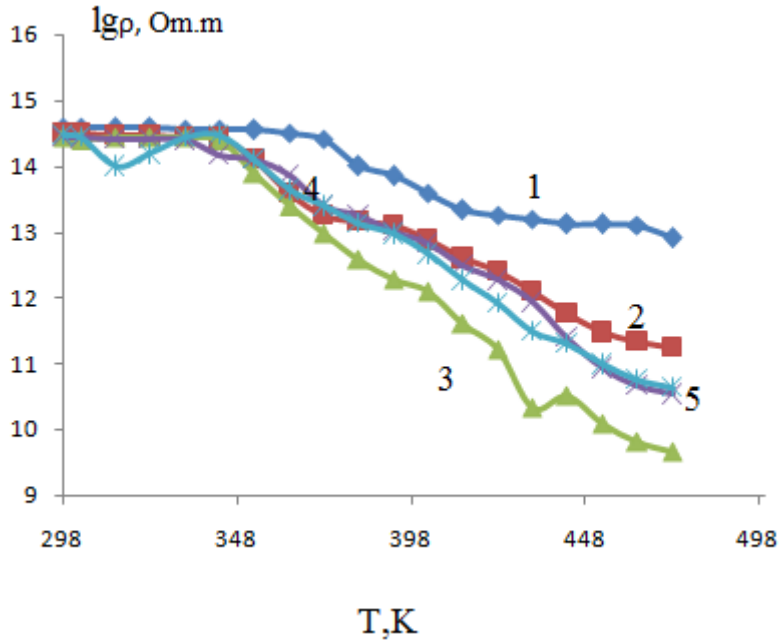


Figure 4. Temperature dependence of resistivity after 50 kGy irradiation, lgρ=f(T): 1 – pristine PP; 2 – PP + 20% α-Al_2O_3; 3 – PP + 20% mica; 4 – PP + 40% α-Al_2O_3; 5 – PP + 40% mica.

Figure 4 shows that the general trend for all samples is a decrease in resistivity with rising temperature. At the same time, the slope of the curves depends significantly on the composition of the composite. The initial PP maintains the highest electrical resistance. In this sample, lgρ gradually decreases as the temperature rises, reaching a value of approximately 13 units in the high-temperature range. The addition of α-Al_2O_3 and mica intensifies the effect of rising temperature on electrical resistance. In particular, the curve for the composite containing 20% mica shows a steeper downward trend.

The graphs also show that, in the high-temperature range, the resistivity values of the filled composites tend to converge. This can be attributed to the dominance of thermal activation processes involving charge carriers in composites of varying compositions under the influence of temperature.

Physical explanation of temperature dependence.

A thermally activated conduction model can be applied to analyze the temperature dependence of specific resistance in polymer composites:

$$\rho = \rho_0 \exp\left(\frac{E_a}{kT}\right),$$

Here, ρ_0 is a constant depending on the material's structure, E_a is the effective activation energy, k is the Boltzmann constant, and T is the absolute temperature.
As a result of taking the logarithm of this expression:

$$\ln \rho = \ln \rho_0 + \frac{E_a}{kT}$$

or for the common logarithm:

$$lg\rho = lg\rho_0 + \frac{E_a}{2.303kT}$$

is obtained.

This relationship indicates that as the thermal activation of charge carriers intensifies, the rise in temperature leads to a decrease in resistivity. In the investigated PP-based composites, the polymer–filler interface is presumed to exert a significant influence on this process in addition to other factors. The generation

of local electric potentials on the surface of mineral particles and in the zone of their contact with the polymer matrix can alter the trajectories of charge carriers.

Combined effect of radiation and filler concentration

An important feature of the obtained results is that the electrical properties of the composite are determined not only by temperature but also by the radiation dose and the concentration of the mineral filler.

Under the influence of ionizing radiation, the following structural processes may occur in PP:

1. formation of radical centers in polymer macromolecules;
2. development of chain scission or cross-linking processes;
3. formation of local energy levels;
4. formation of charge-trapping centers at the polymer–filler interface;
5. Change in the movement mechanism of the load carriers.

The direction and intensity of these processes depend on both the radiation dose and the structure of the composite. The addition of a mineral filler introduces additional interphase boundaries into the system. Therefore, the change in electrical properties in the samples with 20% and 40% filler content differs significantly from that of the virgin PP.

In mica-based composites specifically, the more rapid decrease of lgρ with rising temperature can be attributed to the influence of the material's layered structure and the local electric fields generated at the polymer–mineral interface on charge transport processes. However, to precisely confirm this mechanism, it is advisable to employ dielectric spectroscopy, thermally stimulated current measurements, or a separate calculation of the activation energy.

3. Conclusion

The following key results were obtained during the studies mentioned in the article:

First of all, it should be noted that for each of the PP, PP/α-Al_2O_3, and PP/mica composites, the value of specific resistance decreases as the temperature rises. This indicates that as the temperature rises, there is a significant increase in the number of charge carriers activated by the temperature. For this indicator, the value of the specific resistance remains constant in the initial PP sample, regardless of the increase in the temperature range. As is known, the electrical insulation properties of polypropylene material are very high. However, the addition of α-Al_2O_3 to this material alters the temperature dependence of the electrical resistivity in the new composite. At the end of the study, we increased the filler concentration from 20% to 40%. Increasing the concentration reduces the value of lgρ, as does increasing the temperature.

Unlike α-Al_2O_3, in composite samples containing mica-based filler, the value of resistivity changes more sharply as the temperature decreases. This characteristic can be attributed to the layered structure of the mica particles and the charge transport processes occurring at the polymer–filler interface.

Irradiation doses of 50 kGy and 80 kGy have a noticeable effect on the electrical properties of the composites. The effect of irradiation may be attributed to the formation of structural defects and local energy states within the polymer matrix.

The obtained results indicate that the electrical resistance of α-Al_2O_3- and mica-filled PP composites is a function of their composition, temperature, and radiation dose. Among the systems studied, pristine PP retains its high electrical insulation capability better, whereas mineral-filled composites exhibit greater electrical sensitivity to temperature changes. To control the electrical properties of PP/mineral filler systems, not only the type of filler but also the filler concentration, radiation dose, and temperature regime must be considered together. Research results indicate that the temperature dispersion of the electrical resistance of PP-based composites is determined by the interaction of localized energy states formed at the polymer-mineral interface, alongside thermally activated charge transport processes within the polymer matrix. The incorporation of α-Al_2O_3 and mica fillers alters the microstructure of the composite, thereby affecting the temperature coefficient of electrical resistance. Irradiation further complicates this structure-functional relationship, creating

conditions for the formation of new charge-trapping and charge-transport centers within the polymer's molecular structure.

In this regard, PP/α-Al_2O_3 and PP/mica composites can be considered promising systems for the development of functional insulating materials suitable for use under conditions where electrical and radiation effects coexist.

Author Contributions

The author contributed to the conception, design, analysis, interpretation, and preparation of the manuscript and approved the final version.

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Conflicts of Interest

The author declares no conflict of interest.

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References

[1] Liu W, Cheng L, Li S. Review of electrical properties for polypropylene based nanocomposite. Composites communications. 2018 Dec 1;10:221-5. https://doi.org/10.1016/j.coco.2018.10.007

[2] Vila F, Dhima P, Mandija F. The influence of temperature on the electrical resistivity of the cellular polypropylene and the effect of activation energy. SpringerPlus. 2013 Sep 18;2(1):472. https://doi.org/10.1186/2193-1801-2-472

[3] Chand N., Sharma J. Effect of nanoalumina particles on dielectric behavior of polypropylene // *Journal of Nanostructured Polymers and Nanocomposites*. – 2011. – Vol. 7, No. 4.

[4] Farzaneh S, Tcharkhtchi A. Viscoelastic properties of polypropylene reinforced with mica in Tα and Tαc transition zones. International Journal of Polymer Science. 2011;2011(1):427095. https://doi.org/10.1155/2011/427095

[5] Mittal P, Naresh S, Luthra P, Singh A, Dhaliwal JS, Kapur GS. Polypropylene composites reinforced with hybrid inorganic fillers: Morphological, mechanical, and rheological properties. Journal of Thermoplastic Composite Materials. 2019 Jun;32(6):848-64 https://doi.org/10.1177/0892705718785674

[6] Xie Z, Liu D, Xiao Y, Wang K, Zhang Q, Wu K, Fu Q. The effect of filler permittivity on the dielectric properties of polymer-based composites. Composites Science and Technology. 2022 May 3;222:109342. https://doi.org/10.1016/j.compscitech.2022.109342

[7] Abdel-Hamid HM. Effect of electron beam irradiation on polypropylene films—dielectric and FT-IR studies. Solid-state electronics. 2005 Jul 1;49(7):1163-7. https://doi.org/10.1016/j.sse.2005.03.025

[8] Suljovrujic E, Stojanovic Z, Dudic D, Milicevic D. Radiation, thermo-oxidative and storage induced changes in microstructure, crystallinity and dielectric properties of (un) oriented isotactic polypropylene. Polymer Degradation and Stability. 2021 Jun 1;188:109564. https://doi.org/10.1016/j.polymdegradstab.2021.109564

[9] Suljovrujic E, Trifunovic S, Milicevic D. The influence of gamma radiation on the dielectric relaxation behaviour of isotactic polypropylene: The α relaxation. Polymer degradation and stability. 2010 Feb 1;95(2):164-71. https://doi.org/10.1016/j.polymdegradstab.2009.11.034

[10] Suljovrujic E. Gel production, oxidative degradation and dielectric properties of isotactic polypropylene irradiated under various atmospheres. Polymer degradation and stability. 2009 Apr 1;94(4):521-6. https://doi.org/10.1016/j.polymdegradstab.2009.01.029
[11] Mathakari NL, Bhoraskar VN, Dhole SD. MeV energy electron beam induced damage in isotactic polypropylene. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms. 2008 Jun 1;266(12-13):3075-80. https://doi.org/10.1016/j.nimb.2008.03.165
[12] Liu B, Gao Y, Guo C, Li J, Chen Y, Gao J, Du B. Effect of gamma-ray irradiation on electrical conductivity of polypropylene composite for nuclear cable insulation. High Voltage. 2025 Apr;10(2):470-9. https://doi.org/10.1049/hve2.70002
[13] Suraci SV, Fabiani D. Radiation-Induced Degradation in Polymeric Materials: Alterations in Physical–Chemical Properties and Their Effects on Electrical Performance of Insulation Systems. High Voltage. 2026 Feb;11(1):150-69. https://doi.org/10.1049/hve2.70071
[14] Zhang L, Chen Y, Wang Z, Lu Z, Xing Z, Guo S, Du H, Du BX, Xiao M. Long-Term Thermal Stability of Electron-Beam-Irradiation-Crosslinked Polypropylene Films for Power Capacitors. Electrical Materials and Applications. 2026 Jan;3(1):e70031. https://doi.org/10.1049/ema3.70031
[15] Bao Z, Du X, Ding S, Chen J, Dai Z, Liu C, Wang Y, Yin Y, Li X. Improved working temperature and capacitive energy density of biaxially oriented polypropylene films with alumina coating layers. ACS Applied Energy Materials. 2022 Mar 2;5(3):3119-28. https://doi.org/10.1021/acsaem.1c03735
[16] Lee CY, Chang CW. Dielectric constant enhancement with low dielectric loss growth in graphene oxide/mica/polypropylene composites. Journal of composites science. 2021 Feb 8;5(2):52. https://doi.org/10.3390/jcs5020052
[17] Chen H, Wang Y, Zhang W, Nan Y, Yue X, Zhang Y, Fan H. Effect of Al2O3 and BN compounding on thermal and mechanical properties of PP composites. Materials Today Communications. 2023 Dec 1;37:107300. https://doi.org/10.1016/j.mtcomm.2023.107300
[18] Li SK, Li WP, Shi XN. Simulation and optimization of thermal conductivity and dielectric properties of alumina/polypropylene composites. Insulating Materials. 2025;58(1):20-8.