

Fabrication and Photophysical Response of Fluorescent Polyolefin-based Fibres and Films Incorporated with Perylene Diimide Derivative (EH-PDI-EH)

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Received: 28 April 2026, Revised: 18 August 2026, Accepted: 29 September 2026, Published: 01 October 2026

KEY WORDS

Fluorescent Fibres
Perylene Diimide
Melt Spinning
Hot-pressing
Aggregation Quenching
Polyolefins

ABSTRACT

The development of polyolefin-based luminescent materials has received increasing interest due to their potential applications in labeling, flexible electronics, and security marking. However, incorporating small fluorophore agents into commodity polyolefins such as polypropylene (PP) and polyethylene (PE) remains challenging due to poor compatibility, dispersion, and photostability. To address these limitations, the perylene diimide (PDI) derivative, N, N'-bis(2-ethylhexyl) perylene-3,4,9,10-tetracarboxylic diimide, abbreviated as EH-PDI-EH, was chosen as a fluorescent agent and efficiently incorporated into PP and PE polymer matrices. A range of EH-PDI-EH concentrations (0.01 wt% to 0.8 wt%) was used to investigate the photophysical properties and compatibility in non-polar polymers. To this end, melt blending, melt spinning, and hot-press techniques were used to fabricate fluorescent films and fibres. The prepared fibres and films were characterized for FTIR, UV-Vis spectroscopy, and fluorescence properties. The findings reveal that the host polymer backbones remained chemically stable during the loading of EH-PDI-EH without any aggregates. EH-PDI-EH was homogeneously dispersed at low and intermediate dopant levels (0.01 wt% to 0.16 wt%), which also showed remarkably intense red emission under UV excitation. Additionally, the emission strength increases proportionally to EH-PDI-EH content, especially in PP, due to its flexible molecular chains. However, the fluorescence quantum yields (Φ_f) demonstrate higher fluorescence yields at low concentrations (0.01 wt% to 0.04 wt%) of EH-PDI-EH, which proves that EH-PDI-EH serves as an efficient fluorescent dopant for polyolefins, enabling the production of processable luminescent films and fibres suitable for use in advanced photonic and security applications.

1. Introduction

Fluorescent fibres and thin films represent an advanced class of materials that merge the luminescent properties of organic fluorophores with the structural versatility of polymers [1]. However, their practical use is often limited by complications such as poor compatibility and dispersion of fluorophores within the polymer matrix [2], limited photostability, and emission loss in the solid state [3]. Achieving uniform luminescence with smooth morphology and processability can be challenging, especially when doping with the fluorophores [4–7]. These systems harness light emission from highly excited states while exploiting polymer matrices for their flexibility, expandability, and easy processing, but optimization is still essential to overcome efficiency losses, phase segregation, and long-term stability issues [8–11]. Additionally, the fluorophores are luminescent molecules that absorb light at fixed wavelength patterns, transition

to highly excited electronic states, and subsequently emit luminescence in the form of photons at longer wavelengths through radiative relaxation [12], forming the basis of fluorescence in materials science and light optics. These are classically synthesized through multi-step organic reactions tailored to achieve the desired spectral outcome and properties, high solubility, and long stability [13–15]. Common patterns include perylene diimides (PDIs), derived from perylene-3,4,9,10-tetracarboxylic dianhydride (PTCDA). Other methods involve aggregation-induced emission (AIE) luminogens via polymerization of tetraphenylethene derivatives and aggregation-caused quenching (ACQ); these routes emphasize high quantum yields and compatibility with polymer hosts [16–18].

In this regard, Perylene-diimides (PDIs) and their derivatives have gained significant importance owing to their higher fluorescence quantum yields, often exceeding 90% in dilute solution [19], with excellent photochemi-

cal and thermal stability [20–22]. Perylene molecules consist of five planar benzene rings fused, whose structure and electronic conformation strongly promote the formation of chromophoric aggregates through stacking interactions between the conjugated cores. Perylene diimide's planar, conjugated aromatic cores support efficient π -stacking and electron transport, which support its use as a unique fluorophore in organic electronics, sensors, and imaging [7, 23]. It's a kind of pigment with various colors that are influenced by the packing arrangement. According to the existing literature, owing to the different arrangements and assembly structures, it can theoretically display colors ranging from green to red or even black [15, 24, 25]. Also, it exhibits excellent fluorescence properties in the monomer state, and its fluorescence quantum yield can reach 100%. Although the somewhat strong π - π interaction between PDI molecules results in fluorescence quenching, it also leads to optical and physical property changes in response to environmental stimuli [26, 27]. However, strong intermolecular interactions in the condensed phase lead to high lattice energies, poor solubility [28], and aggregation-induced fluorescence quenching, limiting their ability and performance in solid materials.

To overcome these limitations, numerous strategies have been employed, including core and imide substitution, bulky side-chain engineering, and incorporation into polymer matrices or covalent polymer backbones [29]. At imide positions, the substitution with flexible branched alkyl chains can enhance solubility, stability, and processability while mitigating aggregation behavior, allowing PDI derivatives to be blended into common commodity polymers like polystyrene and bio-based polyesters due to having high solid-state fluorescence quantum yields [30]. Incorporating PDI derivatives into polymer matrices also provides a suitable route to fabricate highly fluorescent fibres, films, and microspheres for applications in anti-counterfeiting, security labeling, and optoelectronic components [31, 32]. However, as one of the significant examples of neutral dyes, the PDIs have a variety of applications in molecular electronics [33, 34], solar cells [35], solar concentrators [13], and as very bright and photostable fluorophores [36–38]. Also, the organic polymers have great photophysical and optical uniformity and very strong chemical compatibility with organic dyes; these remain a desirable source and medium for optical dyes [39]. The main techniques for fabrication include melt spinning and electrospinning for fibre preparation, whereas solution casting or hot-pressing is used for thin film preparation. The incorporation of small fluorophore agents is performed either during polymerization, blending, or post-functionalization techniques. These processes control the polymer melt viscosity for uniform dispersion, high-yielding waveguides in fibres or planar emitters in films through additives like nanoparticles that boost light outcoupling. However, Polypropylene (PP) and polyethylene (PE) are among the most widely used thermoplastic polyolefins due to their low cost, chemical

resistance, and ease of melt processing and hot-pressing. Introducing fluorescent functionality into PP and PE via small-molecule dopants is attractive because it preserves existing processing infrastructure while adding optical performance [38, 40–43].

Here in this research, we report the fabrication of fluorescent films and fibres by the incorporation of an innovative fluorophore agent. In particular, the PDI derivative N, N'-bis(2-ethylhexyl) perylene-3,4,9,10-tetracarboxylic diimide, abbreviated as EH-PDI-EH, was prepared due to having versatile characteristics: branched alkyl chains that efficiently disrupt strong π -stacking to enhance solubility and polymer compatibility. EH-PDI-EH was incorporated efficiently at concentrations of 0.01 wt% to 0.8 wt% into PP and PE through the process of melt spinning and hot-pressing. The morphological and photophysical properties, absorption and emission spectra of films were first characterized to analyze the behavior of the fluorescent agent in non-polar polyolefins, followed by fabrication and photophysical response of fluorescent polyolefin fibres.

2. Materials and Methods

2.1 Experimental Materials

The Perylene diimide derivative, N, N'-bis(2-ethylhexyl) perylene-3,4,9,10-tetracarboxylic diimide, abbreviated as EH-PDI-EH, was prepared according to reference [44]. The host polymers, commercial polypropylene (PP) and polyethylene (PE), were purchased from Sinopharm Group (China). All the chemicals and reagents were of analytical grade and were used without any further purification. The preparation reactions were performed using standard glassware under an inert nitrogen atmosphere.

2.2 Preparation of Masterbatch

The masterbatches of host polymers and Perylene derivative EH-PDI-EH were manually mixed, as the polypropylene (PP) and polyethylene (PE) powder were mixed with different dopant concentrations of EH-PDI-EH. The targeted EH-PDI-EH weight percent concentrations (0.01 wt% to 0.8 wt%) were used with each polymer matrix, keeping the total mass of each sample at 200 g (see Table 1). Furthermore, the EH-PDI-EH and host polymer samples were dried in a vacuum oven at 40 °C overnight to remove the moisture. Additionally, the dried and moisture-free EH-PDI-EH and host polymer powders were manually mixed to achieve homogeneous distribution before melt processing.

2.3 Fabrication Process of Thin Films

The thin fluorescent films of PP and PE loaded with EH-PDI-EH were fabricated by using the hot-press mechanism. Pure and EH-PDI-EH-doped polymer pellets were first obtained by melt spinning, and then the polymer pellets were shaped into bars by using compression molding following the hot-press mechanism (see

Table 1

Concentrations of EH-PDI-EH and host polymers for the preparation of master batches

EH-PDI-EH		Host polymers		Total weightage
Sample (%)	Weightage (g)	PP (g)	PE (g)	(g)
—	—	200	200	200
0.01	0.02	199.98	199.98	
0.04	0.08	199.92	199.92	
0.08	0.16	199.84	199.84	
0.16	0.32	199.68	199.68	
0.3	0.6	199.4	199.4	
0.4	0.8	199.2	199.2	
0.8	1.6	198.4	198.4	

Fig. 1). Pure PP, PE, and EH-PDI-EH-doped pellets with concentrations of 0.01 wt% to 0.8 wt% (see Table 1) were loaded into the polymers, then melt spinning was performed to get the EH-PDI-EH-loaded pellets. For preparing PP films, the polymer pellets were pressed with a pressure of 5 bar at 190 °C temperature, whereas for PE films, the PE pellets were compressed at 3 bar pressure at 150 °C temperature. The prepared films were characterized for UV illumination and corresponding UV-vis and fluorescence spectroscopy measurements.



Fig. 1. Schematic diagram for the fabrication of fluorescent polymeric thin films by the hot-pressing mechanism under specific temperature and pressure

2.4 Fabrication Process of Fluorescent Fibres

The fabrication of fluorescent fibres was performed using the melt spinning process, where the doped material, EH-PDI-EH-PP and EH-PDI-EH-PE, prepared master batch mixtures were fed into the reaction chamber of the extruder (see Fig. 2). Here, the polymer and EH-PDI-EH are melted at a certain temperature [45] and speed [46] to obtain fluorescent fibres. For PP-based fibres, the spinneret zone was operated at 190 °C with a screw speed of 10 rpm. Whereas for PE-based fibres, the melting temperature was 150 °C with a 10-rpm screw speed. The molten polymer is pushed through the spinneret, which results in the production of fluorescent filaments [47]. The extruded filaments were cooled at room temperature by passing over water to cool them rapidly [48]. The filaments were collected at the yarn winder ball attached to the end of the processing setup. Fibres prepared with each EH-PDI-EH concentration were later cut into pieces for examination

under UV light and characterized microscopically and spectroscopically [32].

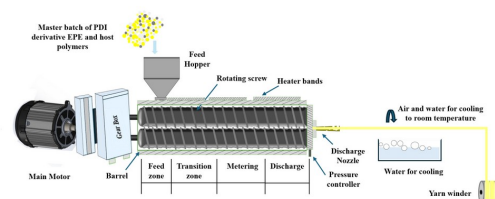


Fig. 2. Schematic illustration for the fabrication of fluorescent fibres by twin extruder melt spinning process connected with a yarn winder ball.

2.5 Characterizations

The prepared filaments and films were characterized for the functional groups by using Fourier transform infrared (FTIR) spectroscopy (Nicolet iS50 spectrometer). The morphology and dispersion of EH-PDI-EH within PP and PE fibres were observed through Fluorescence microscopy (Olympus BX-51 Fluorescent Microscope) under UV excitation. UV-visible absorption spectra were recorded by Thermo Fisher GENESYS 50 to determine the electronic transition. The fluorescence spectra were measured by JASCO FP-6600 to investigate emission properties. The fluorescence quantum yield (Φ_f) was measured using an Edinburgh FLS1000 spectrofluorometer. In addition, qualitative fluorescence observations were made under a 254 nm UV lamp for both fibres and films of PP and PE at varying EH-PDI-EH concentrations. All the above measurements were performed at room temperature.

3. Results and Discussion

The fluorophore agent of perylene-diimide derivative EH-PDI-EH was prepared according to the procedure given in the reference [44] by imidization of perylene-3,4,9,10-tetracarboxylic dianhydride (PTCDA) with 2-ethylhexylamine in molten imidazole. The resulting molecule is a symmetric perylene diimide bearing 2-ethylhexyl substituents at the imide positions. Such branched alkyl chains effectively disrupt strong π - π stacking and help mitigate excessive aggregation, thereby supporting bright fluorescence in the solid state [19]. The EH-PDI-EH was incorporated into PP and PE by melt blending, followed by melt-spinning and hot-pressing to fabricate fluorescent thin films and fibres. The dopant concentration of the EH-PDI-EH varied from 0.01 wt% to 0.8 wt% (see Table 1) to systematically investigate the concentration-dependent emission behavior, aggregation, and structure-property relationships in both films and fibres.

3.1 Structural and Morphological Characterization

The Fourier-transform infrared (FTIR) spectra of pure and EH-PDI-EH-doped PP and PE filaments, as shown

in Fig. 3, display the expected polyolefin backbone vibrations, including C-H stretching bands in the 2800–3000 cm^{-1} region and characteristic bands associated with CH_2 bending and rocking. Upon incorporation of EH-PDI-EH, these main polymer peaks remain essentially unchanged in position and intensity, indicating that the melt blending, spinning, and hot-pressing processes do not chemically degrade the PP or PE chains [2]. Furthermore, the EH-PDI-EH concentration also does not affect the peak intensity and positioning. Additional weak bands attributable to the imide carbonyl stretching $\text{C}=\text{O}$ of the EH-PDI-EH's core and aromatic $\text{C}=\text{C}$ vibrations are observed in the doped samples between 1500–1700 cm^{-1} and are attributable to EH-PDI-EH, although they are relatively small compared to the strong polymer background due to the low EH-PDI-EH concentrations.

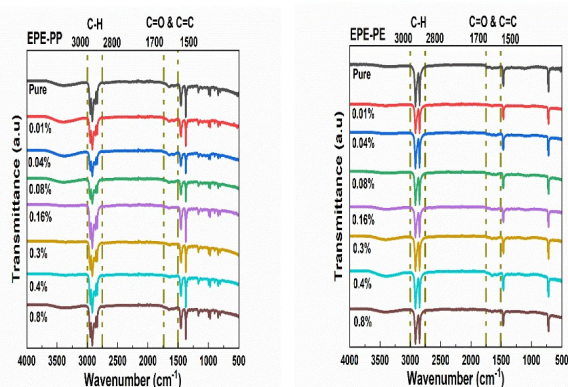


Fig. 3. FTIR spectra of pure and EH-PDI-EH-doped PP and PE Fluorescent Fibres.

The absence of new bands indicative of significant chemical reactions (such as oxidation products or cross-linking) supports the conclusion that EH-PDI-EH is physically dispersed within the polyolefin matrices without covalent bonding to the backbone [38]. This is consistent with the use of EH-PDI-EH as a small-molecule dopant rather than a co-monomer or chain-extender, in contrast to covalently integrated PDI units in polyimides and other engineering polymers.

3.1.1 Microscopy of films and qualitative imaging

Fluorescence microscopic images, as shown in Fig. 4 of polypropylene (PP) and polyethylene (PE) thin films doped with EH-PDI-EH, illustrate that chromophore concentration influences emission uniformity, aggregation, and overall optical performance. At the lowest loading of 0.01 wt%, both PP and PE films exhibit bright, uniformly green fluorescence, signifying a monomerically dispersed phase of EH-PDI-EH with somewhat minimal π - π interactions between molecules [26]. In the intermediate loading range between 0.04 wt% and 0.3 wt%, the PP films continue to display relatively smooth and homogeneous emission, while the PE films begin to exhibit more subtle local bright clusters, suggesting the early onset of new micro-domain creation. However, higher loadings such as 0.4 wt% to 0.8 wt% marked aggregation in both matrices, forming new

bright domains amid dimmer regions and causing partial quenching; nevertheless, both polymers preserve smoothness and mechanical integrity as well. On the whole, PP films have exhibited marginally better uniformity in their fluorescence and retention of optical properties at relatively low EH-PDI-EH concentrations as compared to PE, making PP the more suitable choice for applications that require consistent emission [41]. This illustrates the important relationship between the polymer matrix, dopant concentration, and the aggregation behavior when designing bright, stable, and mechanically durable fluorescent fibres.

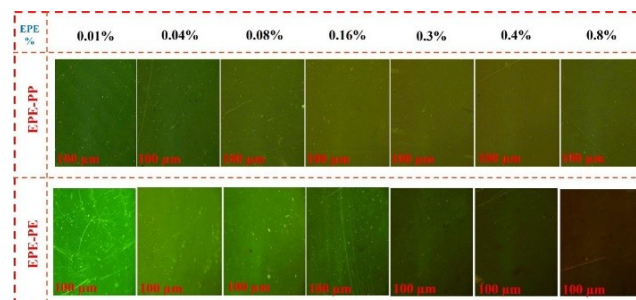


Fig. 4. Fluorescence microscopic images of PP and PE films doped with EH-PDI-EH.

Additionally, under ambient light, pure PP and PE thin films appear colorless and non-fluorescent, as expected for undoped polyolefins. When irradiated with a 254 nm UV lamp, the results show that EH-PDI-EH-PP and EH-PDI-EH-PE films exhibit bright red fluorescence, and the fluorescence intensity increases with an increase in EH-PDI-EH concentration.

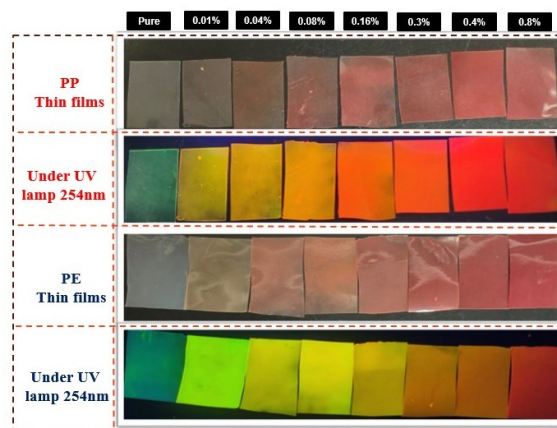


Fig. 5. Digital images of fluorescent polymeric thin films in ambient and under a 254 nm UV lamp for comparison against the EH-PDI-EH loading concentration.

Fig. 4–5 confirms that EH-PDI-EH remains photophysically active after melt processing and hot-pressing. At low dopant loadings, the films display relatively uniform emission, as shown in Fig. 5, resulting in desirable outcomes, especially for PP-based films. It was observed that increasing the EH-PDI-EH concentration increases the color tone towards reddish for PP and PE host polymers, with a similar pattern and behavior. The UV lamp irradiation shows that with an increase in concentration, the PP and EH-PDI-EH change the fluorescence color from greenish (0.01%) to reddish (0.8%), which shows the increased presence of EH-PDI-EH [26]. Further, we analyzed the fluorescence microscopic structure and

photophysical properties of the fluorescent fibre.

3.1.2 Microscopy of fibres and qualitative imaging

Fig. 6 shows the pure and EH-PDI-EH-loaded fibres of PP and PE under daylight and UV irradiance. The results reveal that increasing the concentration of EH-PDI-EH loading enhances the fluorescence glow in the fibre, which is identical to established principles. For further analysis, microscopic analysis was performed to investigate the surface morphology and EH-PDI-EH loading behavior in fibres. Fig. 7 reveals that the fluorescence microscopic images of EH-PDI-EH-PP and EH-PDI-EH-PE doped fibres show smooth surfaces and uniform diameters over the entire doping concentration range, confirming that the overall fibre morphology and mechanical integrity are preserved [43]. At low EH-PDI-EH concentrations (0.01 wt% to 0.08 wt%), the fibres are nearly identical to the undoped counterparts under transmitted light, suggesting a fine, sub-micron-scale dispersion of the dye without formation of large aggregates detectable by optical microscope. As the loading of EH-PDI-EH increases from 0.16 wt% to 0.3 wt%, faint inhomogeneities and small bright domains become visible under fluorescence imaging, indicating the onset of dopant clustering. Although at higher concentrations (0.4–0.8%), more pronounced bright spots and domains appear along the fibres under UV excitation, consistent with partial phase separation and localized EH-PDI-EH-rich regions. Moreover, no significant defects, voids, breaks, or cracks were observed, suggesting that the mechanical performance of the fibres remains intact across all the dopant concentrations [40–43].

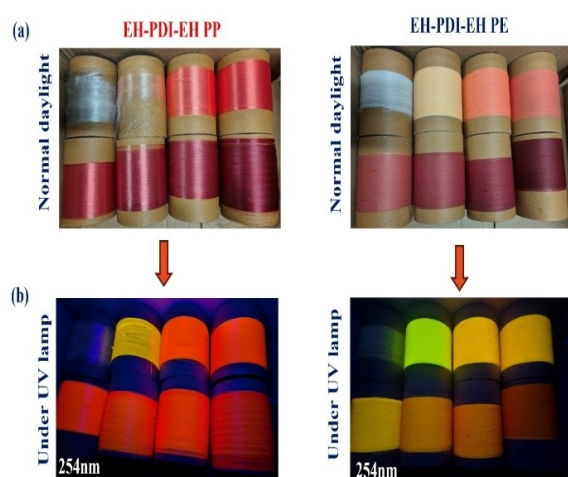


Fig. 6. PP and PE pure and EH-PDI-EH incorporated polyolefin fluorescent filaments; (a) under normal daylight, and (b) under an ultraviolet lamp at 254 nm.

The qualitative characteristics of this concentration-dependent evolution are consistent with earlier findings for PDI-doped polymer microspheres, whereby the aggregation behavior of a PDI chromophore dispersed in a polymeric matrix is influenced by the matrix [49]. Thus, at higher levels of dye loading, the aggregating properties rise and diminish the fluorescence quantum yield [50]. The present study indicates that due to the

hydrocarbon nature of the PP and PE matrices, there are few specific molecular interactions that would prevent the complete isolation of the PDI chromophores [41]. Consequently, as the concentration of dopant in the vicinity of the PDI chromophores increases, the tendency for aggregation will also increase [26]. Notably, all of the fibres demonstrate continuous structural integrity regardless of the level of concentration, without any signs of defects, and cracks [38,40] can be seen in Fig. 7.

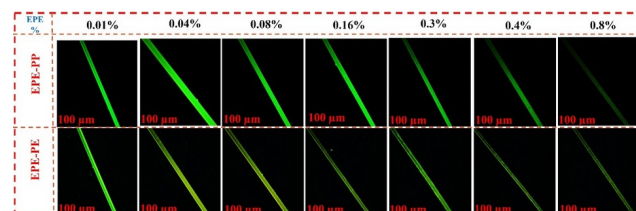


Fig. 7. Fluorescence Microscopic images of EH-PDI-EH loaded PP and PE fibres doped with various concentrations.

3.2 Photophysical Properties of EH-PDI-EH Doped PP and PE Thin Films

As Fig. 8(a) and (c) show, the UV-Vis spectra of EH-PDI-EH-doped PE and PP thin films display characteristic vibronic absorption bands typical of perylene derivatives, with a clear 0-0, 0-1, and 0-2 progression observed between 450 and 550 nm. At the lowest concentration (0.01 wt%), the 0-0 transition dominates, indicating predominantly monomeric dispersion of EH-PDI-EH within both polymer matrices. The sharpness and high relative intensity of the 0-0 peak suggest minimal π - π interactions and effective isolation of chromophores by the polymer matrix. As the EH-PDI-EH loading increases (0.16 wt% to 0.8 wt%), the spectra show broadening and relative intensity reduction of the 0-0 peak, accompanied by a slight increase in the 0-1 and 0-2 vibronic peaks. This spectral evolution signals the onset of H-aggregation or π - π stacking among the planar perylene cores, as aggregation preferentially attenuates the 0-0 transition due to excitonic coupling, while higher vibronic transitions remain comparatively less affected [18].

Fluorescence spectra Fig. 8(b) and (d) mirror these trends. At low concentrations, the emission spectra exhibit well-resolved vibronic peaks corresponding to the 0-0 and 0-1 transitions, confirming monomeric behavior and high radiative efficiency. PP films consistently show stronger 0-0 emission intensity and better retention of the vibronic progression compared to PE, suggesting that the PP matrix better suppresses aggregation-induced quenching. With increasing EH-PDI-EH loading, partial quenching emerges, particularly in PE films, and the 0-0/0-1 intensity ratio decreases, a hallmark of aggregate formation [16]. Additionally, slight red-shifting of the emission maxima at higher loadings indicates weak excitonic interactions in aggregated domains. These observations align with the microscopic fluorescence data, where high EH-PDI-EH concentrations yield localized bright domains amid dim regions,

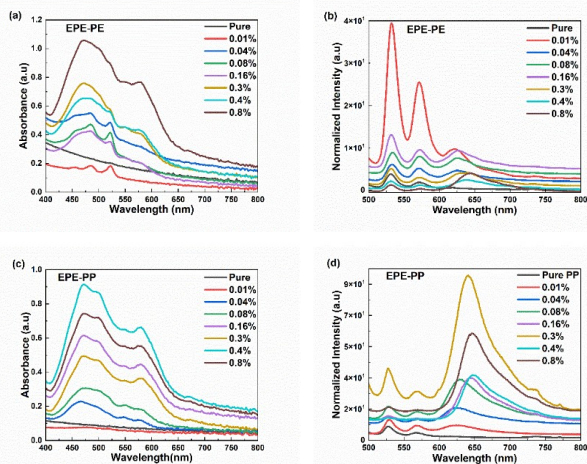


Fig. 8. UV-Vis and Fluorescence spectra of EH-PDI-EH doped PP and PE Thin Films; (a) UV-Vis of PE, (b) Fluorescence of PE, (c) UV-Vis of PP, (d) Fluorescence of PP.

consistent with microaggregate formation.

However, this demonstrates that the polymer matrix plays an important role in controlling the ratio of monomeric to aggregated emissions. In the case of PP, the polymer matrix provides a more favorable environment for maintaining vibronic-resolved fluorescence at the intermediate concentrations as compared to PE, which would suggest that aggregation occurs sooner for PE due to the processing environment parameters, the concentration, the vibronic coupling characteristics of the system, and the flexible molecular chains behavior of PE [41].

3.3 Photophysical Properties of EH-PDI-EH Doped PP and PE Fibres

The absorption and fluorescence spectra of EH-PDI-EH-doped PP and PE filaments, as shown in Fig. 9, exhibit chromophore loadings and their influence on photophysical behavior in solid-state polymer matrices. In the absorption spectra, both PP and PE fibres exhibit well-defined Vibronic transitions of perylene derivatives, with 0-0, 0-1, and 0-2 bands visible between 450 and 550 nm.

However, at the (0.01 wt%) concentration, the sharp 0-0 transition dominates, representing the monomeric dispersion of EH-PDI-EH molecules with minimal π - π stacking. Increasing the doping of EH-PDI-EH from 0.04 wt% to 0.3 wt% enhances overall absorbance and slightly broadens the peaks. Although at higher concentrations (0.4 wt% to 0.8 wt%), further broadening and relative attenuation of the 0-0 peak signal are more pronounced with aggregation.

Additionally, the fluorescence spectra in Fig. 9(b) and (d) show that at low doped concentrations of EH-PDI-EH within PP and PE fibres display strong emission with well-resolved vibronic peaks, confirming high radiative effectiveness. The PP fibres consistently show higher normalized emission intensity and better retention of the vibronic progression compared to PE, signifying that PP more effectively suppresses aggregation-induced

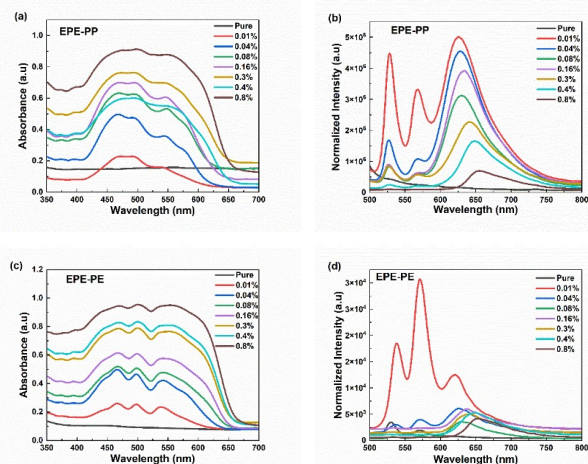


Fig. 9. The UV-Vis absorption and Fluorescence spectra of EH-PDI-EH-doped PP and PE Fibres; (a) UV-Vis of PP, (b) Fluorescence of PP, (c) UV-Vis of PE, (d) Fluorescence of PE.

quenching. As the dopant of EH-PDI-EH increases, fluorescence intensity becomes less uniform, and the 0-0/0-1 peak ratio decreases, indicative of excitonic interactions in microaggregates. Slight red-shifts in emission increase at higher concentrations further support the presence of π - π stacked domains [16,26]. Overall, PP fibres demonstrate superior optical uniformity and higher emission efficiency at moderate EH-PDI-EH loadings, while PE fibres exhibit earlier onset of aggregation, highlighting the critical role of the polymer matrix in modulating chromophore dispersion, vibronic transitions, and solid-state fluorescence performance.

However, the findings reveal that the aggregation-induced quenching occurs mostly through exciton diffusion, leading to the establishment of H-type aggregates, while there is no substantial difference in melt-spun fibres or hot-pressed thin films compared to PP. Although PE has a flexible matrix that permits rapid energy transfer via exciton transport [42], no matter what type of morphology it takes, the fluorescence yields minimal difference between PE melt-spun fibres and hot-pressed thin films, and overall quenching is near 0.08 wt%.

Additionally, the fluorescence quantum yields (Φ_f) of the EH-PDI-EH-doped PP and PE fluorophores are summarized in Table 2. For both fibres and thin films, the quantum yield initially increases with EH-PDI-EH concentration from 0.01 wt% to 0.04 wt%, indicating efficient light emission at low to moderate dopant levels. However, further increasing the EH-PDI-EH content to 0.08 wt% leads to a pronounced decrease in fluorescence quantum yield (Φ_f), particularly in PE fibres and films, which is consistent with the onset of aggregation and non-radiative quenching at higher local chromophore concentrations. These trends show that morphology and host matrix strongly influence fluorescence quantum yield (Φ_f) [17], with PP-based fibres generally exhibiting higher quantum yields than PE-based counterparts at low-to-moderate dopant levels.

Table 2

The fluorescence quantum yields (Φ_f , in %) of the EH-PDI-EH doped PP and PE in different sample forms and dopant concentrations of EH-PDI-EH.

Host polymer	Sample form	Concentrations of EH-PDI-EH (wt%)		
		0.01	0.04	0.08
PP	Fibres	27.5	33.6	9.5
	Thin films	18.2	30	3.25
PE	Fibres	19.6	11.76	7.26
	Thin films	5.5	0.62	7.18

3.4 Comparative Summary of PP vs PE

Overall, the comparison between PP and PE demonstrates that the polymer matrix plays a key role in controlling the optical and morphological response of EH-PDI-EH. At low loadings (0.01 wt% to 0.08 wt%), both matrices exhibit uniform chromophore dispersion, bright fluorescence, and smooth, defect-free morphology, indicating efficient isolation of the fluorophore. At intermediate loadings (0.16 wt% to 0.3 wt%), PP maintains more homogeneous emission and better optical uniformity, whereas PE begins to develop localized fluorescent domains, reflecting the earlier onset of chromophore aggregation. At high loadings (0.4 wt% to 0.8 wt%), both matrices show aggregation-induced spectral broadening, partial fluorescence quenching, and the formation of bright aggregated regions; however, these effects are more pronounced in PE. Despite these optical differences, both PP and PE retain their structural integrity without noticeable morphological defects throughout the investigated concentration range, confirming that the primary distinction between the two matrices arises from their different abilities to suppress chromophore aggregation rather than from changes in bulk morphology.

4. Conclusion

Incorporating perylene-diimide derivative, EH-PDI-EH, at lower concentrations (0.01 wt% to 0.8 wt%) remains challenging due to difficulty in achieving homogeneous dispersion and preventing localized aggregation of dopants within the nonpolar polyolefin matrices at such low loadings. Herein, we have successfully incorporated EH-PDI-EH into PP and PE host polymers via the melt blending technique, followed by fabrication of polyolefin-based films and fibres by melt spinning and hot-pressing, showing excellent photophysical properties without compromising the chemical integrity or bulk morphology of the polyolefin matrices. However, at high dopant levels, H-type aggregation, spectral broadening, and aggregation-induced quenching were observed. FTIR spectroscopy confirmed that the polymer backbones remain intact after processing and that EH-PDI-EH is physically dispersed within the matrix rather than covalently bound.

The fluorescence microscopy and UV light irradiance imaging revealed smooth, continuous fibres and films exhibiting bright red fluorescence under 254 nm excitation, with emission intensity and spatial homogeneity strongly dependent on dopant loading. UV-vis and fluorescence analysis showed that EH-PDI-EH provides efficient visible-range absorption and emission at low concentrations (0.01 wt% to 0.16 wt%), with high fluorescence quantum yields sustained even at these low loadings. Whereas at higher dopant concentrations, H-type aggregation, spectral broadening, and aggregation-induced quenching were observed, consistent with the dispersion challenges noted above and indicating an optimal low-concentration window for maximizing emission efficiency.

Comparative findings of this research reveal that PP fibres offer a more favorable balance between brightness and stability due to shear-assisted dispersion during processing, as compared to PE fibres loaded with EH-PDI-EH, due to a flexible matrix that enables their rapid energy migration regardless of morphology, yielding minimal difference between melt-spun fibres and hot-pressed thin films. These findings establish EH-PDI-EH as an efficient fluorescent dopant for PP and PE, and demonstrate a simple, scalable route for fabricating fluorescent PP- and PE-based films and fibres. This approach offers a promising platform for functional optical materials in applications such as labeling, security, and flexible photonics.

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