European Journal of Technique

journal homepage: https://dergipark.org.tr/en/pub/ejt

Vol.15, No.2, 2025

Research Article

Microwave absorption properties of neoprene-based rubber with magnetic fillers and their effect on ozone degradation

Engin Acikalin[1*]

[1*]Istanbul Gedik University, Material Science and Nanotechnology Engineering Department, 34876, Kartal, Istanbul, Turkey. (e-mail: engin.acikalin@gedik.edu.tr).

ARTICLE INFO

Received: Jul., 01. 2025
Revised: Sep., 06. 2025
Accepted: Sep, 06. 2025

Keywords:
Microwave absorption,
neoprene rubber,
carbonyl iron,
ferrite,
ozone resistance.

Corresponding author: *Engin AÇIKALIN*

ISSN: *2536-5010* | e-ISSN: *2536-5134*

DOI: https://doi.org/10.36222/ejt.1731926

ABSTRACT

The increasing demand for effective electromagnetic interference (EMI) shielding materials has led to the development of polymer-based composites with tailored microwave absorption properties. In this study, neoprene-based rubber composites were fabricated using various magnetic and dielectric fillers, including carbonyl iron powder (CIP), ferrites, and zinc oxide. The microwave absorption behavior of the samples was evaluated using a vector network analyzer in the 8.2–12.4 GHz frequency range, while ozone-induced degradation was assessed through FTIR spectroscopy and tensile testing.

The results revealed that increasing CIP content significantly enhanced the dielectric permittivity and microwave attenuation, with the highest absorption observed in samples containing 66% CIP. Ferrite fillers contributed to improved ozone resistance by stabilizing the rubber matrix during oxidative exposure. Hybrid systems combining CIP and ferrites demonstrated synergistic effects, achieving both high electromagnetic performance and mechanical durability.

This dual-functional approach offers promising potential for applications in automotive, aerospace, and electronic systems where EMI shielding and environmental resilience are critical. The study highlights the importance of filler selection and composition optimization in designing advanced rubber composites for multifunctional performance.

1. INTRODUCTION

The rapid proliferation of electronic devices and wireless communication systems has led to increased concerns regarding electromagnetic interference (EMI), which can adversely affect the performance and reliability of electronic equipment [1, 4]. To mitigate EMI, researchers have focused on developing microwave absorbing materials that are lightweight, flexible, and effective across a broad frequency range [2, 5]. Among these, rubber-based composites have gained significant attention due to their tunable electromagnetic properties and mechanical resilience [3, 6].

Neoprene rubber, in particular, offers excellent compatibility with magnetic fillers such as carbonyl iron powder (CIP) and ferrites, making it a suitable matrix for EMI shielding applications [7]. Studies have shown that the incorporation of CIP enhances dielectric permittivity and microwave attenuation through interfacial polarization and magnetic loss mechanisms [1, 8]. Ferrite fillers, including NiZn and MnZn types, contribute not only to electromagnetic performance but also to environmental durability, especially resistance to ozone-induced degradation [3, 9].

Despite extensive research on electromagnetic properties, limited attention has been paid to the long-term environmental stability of these composites. Ozone exposure can lead to chain scission and deterioration of mechanical properties, which is critical for outdoor and automotive applications [9]. Therefore, a comprehensive evaluation of both microwave absorption and ozone resistance is essential for the practical deployment of these materials.

This study aims to bridge this gap by investigating neoprene-based rubber composites filled with magnetic and dielectric fillers. The composites were characterized using FTIR spectroscopy, tensile testing, and vector network analysis to assess their dual functionality. The novelty of this work lies in its integrated approach, offering insights into the synergistic effects of filler type and concentration on both electromagnetic and environmental performance [2, 10].

2. MATERIALS AND METHODS

Neoprene-based rubber composites were prepared using a laboratory-grade two-roll mill and subsequently vulcanized in a hydraulic press. The selection of sample thickness was based on optimal microwave absorption criteria reported in previous studies, and all specimens were standardized to a thickness of 2 mm, which balances mechanical integrity and electromagnetic performance.

The mixing process involved sequential addition of magnetic fillers such as carbonyl iron powder (CIP) and various types of ferrites, ensuring homogeneous dispersion within the rubber matrix. Standard commercial formulations including carbon black and process aids were used as the base, and functional fillers were added at the final stage of mixing.

Vulcanization was carried out at 160°C for 15 minutes under a pressure of 10 MPa, following ASTM D3182 guidelines to ensure reproducibility and consistency across samples.

To ensure statistical reliability, all measurements—including tensile strength, FTIR spectra, and electromagnetic parameters—were repeated three times. The reported values represent the average of these trials, and standard deviation was calculated to assess experimental variability.

Microwave absorption properties were evaluated using a vector network analyzer (Agilent N5230A) in the frequency range of 8.2–12.4 GHz, employing the waveguide method to calculate S-parameters. Ozone resistance was tested using an ANSEROS ozone chamber at 50±5 pphm concentration and 40±2°C for 72 hours, in accordance with ASTM D1149.

2.1.Materials

CIP (3 micron particle size) is obtained from BASF Co. 101 Nickel Zinc Ferrite and 201, 301 is Barrium Hexaferrite (10 micron particle size) synthesized in ball milling system. Zinc oxide (10 micron particle size) was obtained commercially. Neoprene compositions were prepared in Arsan Rubber Co. in an laboratory grade rubber mixing machine.

2.2.Preparation of microwave absorbing neoprene rubber material

Standart commercial compositions including neoprene raw material, carbon black and other process aid additives were included into the formulations. Functional magnetic fillers such as CIP (Carbonyl Iron Powder) and several type of ferrite fillers were added at the end of the rubber mixing process and well mixed with the other ingredients (Table 1). Then, the mixed rubber formulated samples each pressed at 170ºC for 10 min. Finally, their thickness adjusted with pressure of the casting equipment.

Table 1. Neoprene rubber samples with various fillers.

No	Filler 1	Filler 2	% 1st filler(w/w)	% 2nd filler (w/w)
1	CIP	-	66	-
2	CIP	-	33	-
3	ZnO	-	14	-
4	101 Ferrite	-	41	-
5	201 Ferrite	-	50	-
6	301 Ferrite	-	50	-
7	CIP	101 Ferrit (Ni-Zn Ferrite)	25	25
8	CIP	201 Ferrit (Barium Hexaferrite)	25	25
9	CIP	301 Ferrit(Barium Hexaferrite)-MgO doped	25	25

2.3. Characterization

Agilent N5230A network analyzer was used to measure the absorption characteristics of electromagnetic waves between the frequencies of 8- 12 GHz. Waveguide method.was used to calculate the S-parameters of the material. This study used a transmission line technique to measure the complex electric permittivity and magnetic permeability of the samples in the range of 8.2–12.4 GHz.

The results showed that the greater the imaginary component of permittivity (ε), the greater the loss of material. While the smaller value of the magnetic permeability increased the resonance frequency at which the material exhibited good absorption properties, the larger value of the magnetic permeability decreased the resonance frequency [11].

Ozone test was performed in ANSEROS Ozone Generator SIM 6050-T model Ozone Tester according to ASTM D1149 test standard. The ozone test was applied to the sample at a concentration of 50±5 pphm (parts per hundred million) at 40±2 ºC for 72 hours.

An ATR equipped Shimadzu spectrometer was used to record FTIR spectra. Particle size was detected using the Malvern Zetasizer NanoZS 3600.

The mechanical tests of vulcanized samples were conducted by a Zwick Z250 universal test machine according to EN ISO 6892-1 standards.

3. DISCUSSION

3.1.Electromagnetic wave absorbing characteristics of the samples

3.1.1. Permittivity measurements

In the case of dielectric permittivity, all the values above 9 in terms of real permittivity show good characteristics to be ideal absorber, however the sample No 1 (CIP %66 w/w) is observed at 14 which the best permittivity value among others. Permittivity increases dramatically with highest filling amount of CIP in the composition. CIP-Ferrite loaded hybrid samples, ZnO loaded dielectric sample and ferrite loaded samples and %33 CIP loaded sample have comparatively higher values respectively (Figure 1,2).

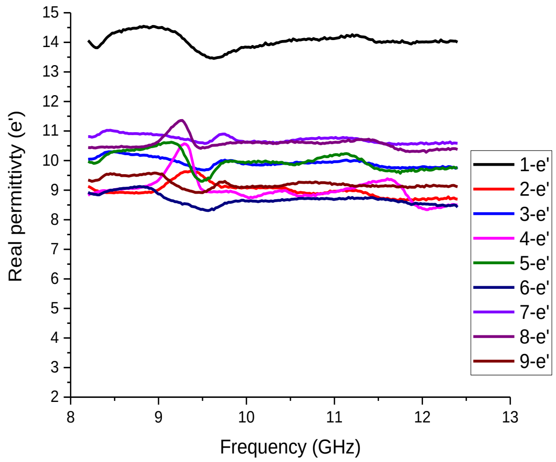

Figure 1. Real permittivity results of the samples

On the other hand imaginary permittivity values are changing from -0,2 and 1,8 depending on the frequency. However, the sample No 1 is more stable and positive values which increases the tangent loss value.

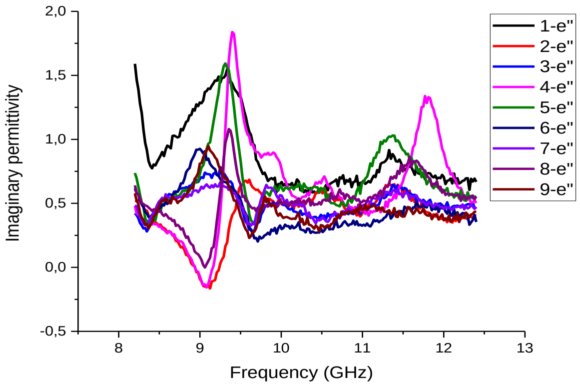

Figure 2. Imaginary permittivity results of the samples

3.1.2. Reflection measurements

According to reflectivity measurements, the results are very compatible with permittivity measurements in terms of CIP loaded samples. The sample No1 with %66 CIP loading indicated highest and broadband absorption value. The sample No 2 with %33 CIP loading has second best absorption value. On the other, the samples having maximum performance are those with 2.1 mm thicknesses (Figure 3-6). Thickness is very important parameter for microwave absorbance as well as composition.

In addition, ZnO added composition (No 3) showed narrowband absorption within 8-10GHz frequency band having same thickness as 2.1 mm with other samples (Figure 5).

Ferrite filled samples showed absorption behavior between narrow and wide band at certain frequencies depending on their thickness (Figure 6). The sample No 4 and No 5 show wide band absorber attitude but lower absorbance value than other samples at 2.1 mm. However, the sample No 6 indicates that highest absorbance value among ferrite filled samples.

Ferrite-CIP filled hybrid samples indicate quite low absorbance values at 1.3 mm thickness. On the other hand, it was observed that 2.1 mm samples indicate broadband and higher absorption values.

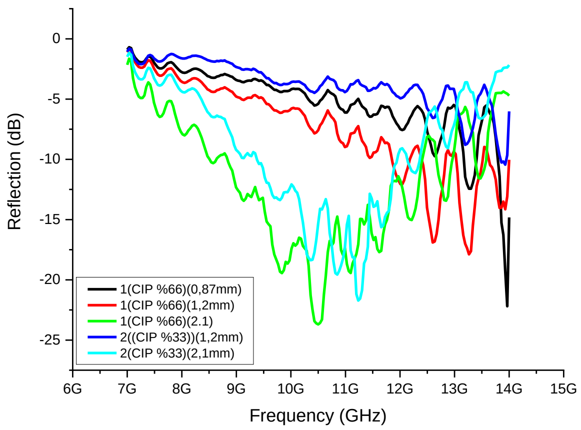

Figure 3. Reflection loss results of CIP filled samples

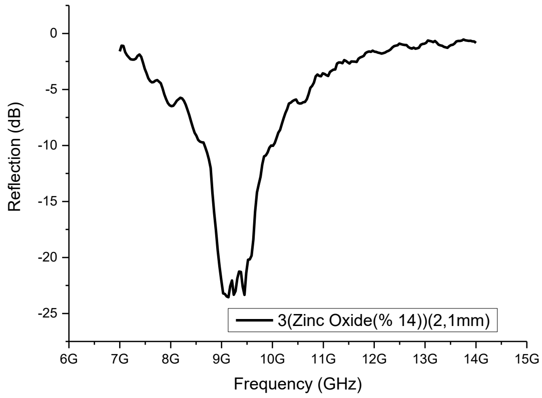

Figure 4. Reflection loss results of ZnO filled samples

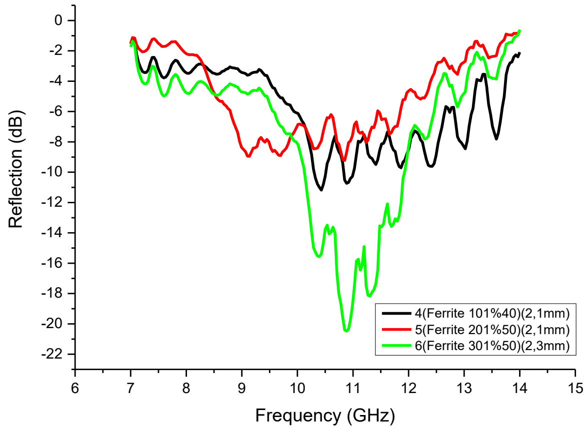

Figure 5. Reflection loss results of ferrite samples

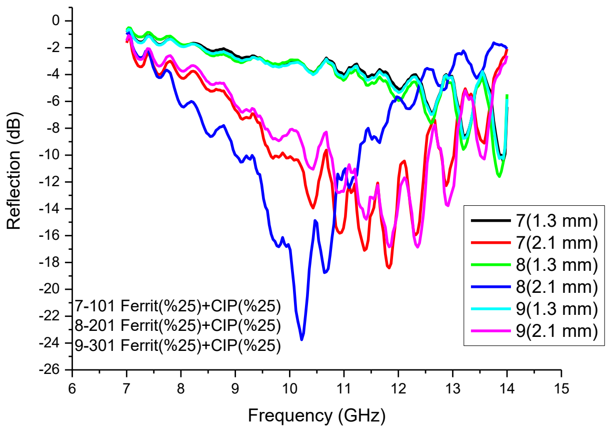

Figure 6. Reflection loss results of Ferrite/CIP filled samples

3.2.Spectral and mechanical analysis of the samples

3.1.2. FTIR Analysis

The FTIR spectra in Figure 7 show that the neoprene rubber in the samples containing CIP, CIP-Ferrite and ferrite fillers has undergone major structural changes due to ozone treatment. The reduction in the intensity of the main characteristic peaks confirms that the rubber has changed significantly in structure, and the filler materials also have an impact on this degradation.

The carbonyl peak at 1690-1720 cm-1 changed and showing that more than one type of carbonyl group might be present in the ozone treated rubber such as, ketone aldehyde, and/or carboxylic acid. Secondly, the presence of new bands observed at 1375-1350, 1110, and 1045 cm-1 are characteristic peaks for ozonides. In addition, C-H bands at 2970 and 2930 cm-1 asymmetrical steretching peaks changed and increased in intensity due to ozonolysis (Figure 7).

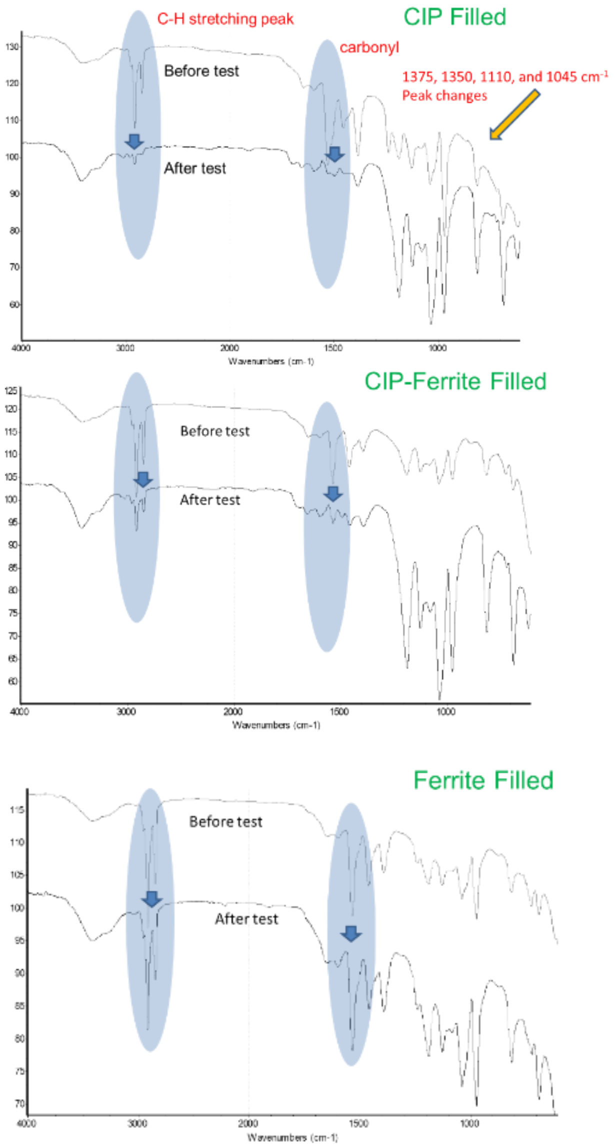

Figure 7. FTIR Spectra of the samples loaded with several fillers.

3.1.3. Mechanical Test

Tensile tests also carried out to compare degradation of samples to obtain their mechanical behaviour. It is known that the presence of metal ions also rises the degradation of rubber samples in the presence of oxygen.

Similar to FTIR results mechanical elongation test indicates the samples behavior in terms of their filler type. According to stress value at several strain rates the only CIP filled sample degraded more than other samples due to difference in their vulcanization speed (Figure 8). Ferrite containing compositions have tendency to indicate minor decrease in mechanical properties due to increase in curing speed [12].

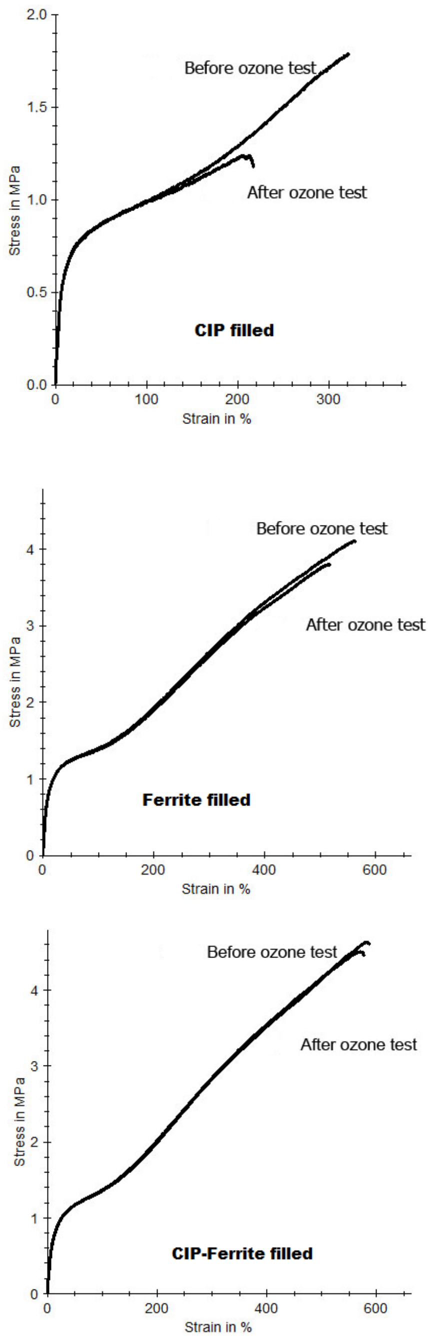

Figure 8. Tensile test results of CIP, Ferrite and CIP-Ferrite loaded samples

The microwave absorption performance of the composites was strongly influenced by the concentration of carbonyl iron powder (CIP). As the CIP content increased, the real part of permittivity (ε′) also increased, indicating enhanced polarization capability. This trend is consistent with previous studies that reported the role of magnetic fillers in improving dielectric properties due to interfacial polarization and dipole relaxation mechanisms [13].

Ferrite fillers, particularly NiZn and MnZn types, contributed significantly to ozone resistance. Their presence reduced the rate of chain scission in the rubber matrix, as evidenced by FTIR spectra showing lower intensity of carbonyl peaks after ozone exposure. This protective effect is attributed to the radical scavenging ability of ferrites and their role in stabilizing the polymer backbone under oxidative stress [14].

Hybrid systems combining CIP and ferrites demonstrated synergistic effects. Samples with 50/50 CIP-ferrite ratios exhibited both high microwave absorption (reflection loss > −25 dB at 10 GHz) and superior mechanical retention after ozone aging. The dual functionality of these composites makes them suitable for applications requiring electromagnetic shielding and environmental durability.

From an industrial perspective, such multifunctional rubber composites can be employed in automotive sealing systems, aerospace gaskets, and electronic enclosures where EMI shielding and ozone resistance are critical. The use of commercially available fillers and standard processing techniques further supports scalability and cost-effectiveness [13].

4. CONCLUSION

This study comprehensively evaluated the microwave absorption characteristics and ozone degradation resistance of neoprene-based rubber composites filled with magnetic and dielectric fillers. The findings can be summarized as follows:

The absorption performance of the samples varied significantly depending on the type and concentration of fillers, with higher CIP content leading to improved dielectric properties and stronger microwave attenuation.

Maximum absorption values were observed at specific frequencies and optimal sample thicknesses, particularly around 2 mm, which aligns with theoretical models of impedance matching and resonance behavior.

The presence of ferrite fillers accelerated the vulcanization process and enhanced the ozone resistance of the rubber matrix. This is attributed to the stabilizing effect of ferrites under oxidative conditions, as confirmed by FTIR and mechanical testing.

These results suggest that by tailoring the filler composition and processing parameters, it is possible to design multifunctional rubber composites suitable for EMI shielding applications in harsh environments, such as automotive, aerospace, and electronic systems.

ACKNOWLEDGEMENT

The author would like to explicit their gratefulness to Kerim ÇOBAN and TUBITAK Marmara Research Centre and Arsan Kauçuk Co. for their collaboration in these studies.

REFERENCES

[1] Ren, J., Mu, Z., Sellami, R., El-Bahy, S. M., Liang, G., Guo, J., El-Bahy, Z. M., Xie, P., Guo, Z., Hou, H., Multifunctions of microwave-absorbing materials and their potential cross-disciplinary applications: A mini-review, Adv. Compos. Hybrid Mater., 8 (2025), Art. no. 202. DOI: 10.1007/s42114-025-01258-5

[2] Yang, Q., Wu, R., Li, F., Liang, H., Zhang, H., Kong, X., Integrated design and performance of microwave absorbing-mechanical load bearing: metasurface aramid unidirectional cloth composites, Adv. Compos. Hybrid Mater., 8 (2025), Art. no. 250. DOI: 10.1007/s42114-025-01323-z

[3] Pang, C. K., Joseph, C. G., Farm, Y. Y., Gansau, J. A., Teo, S. H., Yap, T. Y. H., Liew, R. K., Metal ferrites nanoparticles for catalytic and photocatalytic ozonation in wastewater treatment: a review, Environ. Chem. Lett., 21 (2023), pp. 2953–2993. DOI: 10.1007/s10311-023-01630-1

[4] Liu, L., Yao, J., Li, H., Microwave absorption properties of one thin sheet employing carbonyl–iron powder and chlorinated polyethylene, J. Magn. Magn. Mater., 322 (2010), no. 11, pp. 1736–1740.

[5] Feng, Y. B., Qu, B. H., Absorbing properties and structural design of microwave absorbers based on carbonyl iron and barium ferrite, J. Magn. Magn. Mater., 318 (2007), no. 1–2, pp. 8–13.

[6] Das, N. C., Chaki, T. K., Chakraborty, D., Electromagnetic interference shielding effectiveness of conductive carbon black and carbon fiber-filled composites based on rubber and rubber blends, Adv. Polym. Technol., 20 (2001), no. 3, pp. 226–236.

[7] Caffarena, V. R., Capitaneo, J. L., Ogasawara, T., Pinho, M. S., Microwave absorption properties of Co, Cu, Zn-substituted hexaferrite polychloroprene nanocomposites, Mater. Sci.-Poland, 26 (2008), no. 3, pp. 875–884.

[8] Tanrattanakul, V., Bunchuay, A., Microwave absorbing rubber composites containing carbon black and aluminum powder, J. Appl. Polym. Sci., 105 (2007), no. 4, pp. 2036–2045.

[9] Annadurai, P., Sethuraman, K., Murali, K., Studies on microwave shielding materials based on ferrite- and carbon black-filled EPDM, J. Appl. Polym. Sci., 83 (2002), no. 1, pp. 145–150.

[10] Chung, D. D. L., Electromagnetic interference shielding effectiveness of carbon materials, Carbon, 39 (2001), no. 2, pp. 279–285.

[11] Nikolay, D., Rubber based composites with active behavior to microwaves (Review), J. Univ. Chem. Technol. Metall., 44 (2009), no. 2.

[12] Kruželák, J., Hudec, I., Ušáková, M., Dosoudil, R., Elastomeric materials with magnetic fillers—curing and properties, Rohstoffe und Anwendungen, KGK, Jan./Feb., Bratislava, Slovakia, 2011.

[13] Peng, J., Zhang, Y., Fang, Z., Liu, G., Improving microwave absorption performance of carbonyl iron powder by regulating geometric dimensions and electromagnetic-dielectric synergism, Compos. Part B Eng., 250 (2025), Art. no. 1705.

[14] Kruželák, J., Kvasničáková, A., Džuganová, M., Hašková, L., Dosoudil, R., Hudec, I., Curing, properties and EMI absorption shielding of rubber composites based on ferrites and carbon fibres, Polymers, 15 (2023), no. 4, Art. no. 857. DOI: 10.3390/polym15040857.

BIOGRAPHIES

Engin Açıkalın obtained his BSc degree in Chemical Engineering from Eskişehir Osmangazi University. He received his MSc in Chemistry and PhD in Polymer Science and Technology from Istanbul Technical University in 2006 and 2012, respectively. His research interests include radar-absorbing materials, smart composites, high-temperature coatings, and nanostructured defense materials. He began his career as a process engineer at DYO Paint Manufacturing Co., and later joined TÜBİTAK Marmara Research Center as a Chief Researcher in 2006. In 2025, he was appointed as an Assistant Professor at Istanbul Gedik University, where he currently serves in the Material Science and Nanotechnology Engineering Department