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ORIGINAL STUDY

Improving the UV Resistance and Service Life of Polystyrene-Based Building Materials via Low-Concentration Metal Complex Modifiers

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ABSTRACT

PS is highly susceptible to UV-induced photodegradation, which results in deterioration of its mechanical and aesthetic properties. In the present study, four novel and highly aromatic levofloxacin metal complexes, synthesized from Zn, Sn, Cu, and Ni, were investigated as low-concentration (0.5% w/w) photostabilizer additives for PS. Composite films were prepared by solution casting and subjected to accelerated UV irradiation up to 300 hours. Photostabilizing performance was systematically followed by monitoring changes in the carbonyl index via FT-IR spectroscopy, mass loss measurements, and surface morphology analyses using SEM and AFM. Results showed that all levofloxacin metal complexes had a pronounced inhibition effect on the photodegradation of PS. The additives efficiently suppressed the generation of carbonyl groups, reduced the mass loss, and significantly minimized surface roughness and cracking in the case of pure PS films. This stabilization is considered to be dependent on the aromaticity of the complexes and their heteroatom content, most probably as a result of UV absorption and radical scavenging mechanisms. In this paper, novel levofloxacin metal complexes were established as efficient and promising photostabilizing additives that enhance the durability of polystyrene under UV exposure.

Keywords: Polystyrene, UV radiation, Photodegradation, Levofloxacin, Morphology

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1. Introduction

Polystyrene (PS) is a commonly employed polymer with uses that include packaging, laboratory instruments, and electronic components. Various types of PS emerge depending on the positioning of phenyl groups along its polymer backbone [1]. One of the most important examples of its use is some covering parts within the car [2]. Despite the vital role of such polymers as PS in everyday life, they are very prone to environmental degradation, which includes exposure to UV radiation, high temperatures, and different types of energy [3]. UV exposure can initiate the photo-oxidative destruction of the polymer chains, resulting in free radicals and reduced molecular weights [4]. This breakdown process results in the degradation of mechanical strength and eventual breakdown of the material. Common manifestations of UV-induced degradation include yellow discoloration, loss of surface gloss, cracking, and other physical changes [5], as presented in Fig. 1.

When polymers absorb UV radiation, surface-level photodegradation takes place by means of photolytic, photooxidative, and thermooxidative reactions [6], as seen in Fig. 2. Many studies have been conducted on the degradation behavior of polystyrene, especially its susceptibility to photodegradation and photooxidation [7]. Much work has explained the mechanism of photoinduced deterioration of polymers [8]. Polystyrene, a commodity industrial polymer, presents important problems with respect to its light sensitivity [9]. The degradation of polymers under light might be due to direct UV radiation or via a photosensitizing agent. Although the method of direct irradiation is straightforward, the incorporation of a photosensitizer within the polymer has some important advantages [10]. It provides finer control over degradation processes, and wavelengths may be used that are not directly absorbed by the polymer [11]. Light activation of sensitizers generally gives rise to free radicals, which, in turn, initiate the break-up of the polymer chains [12].

Generally, these radicals abstract a hydrogen atom from the polymer chain, forming an alkyl radical which reacts readily with oxygen and thus initiates an oxidative chain reaction [13]. In addition, these compounds also function as polymer stabilizers, agrochemical agents, wood preservatives, catalysts, disinfectants, and biocides [14].

Figs. 1 and 2 were proposed, designed, and illustrated by the authors of this study and are original works that were not adapted or reproduced from any previously published sources. Levofloxacin is an aromatic, highly stable chiral antibiotic that possesses a high melting point and is highly heteroatom-rich (34.6% O, N, and F) [15]. Such a composition suggests that its tin-based complexes may effectively stabilize PS by preventing its photodecomposition. This work aimed at investigating the efficiency of levofloxacin metal complexes as photostabilizers for PS upon irradiation. Our results reveal that these complexes act indeed as new photostabilizing agents in protecting PS from UV-induced degradation.

2. Materials and methods

2.1. General

Polystyrene was obtained from Sigma-Aldrich Chemical Company (Gillingham, UK). The Fourier Transform Infrared (FTIR) spectra (4000–400 cm^{-1}) were recorded on a Jasco FTIR-4200 spectrometer (Tokyo, Japan). Polystyrene films were irradiated at 25 °C (λ_max $= 365$ nm, 6.43×10^{-9} ein dm^{-3} s^{-1}) using a QUV accelerated weathering tester supplied by Q-Panel Company (Homestead, FL, USA). Surface characterization was performed through atomic force microscopy (AFM) with a Veeco system (Plainview, NY, USA), while scanning electron microscopy (SEM) was carried out using an Inspect S50 microscope (FEI Company, Czechia, Czech Republic) at 15 kV. Film thickness (40 μm) was measured using a Digital Vernier Caliper 2610 A micrometer (Vogel GmbH, Kevelaer, Germany), and samples were fixed onto 0.6-mm aluminum plate supports (Q-Panel Company, Homestead, FL, USA).

2.2. Preparation of PS films

Polystyrene (5 g) was dissolved in 100 mL of chloroform and agitated for 90 minutes at 25 °C. Levofloxacin metal complexes (25 mg, corresponding to 0.5% w/w of the polymer) were then incorporated into the solution and mixed for an additional half hour to ensure uniform dispersion. The prepared mixture was poured onto clean glass slides to produce films with a thickness of roughly 40 μm. These films were left to dry at 25 °C for 24 hours, as illustrated in Fig. 3. Previous research identified 0.5% w/w as the optimal loading of levofloxacin metal complexes for film preparation (Fig. 3) [16, 17].

2.3. Fourier transform infrared spectroscopy of PS films

The FT-IR spectra of the PS films were recorded, and then the carbonyl group index, I_s, was calculated from Eq. (1) based on the absorbance of the carbonyl group, A_s, and that for the reference band, A_r [16]. The FTIR spectra of the PS films were recorded and

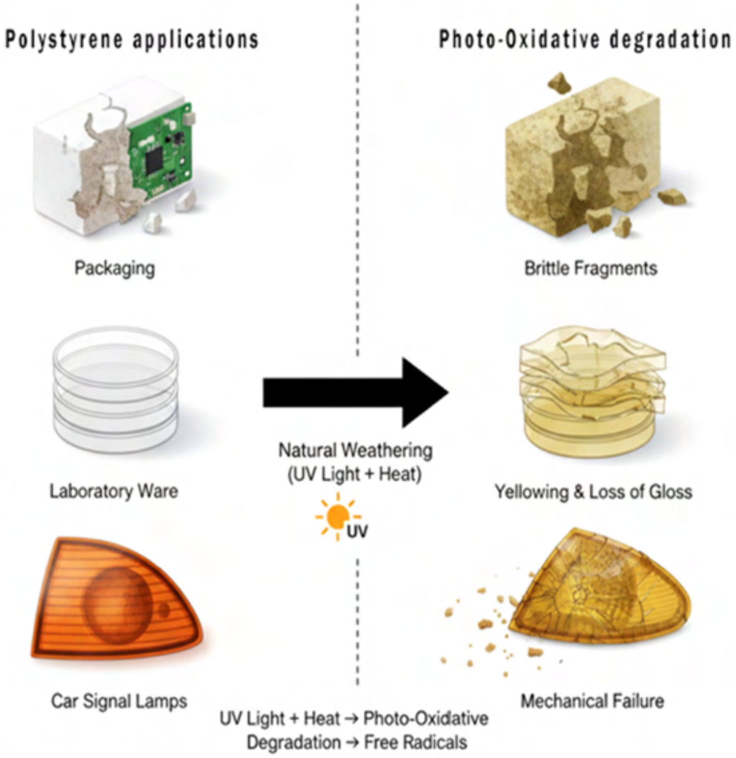

Fig. 1. Photo-oxidative degradation of Polystyrene.

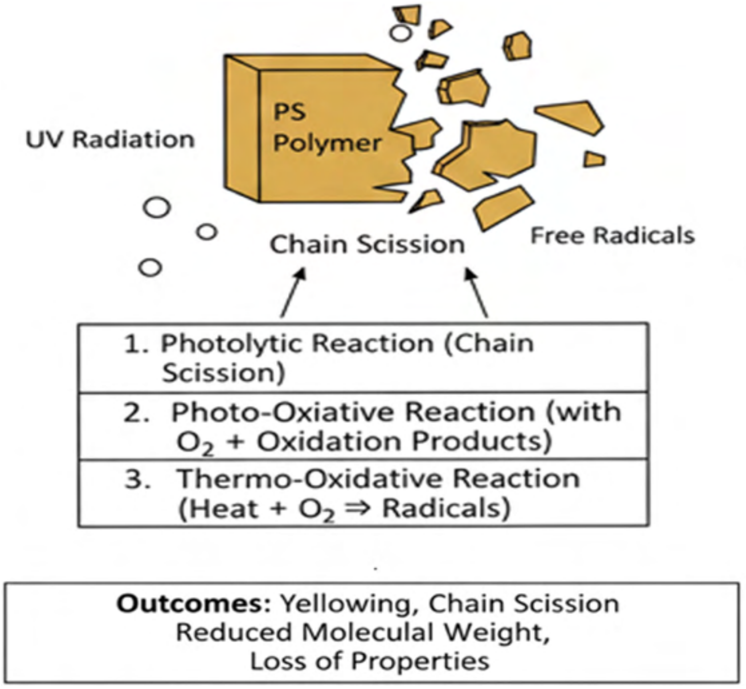

Fig. 2. Direct photodegradation of Polystyrene.

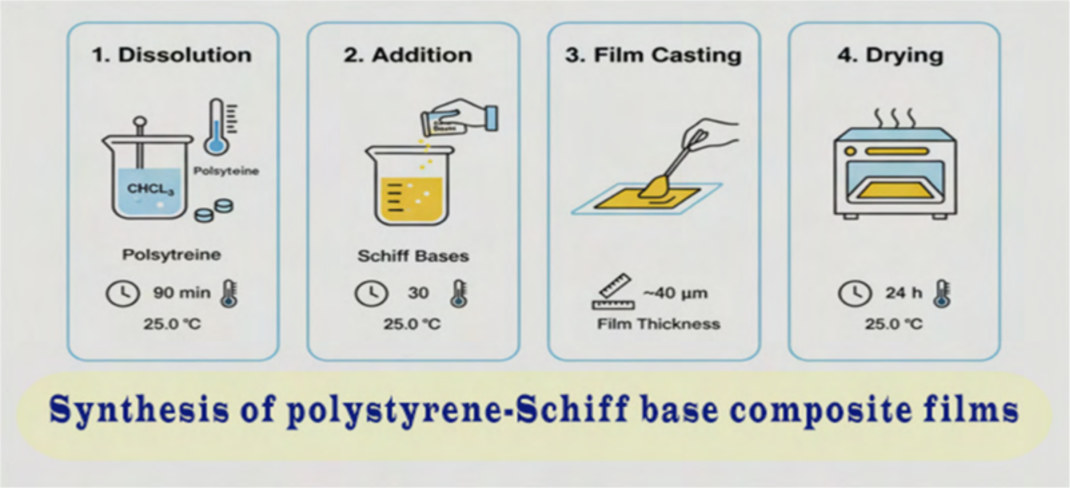

Fig. 3. Preparation of PS/ levofloxacin metal complexes Films.

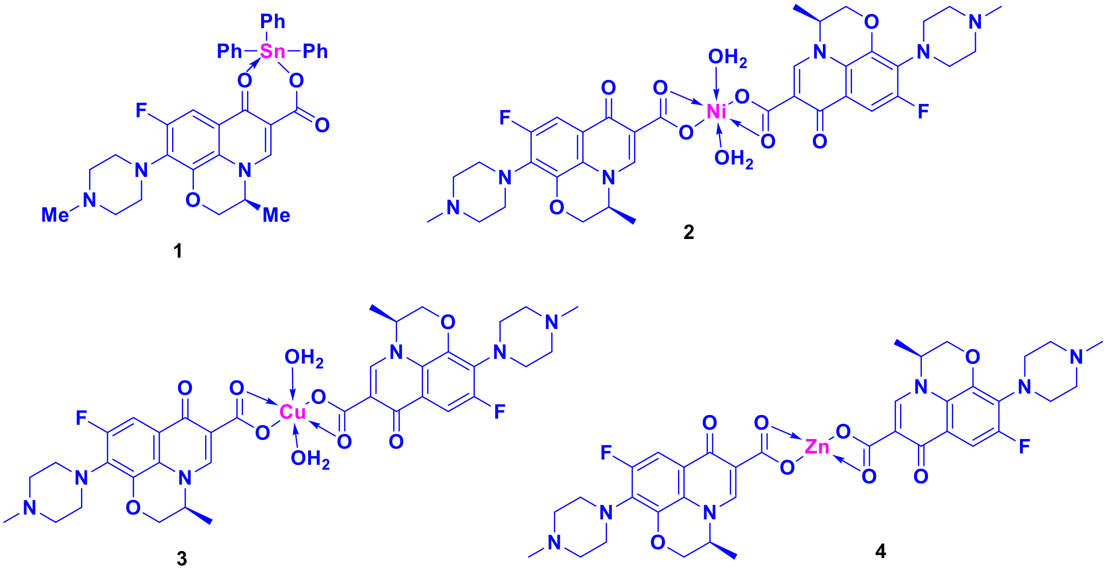

Fig. 4. Levofloxacin metal complexes.

the carbonyl group index, I_s, was estimated based on the absorbance of the carbonyl group, A_s, and that for the reference band, A_r, by applying Eq. (1) [16].

$$I_s = \frac{A_s}{A_r} \tag{1}$$

2.4. Weight loss of PS films

The weight loss ratio of PS upon irradiation was determined by using Eq. (2), based on the weight of the PS film before, W_1, and after, W_2, irradiation [34]. The weight loss ratio of PS upon irradiation was calculated by using Eq. (2), based on the weight of the PS film before, W_1, and after, W_2, irradiation [16]

$$\text{Weight loss } (\%) = \frac{W_0 - W_t}{W_0} \times 100 \tag{2}$$

3. Results and discussion

3.1. Synthesis of levofloxacin metal complexes

Levofloxacin metal complexes 1–4 (Fig. 4) were synthesized according to the previously documented method [16, 17]. The tin complex was synthesized by refluxing levofloxacin with triphenyltin chloride in methanol for six hours. To synthesize the Zn, Ni, and Cu complexes, the respective metal salts ($ZnCl_2$, $NiCl_2{\cdot}6H_2O$, or $CuCl_2{\cdot}6H_2O$) were initially dissolved

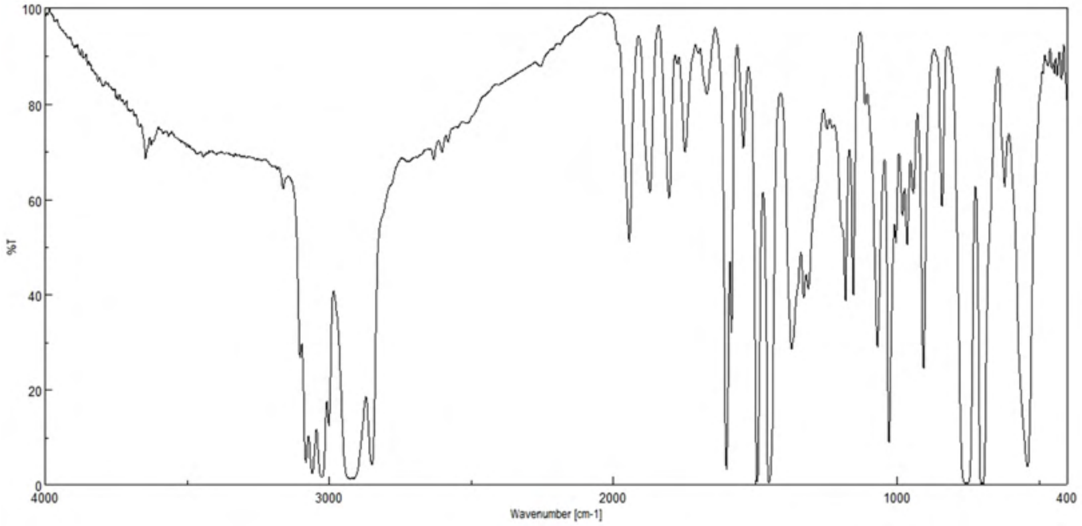

Fig. 5. FTIR spectrum of PS/levofloxacin tin complex film after 300h of irradiation.

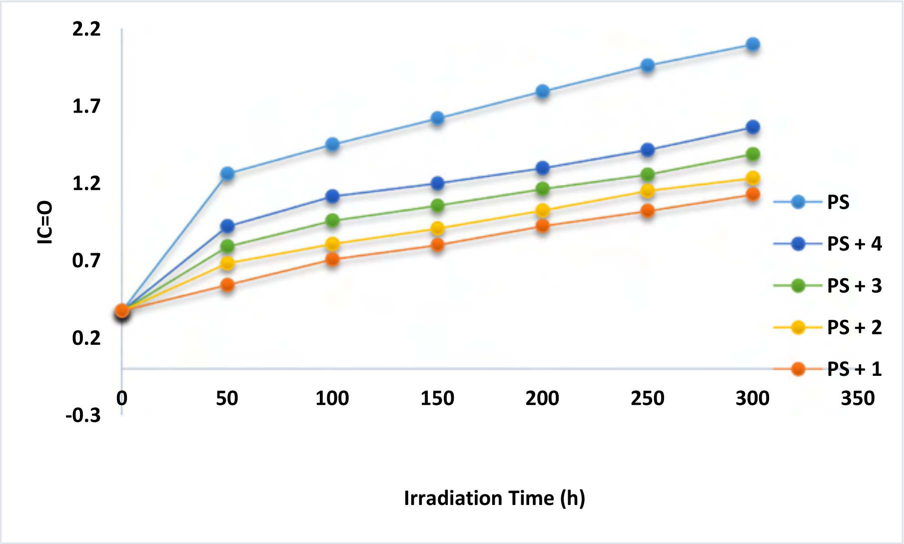

Fig. 6. Effect of irradiation of PS films on carbonyl index.

in 5 mL of methanol and subsequently mixed with a methanolic solution of levofloxacin. Each mixture was then subjected to reflux heating for a duration of 3 hours.

Under prolonged UV exposure and in the presence of oxygen, PS experiences photo-oxidative decomposition. This degradation alters various characteristics of the polymer, including its electrical, optical, mechanical, and chemical properties [18]. A possible pathway for the production of carbonyl groups during PS photo-oxidation is shown in Fig. 5 [19].

The IR signal intensity associated with the carbonyl group in PS can serve as a measure of photodegradation. To evaluate this, FTIR spectra of unmodified PS films were obtained before and following irradiation treatment. The results indicated a significant enhancement in the C=O absorption peak at 1720 cm^{-1} following irradiation in comparison to the initial film. The C–C bond peak at 1328 cm^{-1} was chosen as a reference [20]. The carbonyl group index ($I_{C=O}$) was calculated using Eq. (1). As indicated in Fig. 4, $I_{C=O}$ changed with irradiation period from 0 to 300 h. PS films with 0.5 Wt.% % levofloxacin metal complexes exhibited reduced $I_{C=O}$ values upon irradiation compared to the control films. The most substantial alterations in $I_{C=O}$ transpired during the initial 100 hours, whereas fluctuations in the final 100 hours (200–300 hours) were comparatively negligible, as shown in Fig. 6.

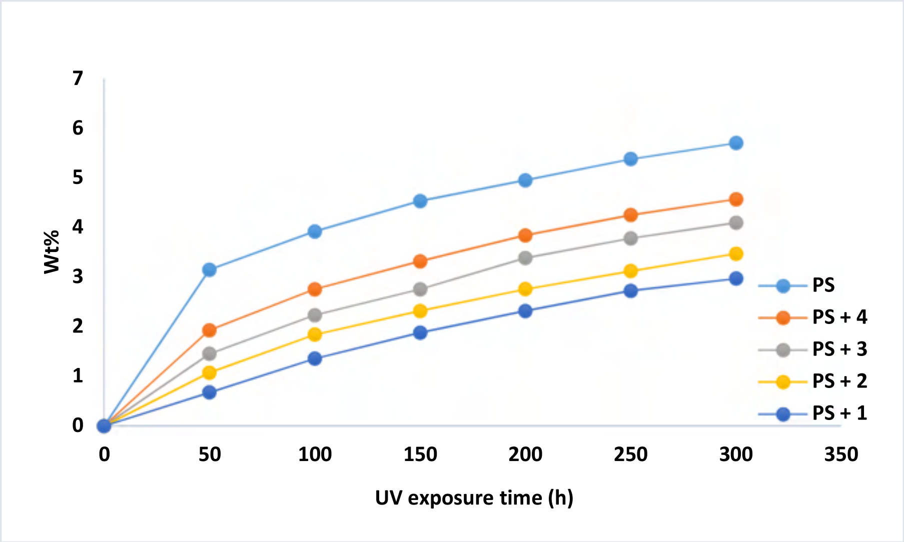

Fig. 7. Weight loss of levofloxacin metal complexes.

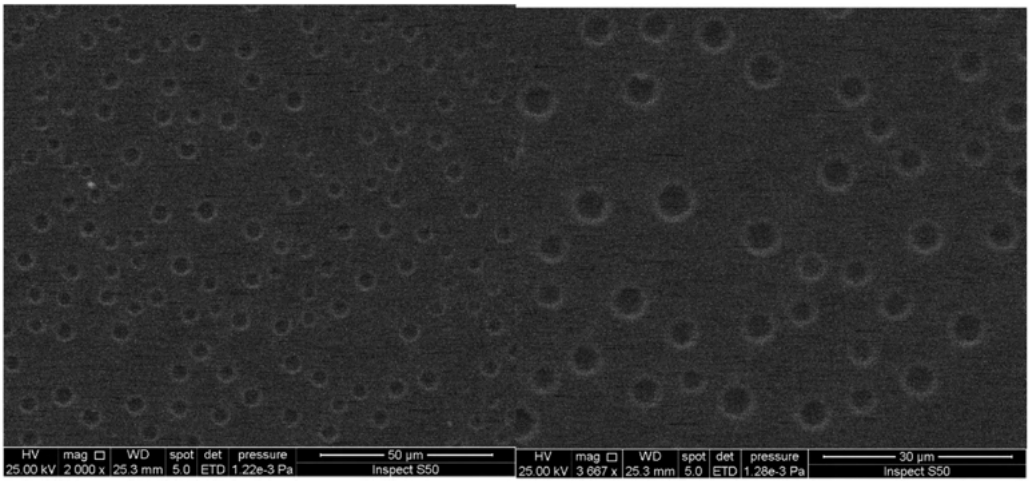

Fig. 8. FESEM images of levofloxacin zinc complex.

On exposure to UV light in a high-temperature environment, polystyrene rapidly changes from colorless to yellow and gradually becomes brittle with the formation of fine fragments, reducing its weight [21]. PS films were thus irradiated for up to 300 hours, and their weight loss was calculated according to Eq. (2). Fig. 7 illustrates how the weight of PS evolved as a function of time during irradiation. The largest weight decrease occurred during the first 50 hours, while the weight continued to decrease much more gradually between 50 and 300 hours. The blank PS films showed significant weight loss compared with those loaded with levofloxacin metal complexes.

FESEM represents a powerful method for the investigation of polymer surface morphology, hence providing information about their interior structures [22]. The surface of PS can be imaged with high resolution by means of electron beams. Incorporation of levofloxacin metal complexes into PS significantly changed the particle size after 300 hours of UV irradiation and resulted in irregular distribution on the surface. The FESEM images of pristine PS films presented a very rugged surface after irradiation, whereas the PS/levofloxacin complex blends retained an essentially undamaged and compact texture with just slight degradation on the surface (Figs. 8 to 11).

PS films containing the metal complexes of levofloxacin showed remarkable resistance toward UV radiation, which pointed to the enhanced chemical stability of the blends. In addition, FESEM characterizations indicated small particles with various morphologies, like spherical and embedded ellipsoidal shapes. The presence of spherical features can be attributed to strong light absorption and multi-

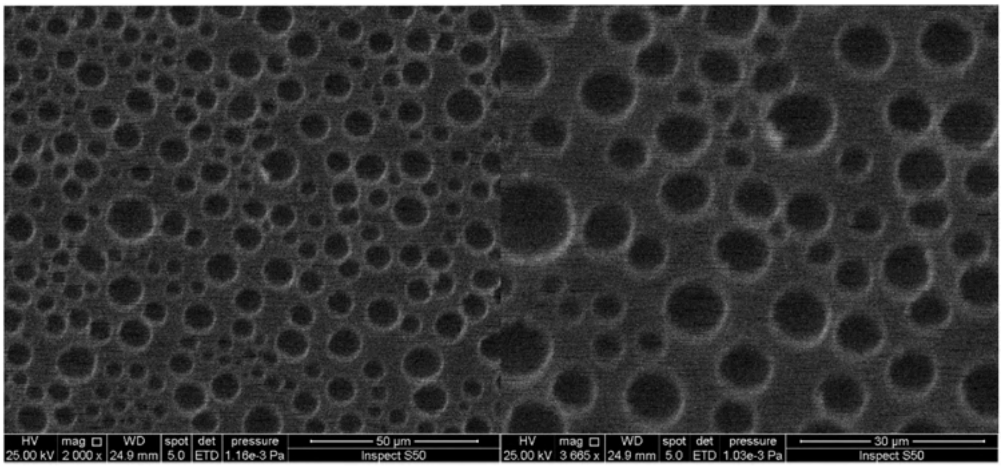

Fig. 9. FESEM images of levofloxacin tin complex.

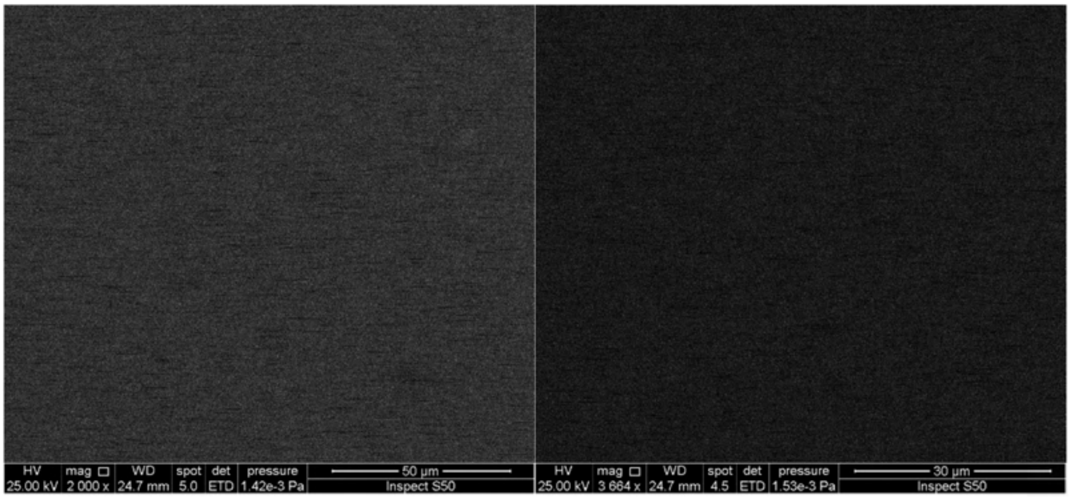

Fig. 10. FESEM images of levofloxacin copper complex.

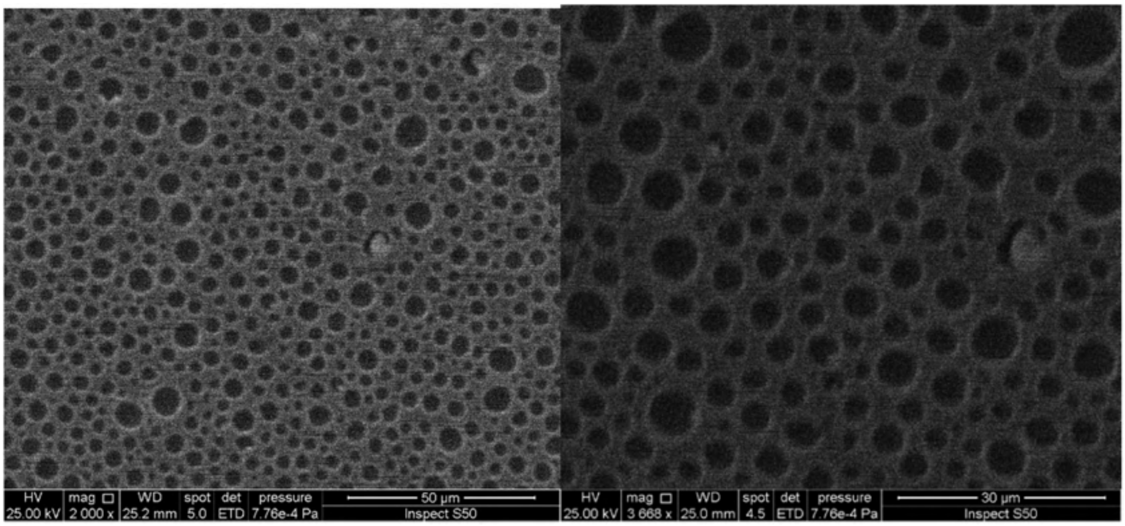

Fig. 11. FESEM images of levofloxacin nickel complex.

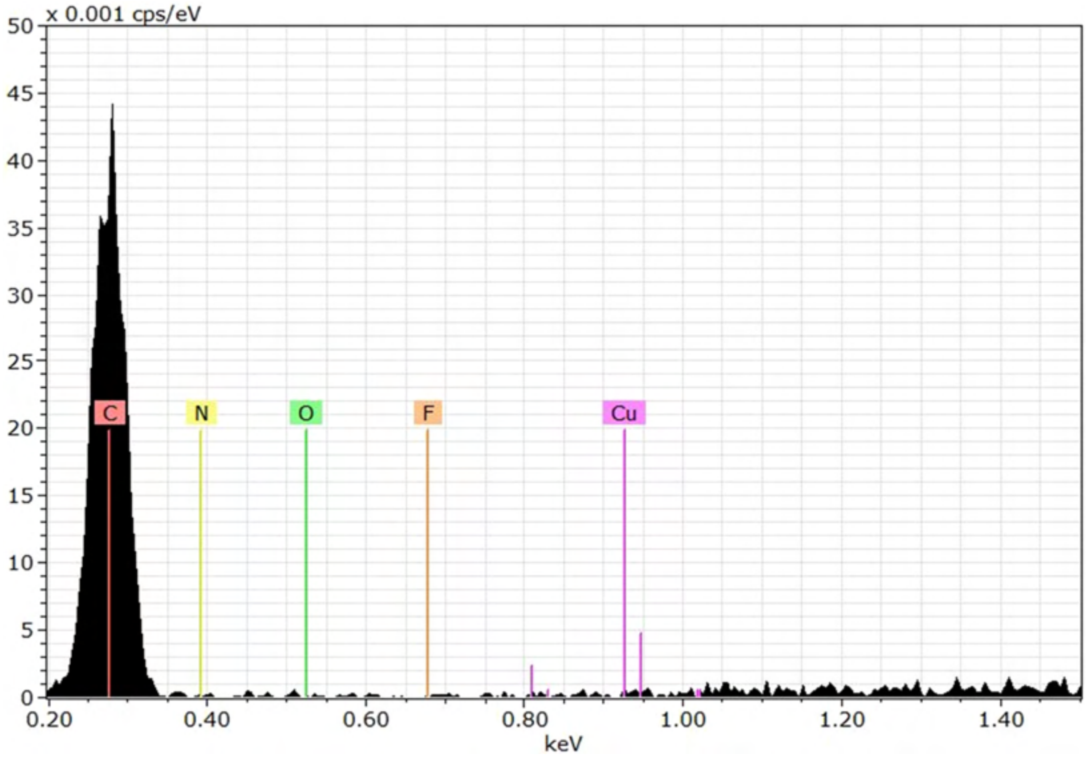

Fig. 12. EDX for levofloxacin copper complex.

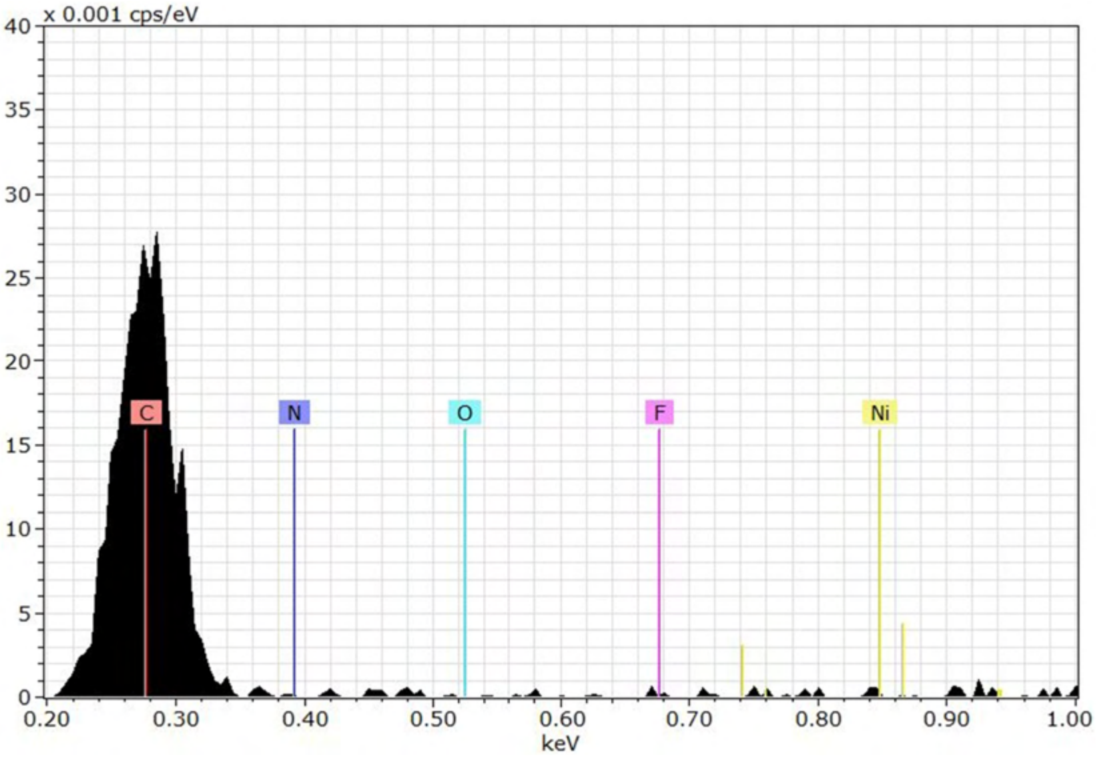

Fig. 13. EDX for levofloxacin nickel complex.

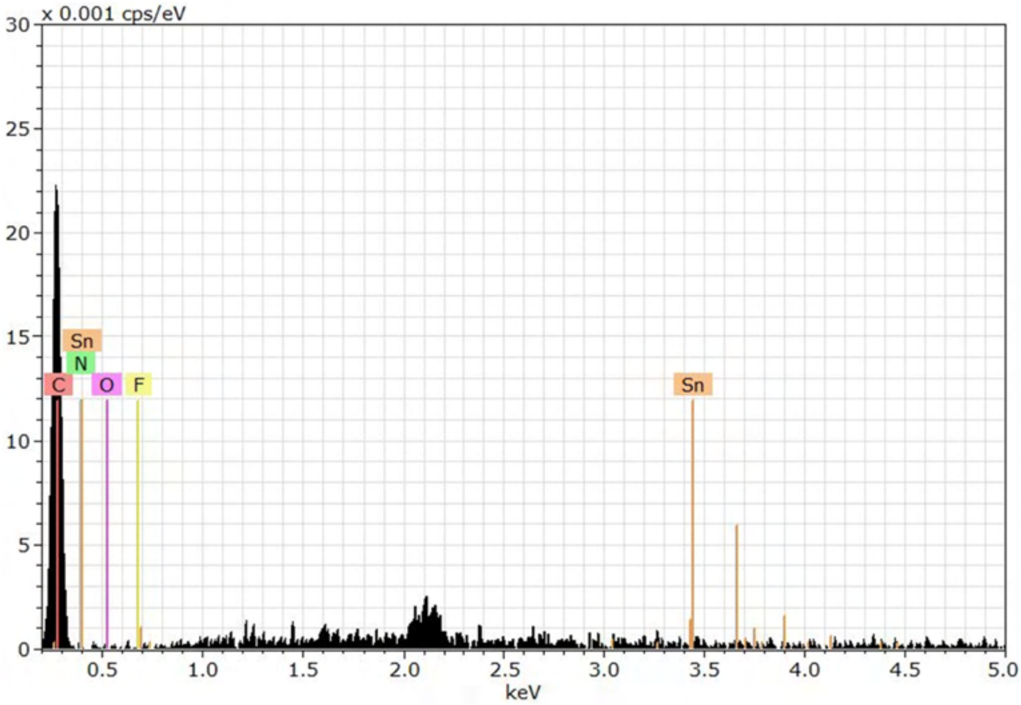

Fig. 14. EDX for levofloxacin tin complex.

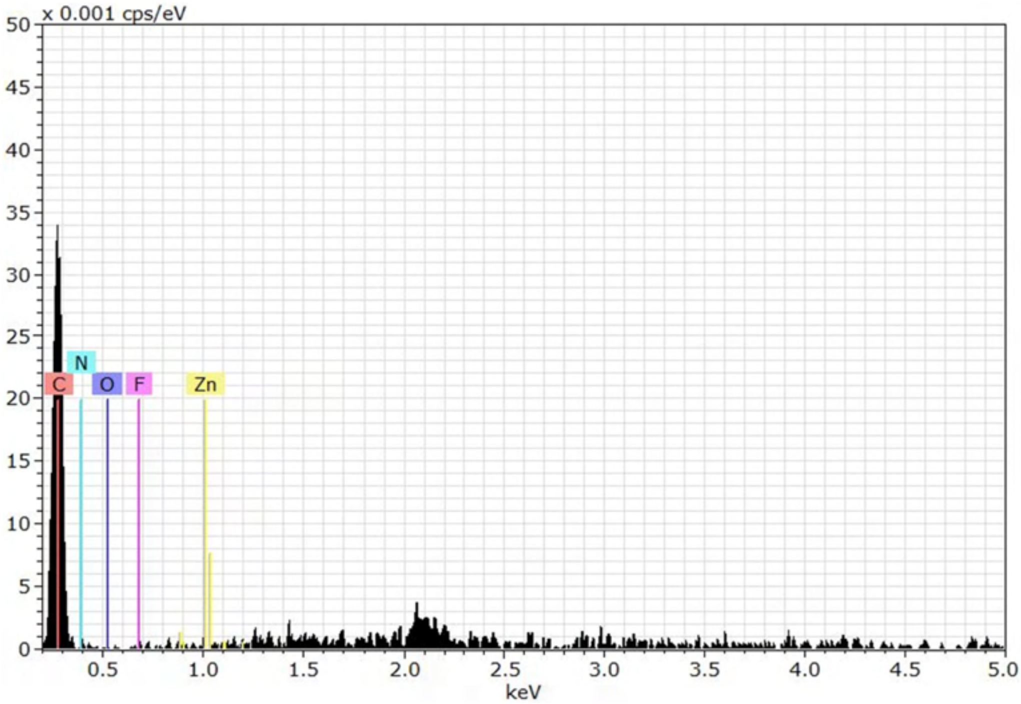

Fig. 15. EDX for levofloxacin zinc complex.

porous structural characteristics of levofloxacin metal complexes [23].

EDX spectroscopy of the PS films showed clear absorption bands, confirming the presence of levofloxacin metal complexes, as depicted in Figs. 12 to 15. The studies confirmed that the complexes were successfully incorporated into the polymer network. The images revealed that the morphology of the surface of the films was different, depending on the concentration of levofloxacin metal complex

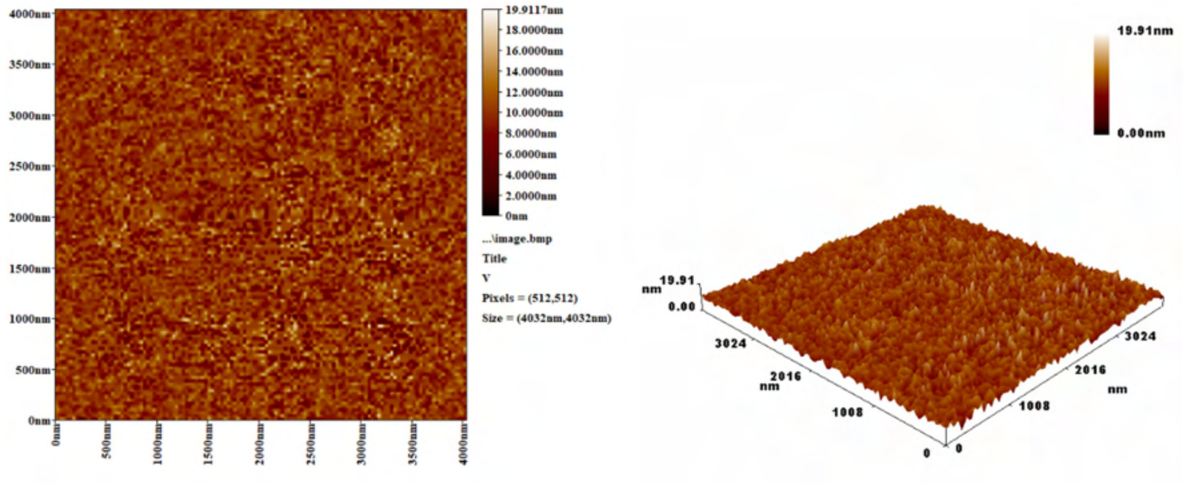

Fig. 16. AFM images for levofloxacin copper complex.

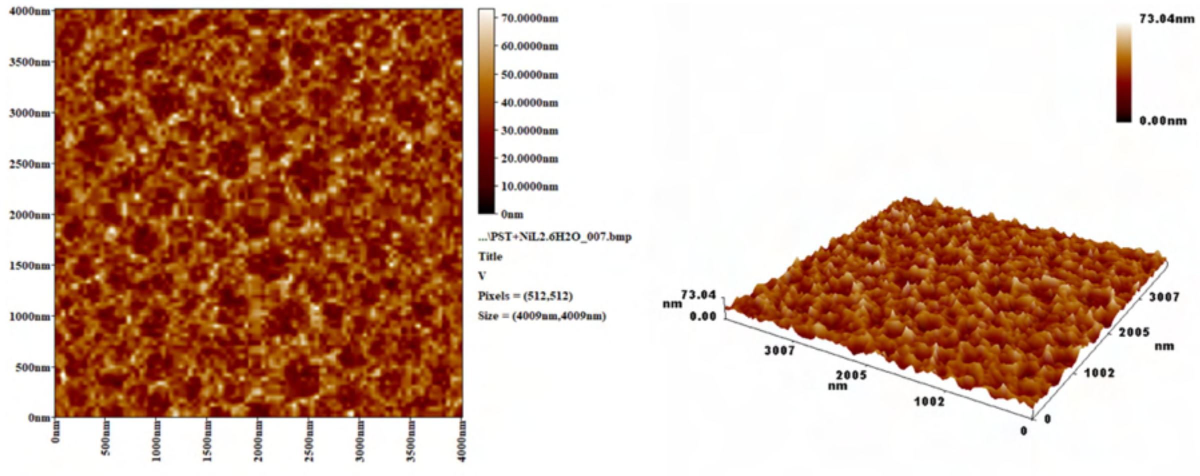

Fig. 17. AFM images for levofloxacin nickel complex.

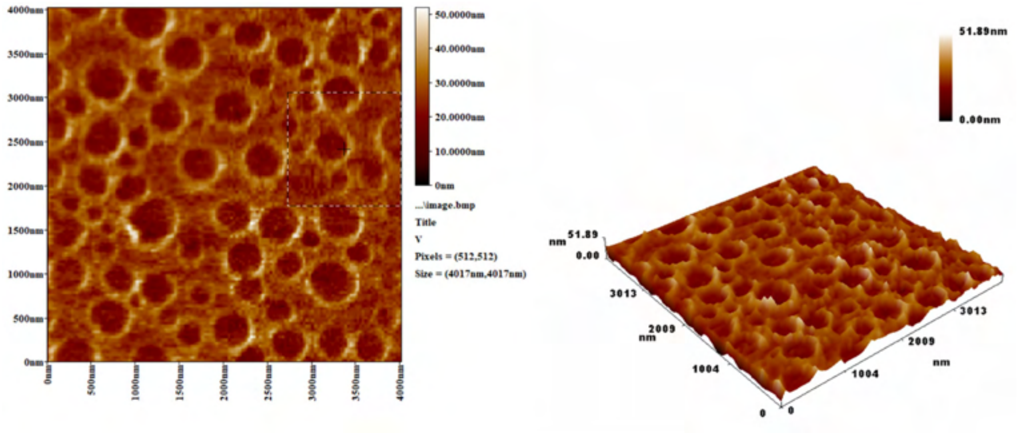

Fig. 18. AFM images for levofloxacin tin complex.

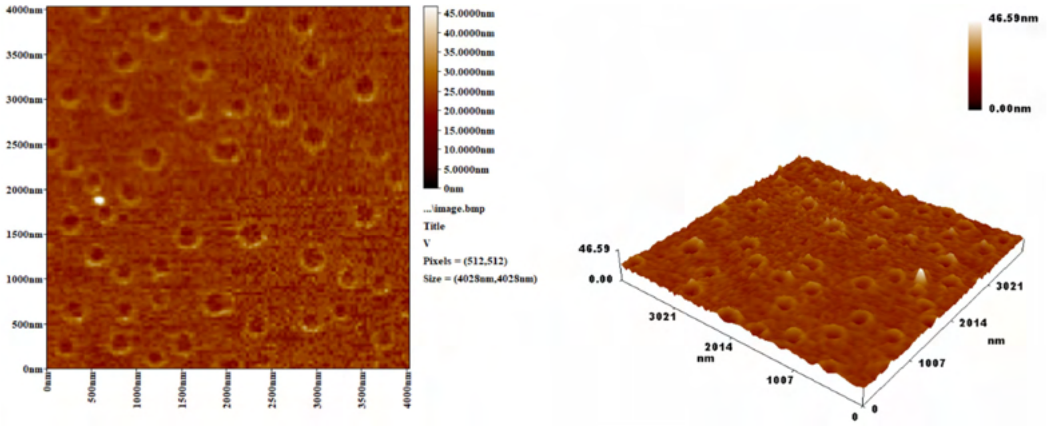

Fig. 19. AFM images for levofloxacin zinc complex.

incorporated. EDX elemental analysis also showed the presence of new peaks in the modified polymers. While EDX does not give precise quantitative information, it gives useful information about the surface composition, showing a significant enhancement in the oxygen signal with respect to the neat PS films [24, 25].

AFM is a high-resolution scanning microscopy technique that is one of the most useful tools to investigate the surface morphology and particle features of materials [26]. PS films initially showed smooth surfaces in both two- and three-dimensional AFM images. The unmodified PS film, on the other hand, showed a rough texture after UV irradiation, indicating severe photodegradation. In contrast, the PS films with levofloxacin metal complexes showed lower surface roughness. Measured values of roughness for PS + 4, PS + 3, PS + 2, and PS + 1 films were 84.1, 77.6, 51.3, and 45.8 nm (Figs. 16 to 19), respectively.

4. Conclusions

Polystyrene is well known for its high susceptibility to UV-induced photodegradation, which limits its long-term performance and practical applications. In this study, four novel levofloxacin-based metal complexes incorporating Zn, Sn, Cu, and Ni were successfully synthesized and evaluated as low-loading (0.5% w/w) photostabilizing additives for polystyrene films. The composite PS films prepared by solution casting demonstrated notable resistance to UV-induced degradation during prolonged irradiation periods of up to 300 hours.

Comprehensive characterization using FT-IR spectroscopy, mass loss analysis, SEM, and AFM confirmed that all levofloxacin metal complexes significantly suppressed the photodegradation process. The additives effectively reduced the formation of carbonyl groups, minimized polymer weight loss, and preserved surface integrity by limiting roughness, cracking, and microscale damage typically observed in irradiated pure PS films. In addition, prolonged UV exposure led to the controlled formation of microspherical surface features, indicating a strong interaction between the polymer matrix and the metal complexes.

The enhanced photostabilization performance is attributed to the high aromaticity of the levofloxacin ligand and the presence of heteroatoms and metal centers, which likely promote efficient UV absorption and free-radical scavenging mechanisms. These combined effects reduce photo-oxidative chain scission and delay the degradation pathways of polystyrene.

Overall, the results establish levofloxacin metal complexes as efficient, low-concentration photostabilizers capable of significantly improving the UV durability of polystyrene. Their effectiveness, ease of incorporation, and strong stabilizing performance highlight their potential for future industrial and commercial applications in polymer materials exposed to outdoor or high-UV environments. Future studies may focus on long-term weathering performance and optimization of metal–ligand structures to further enhance stabilization efficiency.

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Conflict of interest

The authors declare that there is no conflict of interest.

Author contributions

All authors have the same contributions.

Data availability statement

All data will be available when request from the authors.

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References

1. C. W. Yeung, J. Y. Teo, X. J. Loh, and J. Y. Lim, “Polyolefins and polystyrene as chemical resources for a sustainable future: challenges, advances, and prospects,” *ACS Materials Letters*, vol. 3, no. 12, pp. 1660–1676, 2021.
2. Z. He, K. Asare-Yeboah, and S. Bi, “Polystyrene applications in organic electronics,” *Discover Electronics*, vol. 1, no. 1, p. 33, 2024.
3. X. Zhang, Z. Yin, S. Xiang, H. Yan, and H. Tian, “Degradation of polymer materials in the environment and its impact on the health of experimental animals: a review,” *Polymers*, vol. 16, no. 19, p. 2807, 2024.
4. C. Maraveas, I. V. Kyrtopoulos, K. G. Arvanitis, and T. Bartzanas, “The aging of polymers under electromagnetic radiation,” *Polymers*, vol. 16, no. 5, p. 689, 2024.
5. A. Chamas, H. Moon, J. Zheng, Y. Qiu, T. Tabassum, J. H. Jang, . . . and S. Suh, “Degradation rates of plastics in the environment,” *ACS Sustainable Chemistry & Engineering*, vol. 8, no. 9, pp. 3494–3511, 2020.
6. G. A. El-Hiti, D. S. Ahmed, E. Yousif, O. S. Al-Khazrajy, M. Abdallh, and S. A. Alanazi, “Modifications of polymers through the addition of ultraviolet absorbers to reduce the aging effect of accelerated and natural irradiation,” *Polymers*, vol. 14, no. 1, p. 20, 2021.
7. T. Yang and Y. Xing, “Polystyrene Upcycling via Photocatalytic and Non-Photocatalytic Degradation,” *Molecules*, vol. 30, no. 15, p. 3165, 2025.
8. T. Chen, H. Wang, Y. Chu, C. Boyer, J. Liu, and J. Xu, “Photo-Induced Depolymerisation: Recent Advances and Future Challenges,” *ChemPhotoChem*, vol. 3, no. 11, pp. 1059–1076, 2019.
9. M. Asandulesa, A. M. Solonaru, A. M. Resmerita, and A. Honciuc, “Thermal and Dielectric Investigations of Polystyrene Nanoparticles as a Viable Platform—Toward the Next Generation of Fillers for Nanocomposites,” *Polymers*, vol. 15, no. 13, p. 2899, 2023.
10. M. Chen, M. Zhong, and J. A. Johnson, “Light-controlled radical polymerization: mechanisms, methods, and applications,” *Chemical reviews*, vol. 116, no. 17, pp. 10167–10211, 2016.
11. K. Cerdan, M. Thys, A. C. Cornellà, F. Demir, S. Norvez, R. Vendamme, . . . and J. Brancart, “Sustainability of self-healing polymers: A holistic perspective towards circularity in polymer networks,” *Progress in Polymer Science*, vol. 152, p. 101816, 2024.
12. S. O’Halloran, A. Pandit, A. Heise, and A. Kellett, “Two-photon polymerization: fundamentals, materials, and chemical modification strategies,” *Advanced Science*, vol. 10, no. 7, p. 2204072, 2023.
13. C. Chatgilialoglu, C. Ferreri, and K. Matyjaszewski, “Radicals and dormant species in biology and polymer chemistry,” *ChemPlusChem*, vol. 81, no. 1, pp. 11–29, 2016.
14. V. Enwemiwe, A. Oladipo, M. O. Nnyia, J. O. Ayodeji, O. Ejeromedoghene, M. Alowakennu, and G. O. Tesi, “Trace metals encapsulated biopolymers as nanobiocides for crop protection: A review,” *Journal of Trace Elements and Minerals*, vol. 7, p. 100113, 2024.
15. I. Nugrahani, M. R. Sulaiman, C. Eda, H. Uekusa, and S. Ibrahim, “Stability and antibiotic potency improvement of levofloxacin by producing new salts with 2, 6-and 3, 5-dihydroxybenzoic acid and their comprehensive structural study,” *Pharmaceutics*, vol. 15, no. 1, p. 124, 2022.
16. M. Fadhil, E. Yousif, D. S. Ahmed, B. M. Kariuki, and G. A. El-Hiti, “Synthesis and application of levofloxacin–tin complexes as new photostabilizers for polyvinyl chloride,” *Polymers*, vol. 14, p. 3720, 2022.
17. H. Adil, H. Thamer, D. S. Ahmed, R. Alsayed, M. Bufaroosha, K. Zainulabdeen, and E. Yousif, “Synthesis and Characterization of Zn (II), Cu (II), and Ni (II)-Levofloxacin Complexes for Carbon Dioxide Storage Media,” *Indonesian Journal of Chemistry*, vol. 23, no. 5, pp. 1384–1393, 2023.
18. B. Enko, S. M. Borisov, J. Regensburger, W. Bäumler, G. Gescheidt, and I. Klimant, “Singlet oxygen-induced photodegradation of the polymers and dyes in optical sensing materials and the effect of stabilizers on these processes,” *The Journal of Physical Chemistry A*, vol. 117, no. 36, pp. 8873–8882, 2013.
19. P. C. Lucas and R. S. Porter, “Carbonyl functional groups in photo-oxidized polystyrene,” *Polymer degradation and stability*, vol. 13, no. 4, pp. 287–295, 1985.
20. C. Campanale, I. Savino, C. Massarelli, and V. F. Uricchio, “Fourier transform infrared spectroscopy to assess the degree of alteration of artificially aged and environmentally weathered microplastics,” *Polymers*, vol. 15, no. 4, p. 911, 2023.
21. C. Li and P. Li, “Prediction of Yellowing of Polystyrene Materials under Natural Weathering Exposures,” *Applied Mathematics*, vol. 15, no. 12, pp. 834–839, 2024.
22. B. Lewczuk and N. Szyryńska, “Field-emission scanning electron microscope as a tool for large-area and large-volume ultrastructural studies,” *Animals*, vol. 11, no. 12, p. 3390, 2021.
23. D. S. Ahmed, A. Mohammed, A. A. Husain, G. A. El-Hiti, M. Kadhom, B. M. Kariuki, and E. Yousif, “Fabrication of highly photostable polystyrene films embedded with organometallic complexes,” *Polymers*, vol. 14, no. 5, p. 1024, 2022.
24. A. Bamisaye, M. A. Adekola, S. M. Abati, N. O. Etafo, O. S. Ademola, P. T. Joseph, . . . and M. A. Idowu, “Recent advances in metal/metal-oxide nanoparticle-polymer nanohybrid for biomedical applications,” *Materials Today Chemistry*, vol. 49, p. 103086, 2025.
25. A. Lo Presti, F. N. Molinari, C. Abate, E. Fazio, C. Corsaro, O. Giuffrè, . . . and C. Foti, “Electrochemical Detection of Levofloxacin Using a Polydopamine-Based Molecular Imprinting Polymer,” *Molecules*, vol. 31, no. 1, p. 52, 2025.
26. M. Marrese, V. Guarino, and L. Ambrosio, “Atomic force microscopy: a powerful tool to address scaffold design in tissue engineering,” *Journal of functional biomaterials*, vol. 8, no. 1, p. 7, 2017.