ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 18 № 1, 01006(5cc) (2026)

REGULAR ARTICLE

The Electromagnetic Shielding Effectiveness of Polypropylene Nanocomposite Filled with Graphene

Mohammed Al-Tweissi[1,*], Omer Hussein[2]

[1] Physics Department, Collage of Science, Al–Hussein Bin Talal University, P.O. Box 20, Ma'an, Jordan
[2] Physics Department, The University of Jordan, 11942 Amman, Jordan

(Received 14 October 2025; revised manuscript received 19 February 2026; published online 25 February 2026)

The composite samples studied in this work were Polypropylene/graphene nanocomposites prepared with different graphene nanofiller concentrations (2, 6, 10, 15 and 20 wt. %). All samples were prepared using the melt mixing method. followed by compression molding to form the test specimens. The electromagnetic interference (EMI) was investigated for the prepared sheets with different graphene concentrations at microwave frequencies [8-12 GHz], it was found that the Shielding effectiveness (SE) increases with both the graphene content and the applied microwave frequency. The shielding effectiveness (SE) enhances to about 35 dB. These results highlight the potential of these nanocomposites for applications in electronic packaging and other areas requiring effective EMI protection.

Keywords: Polypropylene, Graphene, Melt mixing method, The electromagnetic interference (EMI), The shielding effectiveness (SE).

DOI: 10.21272/jnep.18(1).01006 PACS number: 28.41.Qb

1. INTRODUCTION

Nanocomposite materials are multi-constituent combinations of nano-dimensional phases with distinct differences in structure, chemistry, and properties. These materials typically have an inorganic component in an organic host or vice versa or consist of two or more inorganic/organic phases in some combinational form with the constraint that at least one of the phases or feature in the nanosize [1]. In general, nanocomposite materials can demonstrate unique combinations of mechanical, electrical, optical, electrochemical, catalytic, and structural properties compared to those of each individual component and their micro-size filled counterparts by taking advantage of the different structure, composition and properties of their constituents [2].

Polypropylene (PP) is a linear hydrocarbon polymer, shown as C_nH_{2n}. PP, is a polyolefin or saturated polymer. Polypropylene is one of those most versatile polymers available with applications, both as plastic and as fiber, in virtually all the plastics end-use markets [3]. It is a semicrystalline polymer with a monoclinic crystal structure and low glass transition temperature ($T_g = -2$°C). It has ability to crystallize soon and become well known polymer as a very popular product in different uses. PP was first introduced in 1957, and its usage has exhibited a lot of success in the market [4,5]. Polypropylene is not fragile and offers excellent electrical and chemical resistance at higher temperatures. These include a lower density, higher softening point. PP doesn't melt below 160°C, and higher rigidity and solidness. Additives are utilized to all commercially produced polypropylene resins to protect the polymer during processing and to enrich end-use performance [6].

The graphene is a 2D thin layer of pure carbon; it is a single, firmly packed layer of carbon atoms that are bonded together in a hexagonal honeycomb lattice. In more, it is an allotrope of carbon in the structure of a plane of sp^2 bonded atoms with a molecule bond of length of 0.142 nm. Layers of graphene stored on top of each other form graphite, with an interplanar spacing of 0.335 nm [7, 8].

It is the thinnest compound known to man at one atom thick, the lightest material known at around 0.77 mg/m^2, the strongest compound discovered (between 100-300 times stronger than steel and with a tensile stiffness of 150,000,000 psi), the best conductor of heat at room temperature (at $(4.84 \pm 0.44) \times 10^3$ to $(5.30 \pm 0.48) \times 10^3$ W·m^{-1}·K^{-1}) and also the best conductor of electricity known (studies have indicated electron mobility at values of more than 15,000 cm^2 V^{-1}·s^{-1}). Other clear characteristics of graphene are its unique levels of light absorption at $\pi\alpha \approx 2.3\%$ of white light, and its potential suitability for use in spin transport [9-11].

As graphene, it has been tested to be much more productive at conducting electrons than silicon and is

* Correspondence e-mail: Mohammed.K.Tweissi@ahu.edu.jo

Cite this article as: M. Al-Tweissi et al., *J. Nano- Electron. Phys.* 18 No 1, 01006 (2026) https://doi.org/10.21272/jnep.18(1).01006

also able to transfer electrons at much faster speeds (relatively speaking, 1000 km per second, 30 times faster than silicon) [12].

In a short while, you will start to notice products from consumer electronics companies, such as Samsung (who have been pouring money into researching the uses of graphene in telecommunications and electronics huge number of patents concerned with the uses and produce of graphene have been appeared in the last ten years in electronic devices) based on flexible, robust, touchscreen devices such as mobile smartphones and wrist watches.

What all this means is that this discovery, made by a physics professor and his PhD students in a laboratory in Manchester University, using a piece of graphite and some Scotch tape has completely revolutionized the way we look at potential limits of our abilities as scientists, engineers and inventors. The possibilities of what we can reach with the materials and knowledge are unlimited, and it is now conceivable to imagine such amazing prospective situations as lightning fast, yet super-small computers, invisibility cloaks, smart phones that last weeks between charges, and computers that we can fold up and carry in our pockets wherever we travel [13].

The findings indicate that polypropylene-graphene (PP-G) nanocomposites have improved mechanical strength, thermal stability, and effective EMI shielding. These composite materials have excellent potential to be used in the aerospace and automotive industries, as well as for the protective casings of electronic equipment. The ability to control the electrical and mechanical characteristics of polypropylene by graphene addition presents an appealing opportunity to develop next-generation, high-performance, lightweight polymeric materials [14,15].

Nowadays, there is a rapid growth of electronic devices communication systems, medical instruments, and computers which most of them emit radiation within the same region of electromagnetic spectrum resulting in a phenomenon called electromagnetic interference (EMI). This electrical phenomenon is observed as an undesirable response in a receiving system. Hence, it is required to provide effective screening or shielding components to reduce emission and minimize susceptibility to an external source of radiation by using an electrically conductive material. However, small size and light weight are two preferable major advantages of current electronic devices. These requirements are commonly provided by using plastic materials. Unfortunately, conventional plastics are transparent to the electromagnetic energy [16]. To achieve a successful technique for EMI conductive fillers such as graphene are introduced into polymeric resins providing interesting products called nanocomposites It is essential to mention that the shielding performance of the obtained composites depends on their chemical, mechanical, electrical characteristics. The importance of these composites is apparent in modern technology and industrial applications [17-19].

2. EXPERIMENTAL WORK

2.1 Composite Materials and Preparation

The composite samples studied in this work were Polypropylene/graphene nanocomposites with different nanofiller graphene concentrations [2, 6, 10, 15 and 20 wt. %]. All nanocomposites were prepared by melt mixing in a small (55 cm^3) batch mixer (Plastograph EC, Brabender, Germany). In a typical experiment, (x g graphene particle size is average diameter = 5 nm, average thickness = 7 nm, XG Sciences, USA) was mixed with 30.0 g PP (PP 125, SABIC, Saudi Arabia). The mixing conditions were as follows: mixing time 13 min (3 min for polymer fusion and 10 min for PP–G compounding), mixing temperature 190°C, and mixing speed 100 rpm. For the electrical conductivity, dielectric and EMI (SE) measurements, 1.1 mm thick rectangular samples were prepared by compression molding using Carver hot press (Carver Inc., Wabash-IN, USA) at 250°C under 5 Torr pressure for 10 min.

2.2 Shielding Effectiveness Measurements

EMI is attenuated by three major mechanisms, namely: reflection, absorption and multiple reflections. In cases where the shielding by absorption (i.e. absorption loss) is higher than 10 dB, most of the re-reflected wave will be absorbed within the shield. Thus, multiple reflections can be ignored [20]. In other previous work, they found that contribution of absorption loss to the total shielding is higher than the contribution of reflection loss. Similar finding was reported by many researchers for different nanocomposite materials. In this work, it was also found that absorption loss was higher than the reflection loss. Shielding effectiveness (SE) represents the attenuation of the propagating electromagnetic waves produced by the shielding material. The total EMI shielding effectiveness of a shielding material is the measure of the loss of electromagnetic (EM) energy in transmission through the material compared to direct delivery of energy in the absence of shield. EMI SE is an important electromagnetic compatibility (EMC) requirement for protecting susceptible electronic systems from the electro-magnetic pollution. A good EMI shielding material exhibits maximum attenuation (by reflection and/or absorption mechanism) of the EM wave with lowest possible or negligible transmission. An EMI SE of 20 dB is adopted to be a standard for typical electromagnetic wave shielding materials [21, 22]. It means that 99% of the total energy of electromagnetic wave incident on it is attenuated. The total EMI SE (SET) is measured in dB and can be expressed as [23, 24]:

$$SE_T(dB) = -10\log(P_t/P_i) = SE_R + SE_A \qquad (1)$$

where P_i and P_t are the powers of the incident and transmitted electromagnetic waves and SE_R and SE_A the reflection shielding effectiveness and absorption shielding effectiveness, respectively. Using the scattering parameters S_{11} and S_{21} of vector network analyzer (obtained by the waveguide transmission line technique), the reflection coefficient, *R*, and the transmission coefficient, *T*, can be expressed as [25, 26]:

$$R = |S_{11}|^2 = |S_{22}|^2 \quad (2)$$

$$T = |S_{21}|^2 = |S_{12}|^2 \quad (3)$$

The absorption coefficient, A, can be calculated from the power SE_R and SE_A can be expressed balance relation [27]:

$$A + R + T = 1 \quad (4)$$

SE_R and SE_A can be expressed in terms of '*R*' and '*T*' as [28]:

$$SE_R = -10\log(1-R) \quad (5)$$

$$SE_A = -10\log(T/(1-R)) \quad (6)$$

The power values are calculated using the scattering parameters as:

$$P_r = P_i * (S_{11})^2 = P_i * (S_{22})^2 \quad (7)$$

$$P_t = P_i * (S_{21})^2 = P_i * (S_{12})^2 \quad (8)$$

$$P_a = P_i - (P_r + P_t) \quad (9)$$

where P_r is the reflected power, P_i is the received power, P_t is the transmitted power and P_a the absorbed power.

Electromagnetic shielding was evaluated elsewhere in terms of the insertion loss (IL) and return loss (RL) and is given by [29]:

$$SE = 10\log(1 + 10^{(IL-RL)/10}) \quad (10)$$

$$IL = 10\log P_i/P_t \quad (11)$$

$$RL = 10\log P_i/P_r \quad (12)$$

The EMI shielding effectiveness (SE) in the (8.0 – 12.0 GHz) frequency range was conducted using E5071C ENA network analyzer Fig. 1 connected to a WR-90 rectangular waveguide. The rectangular (2 * 4 cm^2) specimens were inserted between the two sections of the waveguide and the S-parameters (S_{11}, S_{12}, S_{22}, S_{21}) of each sample were recorded. The total EMI SE was calculated as Eq. (1).

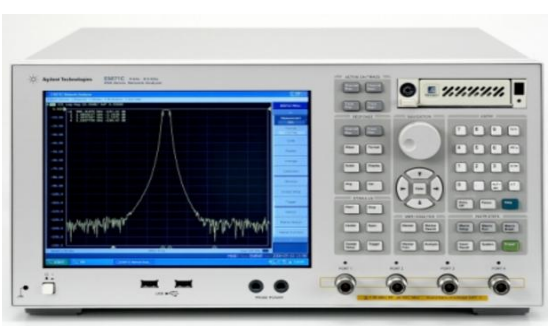

Fig. 1 – Network Analyzer (E5071C ENA Series).

3. RESULTS AND DISCUSSION

The influence of mass fraction on the SE values of graphene nanocomposites, using Eqs. (5) and (6), is presented in Table 1 at a frequency of 12 GHz. From Table 1, it can be seen that the shielding effectiveness (SE) at 12 GHz is 11.5 dB for 2 wt. % graphene content, and it increases to a maximum value of 35 dB for 20 wt. % graphene content.

Table 1 – The influences of graphene contents on SE values at 12 GHz

Graphene contents	SE (dB)
2%	11.5
6%	16.2
10%	21.3
15%	26.8
20%	35.0

The variation of SE values at frequency range (8 – 12 GHz) with graphene concentrations is shown in Fig. 2 and Fig. 3. From the two figures the SE values of all graphene nanocomposites increase with the weight percentage because the higher the mass fraction is the higher the probability that the conductive network can be formed for specimens with the same thickness and diameter.

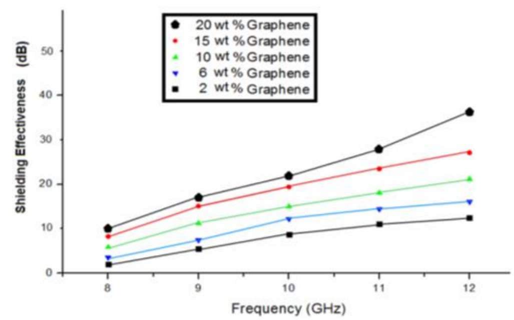

Fig. 2 – Shielding effectiveness with Frequency

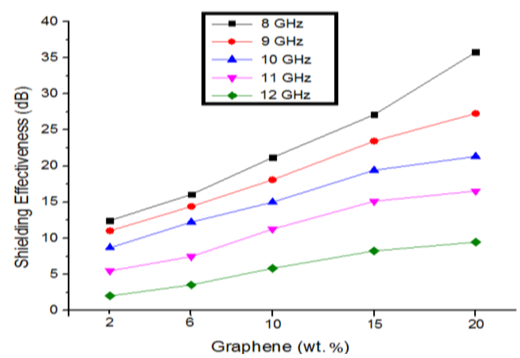

Fig. 3 – Shielding effectiveness with Frequency

The frequency dependence on the insertion loss (IL) and return loss (RL) of each specimen using equations (10, 11, 12) as shown in Fig. 4 and Fig. 5, the insertion loss increases with increasing the concentration of graphene and increasing the frequency, This increase in the attenuation is due to the nature of the structure and the high electrical conductivity of this composite which allows the electromagnetic waves to transmit through the specimen. Furthermore, the filler characteristics (aspect ratio, distribution and particle orientation) play a major role in the attenuation of the electromagnetic waves, and the return loss decreases with increasing frequency, may be due to some structural effects such as the geometrical distribution of the filler and the interaction of the electromagnetic waves with graphene nanoparticles. The wave interaction with graphene seems to reflect and absorb the electromagnetic energy, as with other conductive fillers [30]. This behavior is a direct consequence of the structural properties of the composite sample used. The calculated values for the SE as a function of frequency for 20 wt. % and for 2 wt. % graphene contents are shown in Figs. 4,5. The results show a behavior similar to that of the IL because the return loss is small compared to the insertion loss.

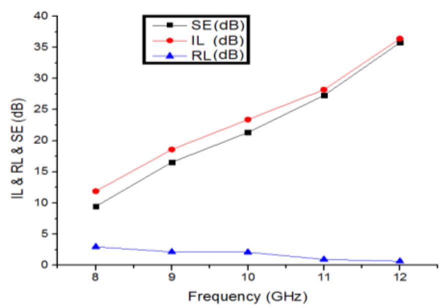

Fig. 4 – Shielding effectiveness, Insertion loss and Return loss with Frequency for 20 wt. % Graphene

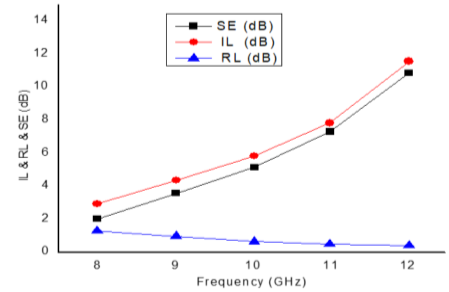

Fig. 5 – Shielding effectiveness, Insertion loss and Return loss with Frequency for 2 wt. % Graphene

4. CONCLUSIONS

The electromagnetic Shielding Effectiveness (SE) of the polypropylene matrix doped graphene was studied as a function of the filler concentrations and frequency range from 8 GHz to 12 GHz. Based on the experimental results obtained, several conclusions can be drawn: the Shielding effectiveness increases with both frequency and graphene content. The insertion loss increases with increasing the concentration of graphene and frequency. And the return loss decreases with increasing graphene and frequency. Increasing the graphene content enhances the (SE) to 35 dB value. The results show a behavior of SE is similar to that of the IL because the return loss is small compared to the insertion loss.

REFERENCES

1. P.M. Ajayan, L.S. Schadler, P.V. Braun, *Nanocomposite science and technology*. John Wiley & Sons, 1-75 (2006).
2. Mohammed Al-Tweissi, Ismail Tarawneh, *J. Nano- Electron. Phys.* **17** No 1, 01023 (2025).
3. A. Bagaria, D. Juneja, *Mater Today: Proceedings*, (2023).
4. C. Ding, M.A. Wenzhong, J.Zhong, *Opt Mater.* **147**, 114627 (2024).
5. S. Murayama, G. Matsuba, *Polymers* **17** No 1, 37 (2024).
6. H. Tao, et al, *Polym Compos.* **45** No 6, 4819 (2024).
7. V.B. Mbayachi, et al, *Results Chem.* **3**, 100163 (2021).
8. Z. Zhen, H. Zhu, *Graphene: Fabrication, Characterizations, Properties and Applications*, edited by Hongwei Zhu, Zhiping Xu, Dan Xie, and Ying Fang, 1–12. (2018).
9. M. Fréchette, et al, *1st International Conference on Electrical Materials and Power Equipment* (ICEMPE), 65 (2017).
10. Y. Kopelevich, P. Esquinazi, *Adv. Mater.* **19** No 24, 4559 (2007)
11. S.-Y. Kwon, et al, *Nano Lett.* **9** No 12, 3985 (2009).
12. N.O. Weiss, et al, *Adv Mater.* **24** No 43, 5782 (2012).
13. J.W. Zondlo, *Graphite, Graphene, and Their Polymer Nanocomposites*, 1 (2012).
14. N. Bagotia, V. Choudhary, D.K. Sharma, *Polym. Adv. Technol.* **29** No 6, 1547 (2018)
15. A. Kausar, et al, *J. Compos. Sci.* **7** No 9, 384 (2023).
16. L. Sevgi, *IEEE Antennas Propag. Mag.* **51** No 1, 211 (2009).
17. J.M. Kim, et al, *J. Appl. Polym. Sci.* **134** No 5, (2017).
18. X. Nan, et al, *Polymers* **16** No 17, 2539 (2024).
19. Y.K. Li, et al, *Carbon* **211**, 118096 (2023).
20. G.K. Sharma, et al, *Carbon* **264**, 120874 (2025).
21. N. Joseph, S.K. Singh, R.K. Sirugudu, V.R.K. Murthy, S. Ananthakumar, M.T. Sebastian, *Mater. Res. Bull* **48**, 1681 (2013).
22. D. Annapurna, K.D. Sisir, *Microwave Engineering*, Tata McGraw Hill, India, 2nd edn, ch. 6, 141-148 (2009).
23. B.S. Villacorta, T.H. Hubing, A.A. Ogale, *Compos. Sci. Technol.* **89**, 158 (2013).
24. W.L. Bao, S. Yang, X.Y. Zhen, W.N. Ce, *Appl. Phys. Lett.* **89**, 132504 (2006).
25. K. Lakshmi, H. John, K.T. Mathew, R. Joseph, K.E. George, *Acta. Mater.* **57**, 371 (2009).
26. J. Joo, A.J. Epstein, *Appl. Phys. Lett.* **65**, 2278 (1994).
27. A. Kaynak, *Mater. Res. Bull.* **31**, 845 (1996).
28. K. Singh, A. Ohlan, P. Saini, S.K. Dhawan, *Polym. Adv. Technol.* **19**, 229 (2008).
29. D.M. Mihut, et al., *Thin Solid Films* **520** No 21, 6547 (2012).
30. Mohammed Al-Tweissi, *Mater. Res.* **28**, e20250201 (2025).

Ефективність електромагнітного екранування поліпропіленового нанокомпозиту, наповненого графеном

Mohammed Al-Tweissi[1], Omer Hussein[2]

[1] *Physics Department, Collage of Science, Al–Hussein Bin Talal University, P.O. Box 20, Ma'an, Jordan*
[2] *Physics Department, The University of Jordan, 11942 Amman, Jordan*

Зразки композитів, досліджені в цій роботі, являли собою нанокомпозити поліпропілен/графен, виготовлені з різною концентрацією графенового нанонаповнювача (2, 6, 10, 15 та 20 мас.%). Всі зразки були виготовлені методом змішування розплаву з подальшим компресійним формуванням для формування тестових зразків. Електромагнітні перешкоди (ЕМП) були досліджені для підготовлених листів з різною концентрацією графену на мікрохвильових частотах [8-12 ГГц], і було виявлено, що ефективність екранування (ЕЕ) зростає як зі збільшенням вмісту графену, так і зі збільшенням застосованої мікрохвильової частоти. Ефективність екранування (ЕЕ) зростає приблизно до 35 дБ. Ці результати підкреслюють потенціал цих нанокомпозитів для застосування в електронній упаковці та інших галузях, що потребують ефективного захисту від ЕЕП.

Ключові слова: Поліпропілен, Графен, Метод змішування розплаву, Електромагнітні перешкоди (EMI), Ефективність екранування (SE).