Effect of TiO_2 nanoparticles filler on structural, optical, thermal, and mechanical properties of TiO_2/LDPE nanocomposites films

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This study blended low-density polyethylene (LDPE) polymer matrix with titanium dioxide (TiO_2) nanoparticles as UV blocking filler to create a greenhouse cover film. The best properties for greenhouse application were discovered in TiO2/LDPE nanocomposites films with 5% wt TiO_2 nanoparticles, according to the results. TiO2/LDPE nanocomposites films prepared in all conditions can block almost 100% of the UV (200-400 nm) radiation and show good thermal stability. The TiO_2/LDPE nanocomposites films with 5% wt TiO_2 nanoparticles has a light transmittance in the visible range of about 80%, sufficient for plant photosynthesis. In addition, it showed good mechanical properties with 12.142 MPa of tensile strength and 319.274% of elongation at break.

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1. Introduction

Greenhouses are crucial to the sustainability of contemporary civilizations due to the unreliability of conventional agricultural techniques, population growth, and rising food and energy consumption. Industrialization and post-industrial expansion have caused environmental degradation, resulting in global warming, climate change, and unpredictable weather patterns, which reduce the dependability of rain-fed agriculture in arid and semi-arid regions [1]. The ecological sustainability of greenhouse covering materials is evaluated in terms of energy, energy-efficient materials, specific optical properties, and synthesis approaches.

Polymers are commonly utilized in food packaging and greenhouses. Polypropylene (PP) [2-3], polyethylene (PE) [4-5], and polyethylene terephthalate (PET) [6] are typical examples of such materials. Low-density polyethylene (LDPE) is often used to construct agricultural greenhouse cover and mulch films. It is a thermoplastic manufactured by a free radical polymerization process at pressures from 150–350 MPa and temperatures from 80–300 ^{o}C [7]. It provides the advantages of low cost, moisture resistance, good chemical resistance, and food-grade availability while also having the disadvantage of high thermal expansion, inadequate weather resistance, cracking due to stress, and flammability. In addition, the degradation of LDPE used in

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agricultural greenhouse cover is mainly due to radiation in the ultraviolet region. For this reason, many researchers bring fillers to help improve its properties.

Among the various fillers employed, such as clays, silicas, nanotubes, inorganics, etc., titanium dioxide (TiO_2) provides a unique role in polymeric matrices, allowing high-performance and bendable polymer networks to be synthesized. Titanium dioxide pigment (TiO_2) in various particle sizes and phases was commonly utilized as absorption/reflection materials. Furthermore, titanium dioxide in the rutile phase is highly reflective of infrared radiation [1,8].

High PAR transmission, NIR reflection, UV filtration, and light diffusion are essential factors in the development of greenhouse cover material. This characteristic will evenly distribute sunlight inside the greenhouse, increasing the efficiency of plant photosynthesis and preventing the leaves from burning. This paper shows structural, optical, thermal, and mechanical studies on LDPE loaded with TiO_2 nanoparticles at various contents (0, 5, 10, and 15% wt). The goal is to create nanocomposites films that prevent UV radiation while allowing visible light to pass through.

2. Experiment

2.1. Materials

Low-density polyethylene (LDPE) was supplied from the supplier (TPI Polene, Thailand) in pellet form. Titanium dioxide (TiO_2) nanoparticles were supplied from Chemipan, Thailand.

2.2 Preparation of LDPE/TiO2 nanocomposites

LDPE and TiO_2 were compounded in a twin-screw extruder (CT CTE-D20L800). The content of TiO_2 nanoparticles varied from 5-15 %wt. Details of the blends and codes are reported in Table 1. The blend temperature was set at 180 ^{o}C. The extruded polymers were cooled and cut into pellets. All blends were blown into films using a single screw-blown film extruder unit (Southeast SE/HD45MI).

Table 1. Blends composition and codes.

Sample	LDPE (%wt)	TiO2 (%wt)
0% TiO_2	100	0
5% TiO_2	95	5
10% TiO_2	90	10
15% TiO_2	85	5

2.3. Characterization

Scanning electron microscopy (SEM, JEOL JSM-5300) was used to examine the surface morphology of the TiO_2/LDPE nanocomposites films. The optical transmittance spectra of the TiO_2/LDPE nanocomposites were measured using a UV-Vis-NIR spectrophotometer (Agilent G6873A Cary7000) at normal incident light wavelengths ranging from 200 to 2500 nm. The FTIR spectra were examined using a Fourier transform infrared spectrophotometer (Thermoscientific Nicolet i5) at a resolution of 4 cm^{-1} and in the 4000–400 cm^{-1} range. Thermal degradation of the TiO_2/LDPE nanocomposites films was studied by thermogravimetric analysis (TGA, Mettler Toledo TGA 2). The experiments were done from 25 to 850 °C at a heating rate of 10 °C·min−1 under a nitrogen atmosphere (gas flow of 20 mL·min−1). The TiO_2/LDPE nanocomposites films' mechanical properties were measured in a universal tensile tester (Vamtage ITK-10668) according to ASTM D882.

3. Results and discussion

The surface morphology was determined by SEM. The morphology of various LDPE nanocomposites films with 0%, 5%, 10%, and 15%wt TiO_2 addition is shown in Figure 1. It was found that the TiO_2 additive particles were evenly dispersed throughout the LDPE matrix, as seen in Figures 1(b) and 4(d). A greenhouse film's PAR transmission is an important parameter that must be sufficiently high for plant photosynthesis [1]. As a result, this factor was regarded for the newly developed film. From the results shown in Figure 2, the TiO_2/LDPE nanocomposites films showed light transmittance in the UV and visible ranges, with light transmittance up to 80%.

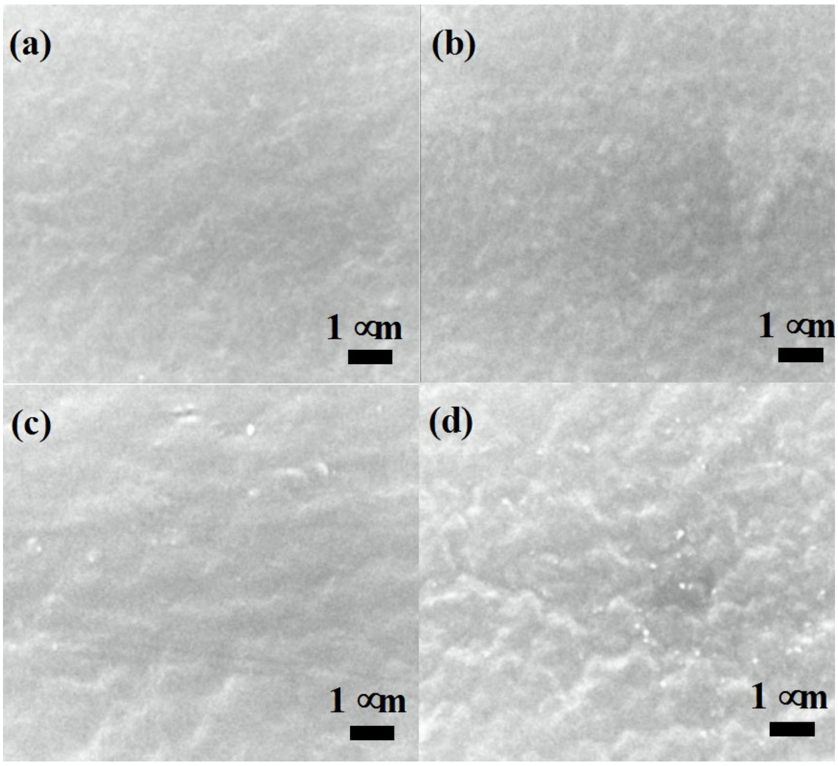

Fig. 1. SEM image of surface morphology of TiO_2/LDPE nanocomposites films containing different contents of TiO_2 nanoparticles (a) 0 %wt, (b) 5w%wt, (c) 10 %wt and (d) 15 %wt.

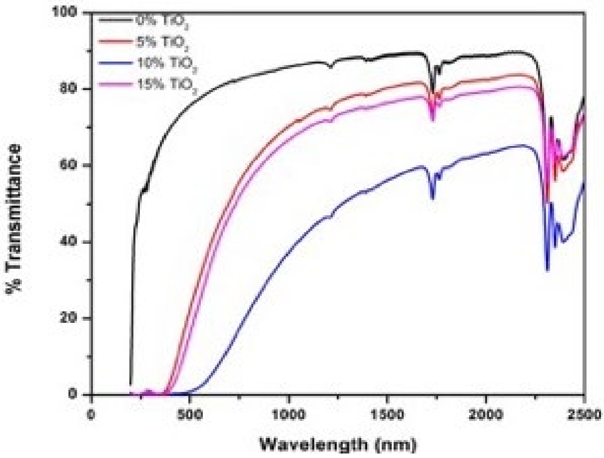

Fig. 2. Transmittance spectra of TiO_2/LDPE nanocomposites films.

Figure 3 shows the chemical structure of unmodified and modified TiO_2 additives analyzed by FTIR. The peaks at 2914 and 2847 cm^{-1} correspond to the CH_2 group, while the peak at 1473 and 716 cm^{-1} are due to the C-H and H-C-H bond, respectively [9, 10]. The peak at 912 cm^{-1} is characteristic of Ti-O bonds, which are found in both TiO_2 and TiO_2/LDPE nanocomposites film. The results confirm the presence of TiO_2 particles on TiO_2/LDPE nanocomposites films [11].

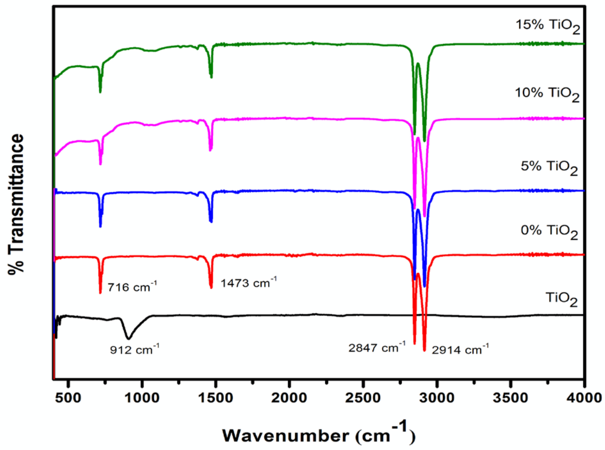

Fig. 3. FTIR spectra of TiO_2/LDPE nanocomposites films.

The thermogravimetric analysis can be used to determine the thermal decomposition temperature. From Figure 4, the percentage weight loss of the TiO2/LDPE nanocomposites films containing TiO_2 content at 0%, 5%, 10%, and 15% by weight at 500 °C were 100%, 97.85%, 91.61% and 94.90%, respectively. The amount of ash formed due to the addition of TiO_2 to LDPE. Since TiO_2 has better thermal stability than LDPE, the decomposition temperature of the TiO_2/LDPE nanocomposites films is higher than LDPE film. As shown in Figure 5, TiO_2/LDPE nanocomposites films with TiO2 content of 0%, 5%, 10%, and 15% by weight had decomposition temperatures of 467.5, 477.3, 480.8, and 480.8 °C, respectively.

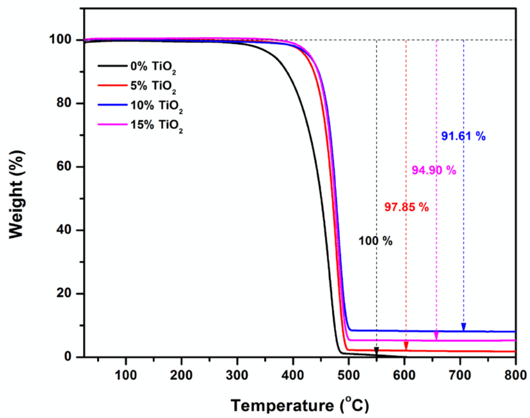

Fig. 4. TGA curves of TiO_2/LDPE nanocomposites films.

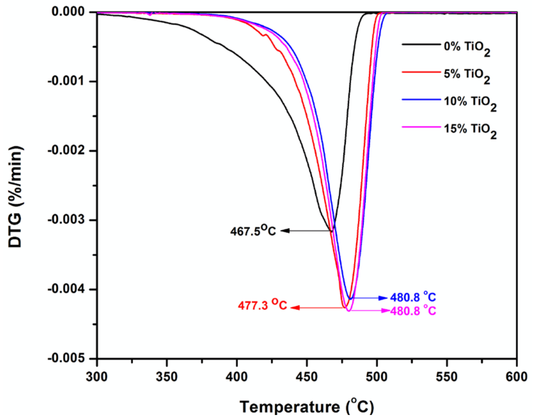

Fig. 5. DTG curves of TiO_2/LDPE nanocomposites films.

The mechanical property of a polymer can help describe its behavior under stress. It provides scientific information about polymer materials that could be useful to scientists and engineers. The mechanical properties of tensile strength and elongation at break were evaluated for the TiO_2/LDPE nanocomposites film, and the results are shown in Table 2 and Figure 6. It can be seen that all mechanical properties of TiO_2/LDPE nanocomposites film decreased as the overall increase in the TiO_2 nanoparticles content increased, excluding TiO_2/LDPE nanocomposites film containing 5 %wt TiO2 nanoparticles. The highest tensile strength of 12.14 MPa was achieved with a TiO_2/LDPE nanocomposites film containing 5 %wt TiO_2 nanoparticles. However, an increase in the loading of TiO_2 nanoparticles by over 5 %wt reduced the tensile strength. This may be due to the poor adhesion between the filler nanoparticles and the required LDPE matrix, which weakens the interfacial zone formed between the polymer and the TiO_2 nanoparticles. The elongation at break of the TiO_2/LDPE nanocomposites films decreased with the increasing amount of TiO_2 nanoparticles.

Table 2. Summary of tensile data of TiO_2/LDPE nanocomposites films.

Sample	Tensile Stress (MPa)	Elongation at break (%)
0% TiO_2	11.542	394.758
5% TiO_2	12.142	319.274
10% TiO_2	10.433	202.359
15% TiO_2	9.709	183.844

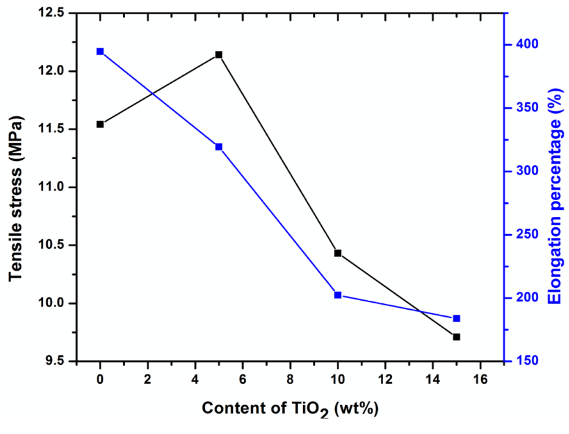

Fig. 6. Combination of strength and elongation versus the content of TiO_2 nanoparticles.

4. Conclusion

In this work, TiO_2/LDPE nanocomposites films were prepared and characterized to evaluate their potential uses as greenhouse cover. The variables considered for this research was TiO_2 nanoparticles content (0%, 5%, 10%, and 15% wt). The effect of TiO_2 nanoparticles content on the structural, optical, thermal, and mechanical properties of the TiO_2/LDPE nanocomposites film was considered. The TiO_2/LDPE nanocomposites films in all conditions have almost 100% UV blocking capability and increased thermal stability. The TiO_2/LDPE nanocomposites films containing TiO_2 of 5% wt TiO_2 are suitable for application as greenhouse cover. It has an approximate light transmittance of 80% in the visible range. In Addition, it showed good mechanical properties with 12.142 MPa of tensile strength and 319.274% of elongation at break. The findings of this work provide preliminary data that will be utilized to choose the optimum condition for producing large-scale nanocomposites films that will be employed as greenhouse covers in the future.

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