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# Natural ageing of tri-layer polyethylene film: Evolution of properties and lifetime in North Africa region

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ABSTRACT

The effects of natural ageing in the north Algeria of tri-layer films lay down hot greenhouse made of low-density polyethylene are presented in this work. Ageing was monitored by observing the changes of physical, mechanical and structural effects on the various greenhouse faces. It has been shown that the structural change occur on the outside face of the films, while the inside faces are protected by the dye. The study shows that the measured parameters are directly related to the criteria of evaluation of the greenhouse effectiveness. The lifetime of these films under natural conditions in north Algerian was estimated to be 10 months.



## 1. Introduction

Greenhouse roofs made with plastic films are widely used by farmers all over the world. The structure (one, tri- or more layers) and the composition (nature, amount of different additives) of these films are adjusted to accommodate specific climatic conditions that they will have to endure during usage [1,2]. The cheaper and more common material is a monolayer films of low-density polyethylene (LDPE) in which additives are incorporated before the extrusion process. More expensive sophisticated systems exist. For instance, here we study a film made of three layers for which two layers are made of LDPE and are located on each side of a central film. Each layer contains specific additives so that each side of the roof will exhibit specific characteristics. The outer layer is colorered and has protection against UV light, anti-moisture effects etc added to the film, while the central layer gives the main mechanical strength. The number of layers can be greater than three, for instance a film containing five layers can be found on the green house roof market. Among the most sophisticated systems proposed nowadays are films made of three layers with trapped air bubbles. This non-exhaustive list gives an example of the diversity of materials proposed.

To choose between the many options, one needs good knowledge of the material's performances and the variations with time of the material's performance. It has been observed that during usage ageing occurs and this ageing follows kinetics that depends on the climatic during usage of the plastic roof. Such observations in specific climatic conditions, as those expected in Saharan or sub-Saharan condition, especially in Algeria, lead to the following conclusion: the average durability of a green house roof made of a LDPE film (film of one layer) is less that 1 year. Recently it was shown that a sand wind is able to accelerate drastically the degradation [3,4]. The role played by erosion on the durability of polyethylene roofs have also been demonstrated by Dilara et al. [5]. When thermal shock exists, drastic ageing effects are also observed, leading to material damages as tears, cracks, etc. [6,7]. On the other hand, a better behavior against the abrasive effect of the sand particles has been demonstrated on more sophisticated films, having sandwich structure made of tri-layers, one ethylene vinyl acetate (EVA19) layer with air bubbles inserted between two LDPE layers [8].

In this work we propose to analyze the ageing behavior of a film made of three co-extruded layers of LDPE. This film was used to build a real greenhouse that was used to produce vegetable and located in the Oran region of Algeria. The samples have been obtained from this greenhouse at different times and evaluated by means of mechanical testing, differential scanning calorimetry, infrared spectroscopy, colorimetry and free surface energy measurements.

## 2. Materials and methods

The film used for the study was produced by Agrofilm SA (Sétif – Algeria). It is made of three co-extruded layers of LDPE. The film thickness is 180 μm, with the following proportions in the layers: ¼, ½, ¼. The real film composition is not known

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(kept confidential by the supplier) but it is established that the two exterior layers have different additives than those added into the medium layer. The density of LDPE before extrusion is 0.923 g/cm$^3$. The initial color of the film is milky yellow. A greenhouse was built with this film (length = 32 m, width = 8 m height = 3.50 m in the surrounding of Oran (Algeria) at latitude = 31°40′ N, longitude = 00°36′, altitude 120 m with an orientation east/west. As shown in Fig. 1, the samples have been taken on each side of the greenhouse roof, which result in north side samples and south side samples.

The greenhouse has been built in February 2005 and samples have been taken every month during a 7 month period. To check the data reproducibility, the surface of greenhouse was large enough to take large samples (30 cm × 30 cm) to allow conducting all the experiments required. The climatic conditions undergone by the roof are displayed in Table 1. We noted that no sand wind was observed during the period of study. The climatic condition was classical and standard in north Algeria.

Calorimetric measurements were performed by means of differential scanning calorimetry (DSC) using the Mettler Toledo FP85 apparatus, France. Samples of approximately 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 was done by measuring the temperature and the enthalpy of melting of indium.

The IR spectra were obtained with a FTIR spectrometer (Avatar 360) USA, 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.

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 Water System, resistivity 18 Ω/cm), 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 $\theta$ was determined from a computerized contact angle meter (NFT Communications Company, Tours, France). Surface energy is calculated using the relationship proposed by Young and Dupre and Fowkes and with the Owen Went method which was used by Adam et. al. [8].

Tensile tests of films were carried out on a universal testing machine (Instron model 4301, France). The tests were performed using a 5 kN load cell 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 according to the AFNOR NF T54-102.

Measurements of color modifications have were performed with a color Reader CR10 from Konica Minolta, Japan.

To ensure good reproducible, all measurements (DSC, color, free surface energy, FTIR and tensile test) values reported are the average of five experiments, in the same direction for tensile test and at different locations for further analysis. A maximum of 3% error for the variation of yellow color, 2.5% for mechanical properties and 5% for the free surface energy is observed.

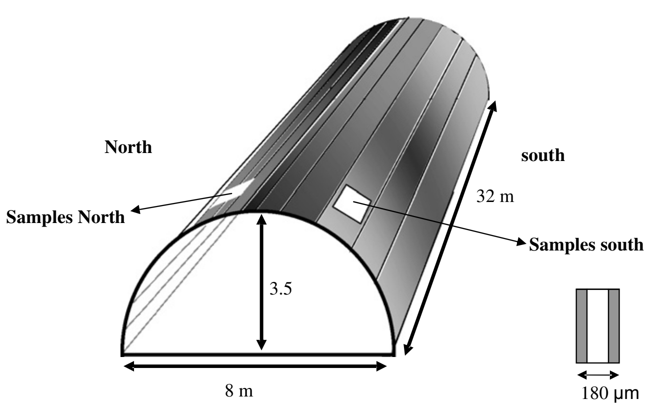


**Fig. 1.** Schematic view of the greenhouse studied and layout samples.

**Table 1**
The average temperature and average moisture during ageing

| | Month | | | | | | |
|---|---|---|---|---|---|---|---|
| | March | April | May | June | July | August | September |
| $T$ (°C) | 32. 8 | 33.6 | 37.6 | 41.6 | 44.2 | 43.6 | 41.1 |
| $H$ (%) | 76.2 | 69.3 | 62.5 | 60 | 58.7 | 59 | 63.7 |

## 3. Results and discussion

The color of the samples collected during these 7 months changed. The change in the "yellow color" of these materials was measured as a function of time. The results are displayed in Fig. 2. The value characterizing the "yellow color" decreases at the beginning of the ageing process, then passes through a minimum at approximately 3000 h (4 months) then increases. No plateau (steady state) was observed after 7 months indicating that the modifications are continuing.

The increasing yellow color observed at high ageing was surprising. It may be due to the decrease in the effect of sunlight. In fact it has been shown that the UV light effects on a LDPE film (exposed under the same condition) are observable for an ageing of 5 months [9]. The decreasing period can be explained by a washing mechanism of the roof surface due to rains.

The mechanical behaviors of the different films were evaluated. The direction of the load applied during the mechanical deformation is parallel to the average molecular orientation of the film obtained by the film processing. The stress as a function of the strain has been recorded for films submitted to ageing during period up 7 months. The curves obtained are displayed in Fig. 3. The reproducibility of the mechanical results is relatively good and error bars of approximately 10% are representative of the data dispersion (10% is a good accuracy for this kind of measurements). Moreover, a quantitative estimation of the effects of ageing on the mechanical performances of the film can be done by the knowledge of the values of the yield stress, the values of the tensile strength, the value of the elongation at break and finally the value of the rigidity modulus. For each curve, these values have been estimated and for the virgin material the yield stress value is 10 MPa for the three layers sheet, which is identical to a monolayer sheet as measured by Briassoulis and Aristopoulou [10]. For the tensile strength a value of 16 MPa is found for the sheet made of three layers, which is of the order of what is expected for a monolayer of LDPE used in the greenhouse technology. For instance Dilara and Briassoulis [11] propose values between 4 and 16 for a monolayer LDPE sheet. For the elongation at break this three layers have a value of 425%, which is of the same order of magnitude as the 550% reported by Briassoulis et al. [12] for a mono layer of LDPE sheet. The value of the rigidity modulus is 340 MPa for the three layers while a value between 100 MPa up to 260 MPa is generally expected for a mono layer of LDPE sheet [13,14]. As a consequence, the material obtained with three co-extruded layers does not drastically differ in terms of mechanical characteristics from what is obtained for a material made from a monolayer.

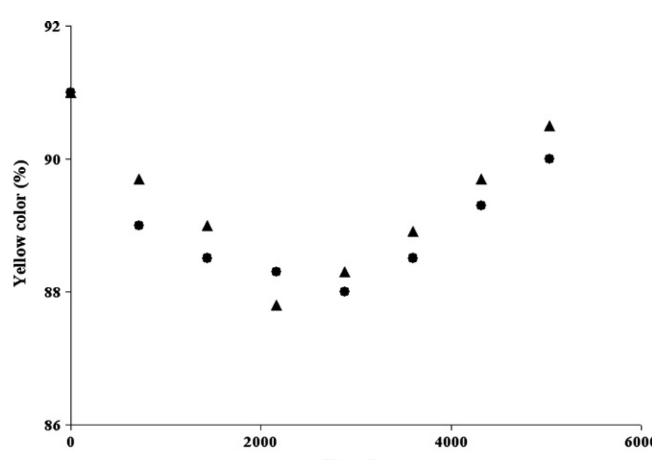


**Fig. 2.** Variations of the yellow color with the ageing time.