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The effects of thermal aging and ultraviolet radiation aging on the performance of greenhouse plastic films with different thicknesses

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Abstract

Due to Taiwan's hot and humid climate, it is necessary to consider the haze, tensile strength, and aging resistance of greenhouse plastic films of different thicknesses to evaluate whether replacement is required. This study focuses on commonly used commercial plastic films in Taiwan's agricultural facilities, mainly composed of linear low-density polyethylene (LLDPE), with thicknesses of 0.15 mm, 0.18 mm, and 0.20 mm. These greenhouse films were subjected to artificial accelerated aging through thermal aging and ultraviolet (UV) radiation to understand how aging affects the mechanical properties of films of different thicknesses.According to ASTM D3045 standards, standard samples were heated at 90°C for 110 hours, 336 hours, and 576 hours, equivalent to storing samples at 30°C for one, three, and five years, respectively. For UV radiation aging (ASTM D4329 standard), standard samples were exposed to UV lamps with wavelengths ranging from 360 nm to 400 nm, and the cumulative UV energy required for one year of exposure was calculated based on the recorded instantaneous UV intensity.The results showed that the initial maximum elongation at break for 0.15 mm, 0.18 mm, and 0.20 mm films was 865.7%, 967.4%, and 1019.37%, respectively, all of which decreased with increased aging time. The initial tensile strength of the 0.15 mm film was 17.58 MPa. After one year of thermal aging, the tensile strength increased to 19.35 MPa, but significantly decreased to 15.95 MPa in the third year. For the 0.18 mm and 0.20 mm films, tensile strength decreased with longer thermal aging durations. Haze test results for different thicknesses showed that films subjected to thermal aging had higher haze values than those subjected to UV radiation aging. These findings contribute to evaluating the performance changes over time of commercial greenhouse plastic films of different thicknesses.

Keywords: Greenhouse, Plastic Film, Thermal Aging, Ultraviolet, Haze

INTRODUCTION

Greenhouse plastic films play a crucial role in modern protected agriculture by effectively regulating the microclimatic conditions required for crop growth, thereby enhancing both yield and quality. However, prolonged exposure of these materials to external environmental factors such as high temperature, oxygen, and solar radiation—particularly ultraviolet (UV) radiation—can induce photo-oxidative and thermo-oxidative aging reactions. These processes deteriorate the physical and chemical properties of the films, ultimately impairing their mechanical performance and service life. In addition, film thickness is a critical factor influencing aging behavior and durability [1]. Films of different thicknesses exhibit significant differences in light penetration and heat conduction, which may result in varying rates of degradation and mechanical deterioration. While thicker films generally possess superior mechanical strength and greater resistance to UV radiation, they may also experience accelerated degradation due to internal heat accumulation. Conversely, thinner films, with higher light transmittance, are more prone to surface-level aging. This study evaluates the aging behavior and mechanical property changes of agricultural plastic films with different thicknesses, providing a scientific basis for material selection and replacement cycles in greenhouse construction, as well as for predicting service life.

MATERIALS AND METHODS

In this study, greenhouse plastic films of different thicknesses commonly used in Taiwanese agricultural facilities were selected as the primary materials, with thicknesses of 0.15 mm, 0.18 mm, and 0.20 mm. Film aging was simulated through thermal treatment in a constant-temperature oven and ultraviolet (UV) irradiation. Thermal aging was performed in accordance with ASTM 3045, where samples were heated at 90 °C for 110, 336, and 576 hours [2], corresponding to simulated aging of one, three, and five years under an environmental temperature of 30 °C. UV aging was conducted according to ASTM D4459-06, in which standard samples were placed in a custom-built UV chamber and exposed to UV radiation with wavelengths of 365–400 nm (Fig. 1(a)). The cumulative UV exposure was then calculated to represent one year of natural UV radiation in Taiwan.

The haze test of the films was performed in accordance with ASTM D1003 using a haze meter [3], measuring parallel transmittance, diffuse transmittance, total transmittance (parallel + diffuse transmittance), and haze (diffuse transmittance/total transmittance × 100%). Tensile testing of the films followed ASTM D882, where film samples were cut into standardized specimens with a width of 20 mm and a length of 150 mm (Fig. 1(b)). These specimens were mounted on a tensile testing machine (Fig. 1(c)) and stretched at a crosshead speed of 500 mm/min to obtain force–displacement curves, which were then converted into stress–strain curves for analysis of maximum tensile strength and elongation at break.

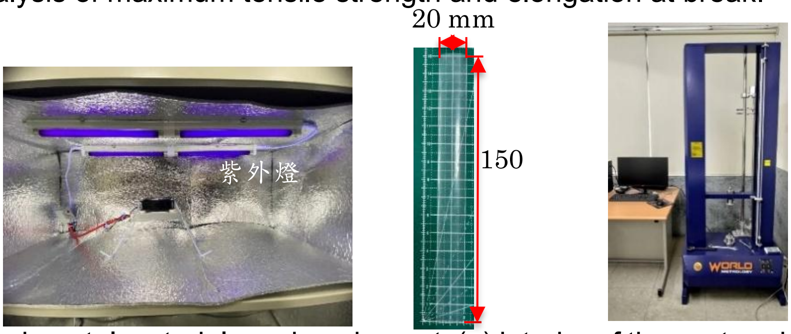

Figure 1. Experimental materials and equipment: (a) interior of the custom-built ultraviolet (UV) chamber, (b) standardized film specimen, and (c) tensile testing machine.

RESULTS & DISCUSSION

This study analyzed the haze variations of greenhouse plastic films with different thicknesses (0.15 mm, 0.18 mm, and 0.20 mm) to evaluate changes in their optical properties under thermal and ultraviolet (UV) aging conditions. The results indicated that haze increased with aging time for all films, although different thicknesses exhibited distinct trends and stability, as shown in Table 1. This phenomenon is presumed to be related to the relaxation of the film structure upon heating, which increases light scattering. The initial haze values of the 0.15 mm, 0.18 mm, and

0.20 mm films were 31.48%, 35.84%, and 41.26%, respectively, and increased to 40.13%, 50.27%, and 50.25% after three years of thermal aging. The increase was most pronounced in the 0.18 mm film, whose haze rose by 14.43% compared with its initial value. This is likely due to structural degradation in crystalline regions and microstructural variations on the surface caused by long-term thermal exposure, which significantly enhanced scattering. However, the change from the third to the fifth year of thermal aging was relatively modest, suggesting that haze stabilized during this period.

Under UV aging, haze also increased across all thicknesses. The 0.15 mm film reached a haze of 37.17%, slightly higher than the value observed after one year of thermal aging (36.48%), suggesting that this thickness is more sensitive to UV radiation. Similarly, the 0.18 mm and 0.20 mm films exhibited haze values of 40.77% and 42.61%, respectively, both exceeding their one-year thermal aging values. This further confirms that UV aging exerts a stronger impact on the surface optical quality of films compared to equivalent thermal aging, a finding consistent with photo-oxidative degradation mechanisms [4].

Overall, film thickness, aging time, and aging method significantly influenced haze behavior. The 0.15 mm film, although exhibiting the lowest initial haze, demonstrated better long-term stability. The 0.20 mm film, while starting with a higher haze, showed superior resistance to degradation. In contrast, the 0.18 mm and 0.20 mm films require closer monitoring after three years of use due to potential optical deterioration.

Table 1. Haze properties of plastic films with different thicknesses under various aging treatments

Aging status	Thickness 0.15 mm		Thickness 0.18 mm		Thickness 0.20 mm	
	Haze ** (%)	Total light transmittance (%)	Haze (%)	Total light transmittance (%)	Haze (%)	Total light transmittance (%)
Initial	31.48^{C}	91.02	35.84^{C}	91.37	41.26^{B}	92.25
Heat aging 1 year	36.48^{B}	92.71	37.38^{C}	92.83	42.05^{B}	93.01
Heat aging 3 years	40.13^{A}	93.32	50.27^{A}	93.37	50.25^{A}	94.06
Heat aging 5 years	41.55^{A}	93.93	52.20^{A}	93.58	52.06^{A}	94.35
UV aging 1 year	37.17^{B}	93.12	40.77^{B}	92.52	42.61^{B}	93.61

* The number of standard test samples is 50

** Mean values,Different capital letters in the same row indicate significant differences ($p < 0.05$) in the average haze values at different aging levels, using Tukey's HSD test.

The tensile test results of films with different thicknesses are shown in Tables 2 to 4. As presented in Table 2, the tensile strength of the 0.15 mm film increased from 17.58 MPa to 19.35 MPa after one year of thermal aging, which may be attributed to initial heat-induced crosslinking or chain segment rearrangement leading to structural densification. However, the strength decreased with prolonged aging, dropping to 15.94 MPa after three years, and slightly recovering to 16.55 MPa after five years, indicating that its mechanical properties are strongly affected by long-term thermal degradation. In contrast, the tensile strength of the 0.18 mm (Table 3) and 0.20 mm (Table 4) films exhibited a continuous decline, decreasing from 20.79 MPa to 16.03 MPa and from 22.32 MPa to 19.22 MPa, respectively. This suggests that although thicker films initially demonstrate superior mechanical strength, degradation of the polymer backbone under long-term thermal exposure remains unavoidable.

The results of maximum elongation also revealed significant deterioration. The 0.15 mm film showed a slight increase to 601.52% after the first year, but subsequently decreased to 531.36%. The 0.18 mm film exhibited the greatest reduction, dropping sharply from an initial value of 967.42% to 169.32% after five years, suggesting that medium-thickness films are particularly sensitive to thermal-aging-induced deterioration of ductility. By contrast, the 0.20 mm film decreased from 1019.37% to 587.78%, still maintaining relatively better elongation capability.

Table 2. Thickness 0.15 mm Film tensile test

Aging status	tensile strength ** (MPa)	Maximum elongation (%)
Initial	17.58±2.44^{BC*}	537.89±112.46
Heat aging 1 year	19.35±1.72^{B}	601.52±87.71
Heat aging3 years	15.94±1.90^{C}	559.25±178.75
Heat aging 5 years	16.55±2.67^{BC}	531.36±141.19
UV aging 1 year	18.86±1.58^{A}	649.34±78.70

* The number of standard test samples is 50

** Mean values,Different capital letters in the same row indicate significant differences ($p < 0.05$) in the average haze values at different aging levels, using Tukey's HSD test.

Table 3. Thickness 0.18 mm Film tensile test

Aging status	tensile strength ** (MPa)	Maximum elongation (%)
Initial	20.79±1.43^{B*}	967.42±158.83
Heat aging 1 year	19.03±1.82^{BC}	706.53±110.09
Heat aging3 years	16.37±2.43^{D}	508.1±399.35
Heat aging 5 years	16.03±1.35^{CD}	169.32±313.72
UV aging 1 year	22.15±2.22^{A}	638.93±109.15

* The number of standard test samples is 50

** Mean values,Different capital letters in the same row indicate significant differences ($p < 0.05$) in the average haze values at different aging levels, using Tukey's HSD test.

Table 4. Thickness 0.20 mm Film tensile test

Aging status	tensile strength ** (MPa)	Maximum elongation (%)
Initial	22.32±2.17^{A*}	1019.37±154.16
Heat aging 1 year	21.04±2.01^{A}	961.88±125.14
Heat aging3 years	19.77±2.43^{B}	829.75±221.38
Heat aging 5 years	19.22±2.17^{B}	587.78±337.40
UV aging 1 year	21.86±2.01^{A}	872.41±125.14

* The number of standard test samples is 50

** Mean values,Different capital letters in the same row indicate significant differences ($p < 0.05$) in the average haze values at different aging levels, using Tukey's HSD test.

CONCLUSIONS

This study investigated three commercially available greenhouse plastic films in Taiwan with different thicknesses (0.15 mm, 0.18 mm, and 0.20 mm), evaluating their mechanical and optical property changes after thermal aging (1, 3, and 5 years) and ultraviolet (UV) aging (1 year). The results indicated that, during thermal aging, the tensile strength and elongation at break of all three film thicknesses generally exhibited a degradation trend. The 0.15 mm film showed a temporary increase in tensile strength after one year of thermal aging, which is presumed to be related to early-stage thermally induced structural reorganization; however, its performance subsequently declined rapidly, indicating limited durability. In contrast, the 0.18 mm and 0.20 mm films demonstrated relatively stable tensile performance. Haze increased significantly with aging time for all thicknesses, with a marked rise observed after the third year of aging. These findings provide a basis for assessing the durability of greenhouse plastic films with different thicknesses and can inform material selection and replacement cycle planning in agricultural practice, thereby enhancing the overall operational efficiency of protected cultivation systems.

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