Product Performance

Studies of polyethylene multi layer films used as greenhouse covers under Saharan climatic conditions

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Received 19 May 2005; accepted 6 July 2005

Abstract

The behavior with regard to abrasion of a new generation of polymeric greenhouse covers presenting a sandwich structure made of three layers, one EVA19 layer inserted between two low density polyethylene layers, has been studied. Optical, thermal, surface analysis and mechanical properties have been analyzed on samples having undergone different thermal treatments associated with sand and wind simulation in order to test their performance when used in a Saharan environment. The data analysis is performed by comparing these results with those obtained on a monolayer polyethylene film often used in Algeria for plasticculture devices. The performance of these new multi layers materials is found better than that obtained for the mono layer film, with regard to the mechanical, the optical properties and resistance to the abrasion effect due to sand/wind.

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Keywords: Polyethylene; Multi layers; Ageing; Greenhouse

1. Introduction

The large development of greenhouse plasticulture in Mediterranean and African countries as observed, for instance, in Algeria in the last few decades leads to new outlets for farmers and has an important economic impact factor [1,2]. However, less satisfying is the consequence from an environmental point of view. Indeed, as a major part of the greenhouse, plastics have been developed initially for European and American countries, and it was quite reasonable that the standards requirements have been formulated using the corresponding climatic environments [3–5]. In sub Saharan or Mediterranean climatic conditions the European or American standards cannot work [6,7]. One perfect example is greenhouse covers in south Algeria, which exhibit an average life time duration close to one year, which is very small. It follows that the destruction of the plastic creates a lot of waste, not collected, that blows away everywhere—in the desert, in the sea—leading to the well known plastic pollution problem. To overcome this difficulty three possibilities occur to us. The first one is to banish plastic and to come back to glass cover. This is not a reasonable proposition because the cost would be too high. The second could be to seriously organize waste collection and a recycling protocol. This is a more reasonable solution, but up to now its efficiency has not been proved in these countries, in spite of the fact that it is technically feasible. The last solution consists of diminishing the amount of waste by increasing the life of the plastic. It may be noted that the two last propositions are not in opposition but are complementary.

To increase the life of the greenhouse cover, we have to analyze the behavior of the cover under normal usage conditions (climate, sand–wind), thus allowing us to select
2. Materials and methods

The material used is a film manufactured by PROSYN-POLYAN®. This film is made of three layers: low density polyethylene/poly(ethylene vinyl acetate) copolymer/low density polyethylene (LDPE/EVA19/LDPE, the copolymer is obtained with 19% W/W of vinyl acetate). During the film extrusion, an expansion process of the central layer has been performed leading to the existence of air bubbles confined between the two LDPE layers. The geometry obtained is a film with a thickness of ≈220 μm, each LDPE layer having a thickness of ≈20 μm. Fig. 1 gives a schematic representation of this complex structure.

The different samples studied in this work are: sample A is the initial PE monolayer film studied previously [9]. Sample B is PE monolayer film after sand/wind treatment performed for 4 h at 40 °C. Sample C is the initial new three layers film. Sample D is the three layer film after sand/wind treatment performed for 4 h at 40 °C. Sample E is the three layer film with only an annealing at 40 °C for 4 h and sample F is the three layer film with only an annealing at 40 °C for 8 h. Sample G is the three layer film after sand/wind treatment performed for 8 h at 40 °C.

The effects of sand and wind were simulated with an apparatus developed in our laboratory [9]. The equipment is composed by a thermostated tube, a sand/wind chamber and a keyboard control. From an air turbine, the flux is heated up to an experimental temperature ($T=40 \degree C$), under a pressure of 100 kNm$^{-2}$, inside the thermostated tube. The mass flow of air is about 1.128 kg/m³. This dry air is introduced in the sand/wind chamber where natural sand particles were deposited. There follows a Brownian-like movement of the sand particles that strike randomly on the polymer surface.

The existence of chemical modifications of the polymeric surfaces has been checked by determining the free surface energy of the different samples by means of contact angle measurements. Three reference liquids, ultra pure water (milli-Q WaterSystem, resistivity 18 Ωcm), glycerol and diiodomethane, were used. All measurements were carried out at room temperature (23 °C). For each liquid deposited on the sample surface, we made an average of five measurements. A drop of 3 ml, deposited with a micro syringe, was photographed with a black and white CCD camera (500×500). Contact angle θ was determined from a computerized contact angle meter (NFT Communications Company, Tours, France).

UV–visible spectroscopy was achieved with a Perkin Elmer Lambda 9, in transmission mode, with a scanning velocity of 4 nm$^{-1}$.

The IR spectra were obtained with a FTIR spectrometer (Avatar 360), using ATR (attenuated total reflection) with a Ge crystal, by collecting and averaging 32 scans, at a resolution of 4 cm$^{-1}$. IR spectra are presented in reflection.

Calorimetric measurements were performed by means of a Mettler Toledo FP85 apparatus. Samples of ≈ 10 mg, put in an aluminum pan, were heated in air from ambient up to 200 °C with a heating rate of 10 °C/min. Calibrations in temperature and energy were achieved by measuring the temperature and the enthalpy of melting of Indium.

Tensile tests of films were carried out on a universal testing machine (Instron model 4301). The tests were performed using a load cell of 5 kN at a cross head speed of 2 mm/min. Determination of tensile modulus (E), was obtained from the tangent at the origin of the stress–elongation curve.

3. Results and discussion

From UV–visible spectroscopy measurements, Fig. 2 shows the percentage of transmitted light as a function of the wavelength obtained for samples C and D. For comparison, the data obtained previously on samples A and B are also reported. For the whole domain of the UV–visible wavelengths scanned in this work, the light transmission is found to be greater for sample A (mono layer) than for sample C (multi layers). That is not surprising considering the thickness of the films. More surprising is the role played by the sand and wind. Indeed, for samples A and B (mono layer) the erosion process leads to drastic decrease of the light transmitted (by two in the whole wavelength domain), as pointed out in reference [9], while for samples C and D (multi layer) the inverse behavior is revealed by the increase
of the light transmission after a sand/wind test performed at 40 °C for 4 h. In fact, it appears that the sand particles stamp the material surface like many small hammers with high enough energy to be able to break some air bubbles. This breaking leads to decrease in the number of bubbles and at the same time to increase their surface by connecting them. This phenomenon is associated with small deformations of the sample surface (Fig. 3).

Fig. 4 shows the IR spectra obtained on a LDPE (used as a reference) a poly (vinyl acetate) (used as the second reference), for samples E and D (4 h at 40 °C), and for samples F and G (8 h at 40 °C, without and with sand/wind erosion respectively). For these IR measurements, the spectra are normalized by using the band corresponding to the CH₂ group located at 2920 cm⁻¹. For all the spectra, modifications occur for bands located at 1470 cm⁻¹ and 1430 cm⁻¹, and for a small band located at 1640 cm⁻¹ (arrows on Fig. 4). The bands at 1470 and 1430 cm⁻¹ occur only for the sample having undergone a thermal treatment of 8 h at 40 °C and a sand/wind test. These bands are characteristic of silicon compounds [11], and are due to small sand particles inlaid on the sample surface. For the monolayer film, the same effect of particle inclusions on the surface have been reported for samples aged only for 4 h and the amplitude of the modifications was found more important [9]. The small band located at 1640 cm⁻¹ observed for the multi layer samples is due to the existence of additives in the sample composition and varies such that the higher the annealing temperature and the higher the annealing duration, the lower the band magnitude. The progressive disappearance of this band could be due to a migration of these added molecules toward the sample surface. During ageing, these molecules can be easily removed, for instance because of surface washing. A second possibility could be an oxidization process, however such evidence of oxidization effects requires larger ageing durations (several months) [8,9,12]. Hence, we find that the multi layer samples exhibit a better resistance to abrasion than the monolayer sample.

The effects of sand inclusions have been revealed also by means of free surface energy measurements for monolayer samples. To check this point, the free surface energy measurement was performed on the multi layers samples. The methods used consist of determining the contact angle that different liquids make on the sample surface. According to the relationship proposed by Young and Dupré [13] and Fowkes [14], and with the Owens Went method [15], this free surface energy is obtained from:

\[
\gamma(1 + \cos \theta) = 2\sqrt{\gamma_d^s \gamma_l^s} + 2\sqrt{\gamma_d^p \gamma_l^p} \tag{1}
\]

where \(\gamma\) is the free surface energy, \(\theta\) the contact angle, indexes \(s\) and \(l\) denoting the solid and liquid phases respectively, and the exponents \(d\) and \(p\) refer to disperse and polar components of the free surface energy. The data obtained are reported in Table 1. Only the situations corresponding to: 8 h at 40 °C, with and without sand/wind, are presented.

PE is known to be a non polar polymer [16], this is well evidenced by the very low value of \(\gamma_p\) obtained for samples A, C and G. Sample C (initial multi layer) and sample G (multi layer + sand/wind + 40 °C) present basically the same values for both \(\gamma_d\) and \(\gamma_p\). This lack of variation in the values of \(\gamma_d\) and \(\gamma_p\) is in good agreement with the IR data showing only a small possibility of sand particles inclusion. As we may see, the situation was different for sample A (monolayer) and B (monolayer + sand/wind) for which the effects of sand/wind had led to increase the polar component
from 2 to 14 mJ/m². This was due to the presence of sand particles inlaid on the surface [9].

Because experiments have been performed at 40 °C, we have also checked the possible temperature effects on the crystalline morphology of the film. The same endothermic reaction of melting appears for the two samples. No structural modifications have been observed in the multi layers film after annealing for 4 h at 40 °C. The thermal behavior of the multi layers film is also found to be different from the thermal behavior of the monolayer film. Indeed, for the monolayer, annealing at 40 °C had led to homogenization of the crystallite size [17].

The last experiments concern the mechanical behaviors of the different films. During the film processing, it is established that the crystals of the PE films are preferentially oriented parallel to the machine direction [18,19]. Hence, load applied in the machine direction may yield higher values of tensile strength than load applied perpendicular to that direction. This is observed for the multi layer film, as proved by the curves displayed in Fig. 5. The perpendicular and parallel directions exhibit basically the same elastic behavior (see the zoomed part in Fig. 6) but the plastic behavior is very different. The sand/wind (4 h at 40 °C) does not modify the mechanical property of the sample as shown in Fig. 5. This is in agreement with the other results obtained for this material. Finally, in Fig. 6 we have also reported the mechanical characteristics of the monolayer PE film used in our first study. The comparison of the mechanical behavior of the mono and multi layers films allows the immediate conclusion that the mechanical performance of the multi layers films is better than the monolayer film.

4. Conclusion

A new generation of polymeric greenhouse covers have been tested with regard to the resistance to a simulated...
erosion process. Only the optical properties of the material have been modified by the erosion process. Thermal, surface chemistry, surface roughness and mechanical properties are not modified. This new generation of polymeric film exhibits better resistance to the aggressive environment, which characterizes Saharan countries than the monolayer polyethylene film classically used.

References