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# Ageing Effect on the Properties of Tri-Layer Polyethylene Film Used as Greenhouse Roof

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**Abstract**

This work aims at studying the degradable effect of natural and artificial ageing on tri-layer polyethylene films used as greenhouse cover in the North Africa environment. The film was supplied by Agrofilm and made of low density polyethylene (LDPE), containing additives (e.g., color and infrared IR and ultraviolet UV stabilizers). This film was used to build a real greenhouse located in the North of Algeria. Impact of ageing was monitored by observing the changes in mechanical (strength and ductility) properties. The study has been carried out over a period of eight-months of natural and artificial ageing. The films have been artificially aged at 40°C, 40°C + UVA, 50°C and at 50°C + UVA. The findings show that the environmental factors have degradable effects on the durability and all properties of the polyethylene film. The study revealed also that the degradation parameters measured are directly related to criteria for evaluating the effectiveness of agricultural greenhouse. The simultaneous effect of temperature and UVA radiation induced the most significant degradation on the film surface and consequently a reduction in the lifetime of the material.


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Keywords: LDPE; Tri-layer films; Ageing; Degradation; Temperature and UVA; Lifetime.

## *1. Introduction*

Low density polyethylene LDPE is one of the most used materials in plasticulture and its utilization as agricultural greenhouse covers is a common application. The main properties that have ensured its success are especially its lightness and transparency. However, despite its good chemical inertness, polyethylene like all organic substances degrades slowly under the combined influence of heat, solar ultraviolet UV radiation, mechanical stress and chemical agents (Mourad et al. [1-6]). Sunlight is the primary detrimental factor in the ageing of greenhouse. The antioxidants protect the film from the


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harmful effect of UV radiation and heat for long periods. A large number of additives are currently available and when added in low concentration to polymers make them more stable under exposition to heat and UV radiations. This enabled a considerable number of possible formulations of polyethylene films to be synthesized with adapted properties to be more suitable for their applications. Nevertheless, the degradation mechanism of PE is yet not well understood [7]. Polyethylene (PE) environmental degradation is a complex process, as many degradation mechanisms act together toward the total destruction of the material.

Briassoulis and Waaijenberg [8] have attempted to collect and compare the standards of plastic films for use as greenhouse cover. They have noted about the disparity of the results and the lack of coordination in the field of greenhouse covering [9-11]. The Existing standards are not generalized and unified. In sense, they are adapted to serve for the local conditions in the developing countries and therefore inappropriate for application or use in particular conditions. The duration of use of plastic materials is relatively short compared to their life time. It ranges from several months to few years, depending on the conditions of use and environment. The degradation of polymers in outdoor use is mainly due to UV radiations of the solar spectrum [12]. Mourad et al. [3, 4] have reported about the severe effect of UV radiation and some of the environmental conditions on the thermo-mechanical properties of PE. Some researches have investigated the long term behaviour of polyethylene films. Hassini et al. [13] have studied the effect of simulated sand wind during four hours on a polyethylene film. They have showed that the sand wind creates, on the exposed surface of the film, a very thin layer encrusted with sand particles producing a phenomenon of impact. Dilara and Briassoulis [14] have shown that the durability of the film material depends on its ability to resist erosion. The effect of some aging parameters (e.g. heat, UV radiation) on the mechanical, thermal and structural stability and degradation behaviour of different grades of PE has been examined by Mourad et al. [1-6]. The degradation behaviour of mono-layer LDPE films used as greenhouse covers has been studied by many authors. However, the degradation behaviour of multi-layer films is very lacking. Few studies [15] have considered the effect of ageing in the North-Africa climatic conditions. Adam et al. [12] have studied the behaviour of polymeric greenhouse covers made of a sandwich structure of three layers, one EVA layer inserted between two low density polyethylene layers. Optical, thermal, surface analysis and mechanical properties have been analyzed on samples having undergone different thermal treatments associated with sand and wind simulation. In the light of the above the effect of aging conditions on the behaviour of multilayered LDPE films needs more attention. In the current work the degradation behaviour of tri-co-extruded layers LDPE film used as agricultural greenhouse cover was investigated under both natural and artificial ageing. In the natural ageing, there are many weathering or climatic conditions behind the deterioration of the properties of greenhouse cover. Among these conditions are solar irradiation, temperature, humidity and rainfall, snowfall, hail and wind. In the artificial ageing, the film was exposed to the most deteriorative parameters, that is, temperature and UV-A radiation. These ageing conditions are considered the most responsible conditions for ageing of agricultural greenhouse covers in the regions of North Africa and the Sahara. The main aim of this work is to contribute to broad the pool of the available data and information for the adaptation of plastic films used as greenhouse cover in the regions of North-Africa and the Sahara. To accomplish this study, the LDPE film has undergone natural and artificial ageing processes. In the natural ageing the film was exposed to the climate of northern Algeria. In the artificial ageing the film was exposed to four different combined and simultaneous conditions of temperatures and UV-A radiations. These are 40 °C, 40 °C with AV-A radiation, 50 °C and 50 °C with UV-A radiations. The exposure has been performed over a time period ranging from 0.0 to 5486 hours (7.6 months). This study could be extended to cover more areas with different environmental conditions to establish a generalized standard.

## *2. Experimentations*

### *2.1 Materials*

The employed LDPE film was manufactured by Agrofilm SA (Setif-Algeria) using the threelayer co-extrusion technology. The total thickness of the three co-extruded layers film is 180 µm with the proportions of ¼, ½ and ¼ in the layers. The raw LDPE (before extrusion) has density of 0.923 g/cm$^3$ and the weight average molecular weight is in the range 90 000-12000.The melt flow index MFI of the raw LDPE is 0.33 g/10 min and the MFI with stabiliser is 10g/10min. The initial colour of the film is milky yellow. The real composition of the film is not known (kept confidential by the supplier. The usually used greenhouse cover is made from a mono-layer film with 180 µm, same as the overall thickness of the tri-layers film LDPE film. It has been confirmed from the supplier that, self adhesion between the three coextruded layers occurs under an extrusion temperature of 70 $^o$C.

### *2.2 Methodology*

The study was conducted over a period of time ranging from 0.0 to 5486 hours (7.6 months) under natural and artificial ageing. Approximately 6% of the total solar radiation falling on the earth is ultraviolet. The UV is normally sub-divided into UV-A, UV-B and UVC radiation with wavelengths range of 100-280 nm, 280-315 nm and 315-400 nm respectively. The artificial ageing has been conducted at four different conditions (40°C, 40oC with UV-A radiations, 50oC and 50°C with UV-A radiations. The chamber is equipped with UV-A lamp and fully controlled heating system. It is sealed and isolated properly to ensure proper degradation procedures.

The LDPE films were photooxidized with UV-A lamp of 40 W power (Philips: TL-K 40W UV-A). This lamp gives radiation with wavelengths of between 315 and 380 nm (equivalent to that of the UV-A of the solar radiation). The distance between the lamp and the sample is 40 cm. samples were irradiated for the different mentioned amounts of time. The same materials were also subjected to thermal aging at the different mentioned temperatures and times. A greenhouse of 32m length, 8m width and 3.50m height was specially design, built and equipped with a tri-layer LDPE film of 180µm total thickness. The greenhouse was located in the neighbourhood of Oran region of Algeria at 31° 40' N latitude, 00° 36' longitude and 120m altitude with an east/west orientation. The samples have been taken from each side of the greenhouse roof to represent the north side film and south side film. The samples have been taken every month over the total ageing period. To ensure the consistency in the results at each time of testing, one large sample (30mm x 30mm) was firstly cut and then all required specimens for different experiments were then cut from it. To ensure the consistency in the results, a relatively large sample (30mm x 30mm) was firstly taken from the roof, at each ageing period, from which the required tests specimens were then cut. The tensile tests were performed (according to ISO 527-3 standard) using a universal testing machine (Instron model 4301) with a load cell of 5 kN. All tests have been performed at room temperature with a cross head speed of 50 mm/min and displacement controlled 7 condition. The specimens used have the following dimensions: width = 10 mm, initial overall length = 180 mm, initial length between the jaws = 80 mm and thickness = 6.5 mm.

## *3. Results and discussion*

### *3.1 Effect on the mechanical behaviour*

The mechanical behaviour of the unaged/virgin and naturally (up to a period of 7 months) and artificially aged films (up to a period of 5486 hours) was evaluated by conducting the tensile test. The load was applied on specimen in a direction parallel to the average molecular orientation obtained during the film processing. The engineering stress as a function of the engineering strain has been recorded for each film. The tests were conducted to determine the tensile properties (modulus of elasticity E, fracture stress, and elongation at break) of the material. A quantitative estimation of the effects of natural and artificial ageing on the mechanical performances of the film is then done based on the knowledge of the measured properties.

The variation of the modulus of elasticity E with ageing time is given in Fig.1. These values are calculated from the slope of the initial part of the curve. The value of the modulus of elasticity was found to be 340 MPa for unaged film. Value between 100 MPa and 260 MPa is generally expected for a monolayer LDPE film [11-12]. The values increase with ageing time for the investigated five natural and artificial aging conditions. The trend of variation for natural and ageing at 40 $^{o}$C are similar. The variation is nearly bilinear and the rate of rise in the values is higher after approximately 3000 h of ageing. The trend of variations for other three conditions is also bilinear, however, the rate of variation is little less after 500 h of ageing. The modulus of elasticity after 5486 hours of ageing are 436 MPa, 460 MPa, 470 MPa, 480 MPa and 510 MPa, under natural ageing and artificial ageing at 40 ° C, 40 ° C + UVA, 50 ° C and 50 ° C + UV-A, respectively. The values have increased by about 27 %, 34 %, 37 %, 40 % and 47 % under the five different ageing conditions if compared with its original value a virgin material. The highest increase was under 50 $^{o}$C and UV-A radiation conditions.

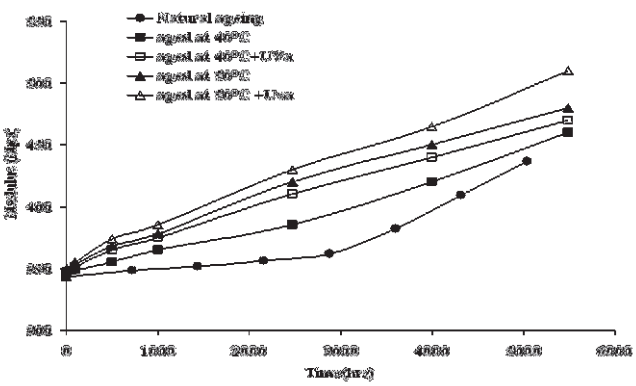


Fig.1 Evolution of the modulus of elasticity with the ageing time (● natural, ■ 40 ° C, □ 40 ° C + UV-A, ▲ 50 ° C and Δ 50 ° C+UV-A).

Fig.2 show the variation of the fracture stress (the stress at break with the ageing time. The trend of variation resembles that for the yield strength. The fracture stress reduces with aging time and the harshest effect of ageing was under 50 $^{o}$C with exposure to UV-A radiation. The maximum achieved fracture stress for unaged film was 16,2 MPa. Values of 12.2 MPa for natural ageing and 9.82 MPa, 7.33 MPa, 6.11 MPa and 5.59 MPa for artificial ageing (at 40 $^{o}$C, 40 oC + UV-A, 50 $^{o}$C, 50 $^{o}$C + UV-A) were achieved at the end of aging periods. In sense, the material lost 25 %, 40 %, 55 %, 62 % and 65 %, respectively, of its fracture stress as a virgin material.

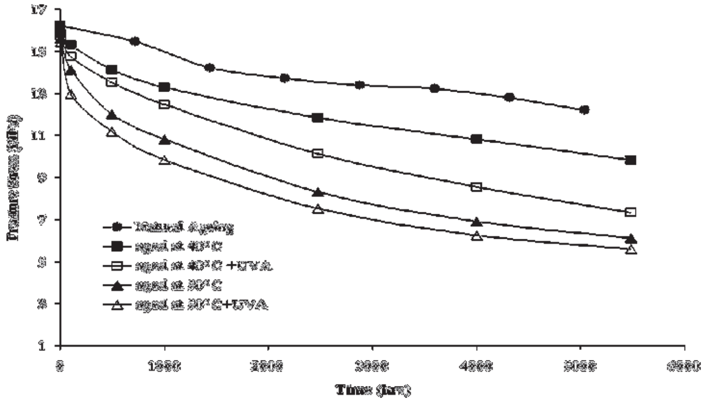


Fig.2 Variation of the fracture stress with ageing time for different ageing conditions.

Fig.3 shows the variation of the elongation at break (strain) as a function of the ageing time. The maximum achieved percent elongation of unaged material at break was 425 % which reflects the ductile behaviour of the virgin material. Briassoulis [10] has reported a value of 550 % for a monolayer of LDPE sheet. The percent elongations after 5486 hours of ageing are 265 %, 255 %, 190 %, 159 % and 145 %, under natural ageing and artificial ageing at 40 ° C, 40 ° C + UVA, 50 ° C and 50 ° C + UV-A, respectively. This reveals that the material lost about 37 %, 39 %, 55 %, 62 % and 65 % of its percent elongation as a virgin material under the five different ageing conditions. These values also reflect the harsh deteriorative influence of the ageing on the ductility of the material. The harshest effect is under 50 °C and UV-A radiation. It is also noted that the variation under the natural ageing is very close to the artificial aging at 40 ° C.

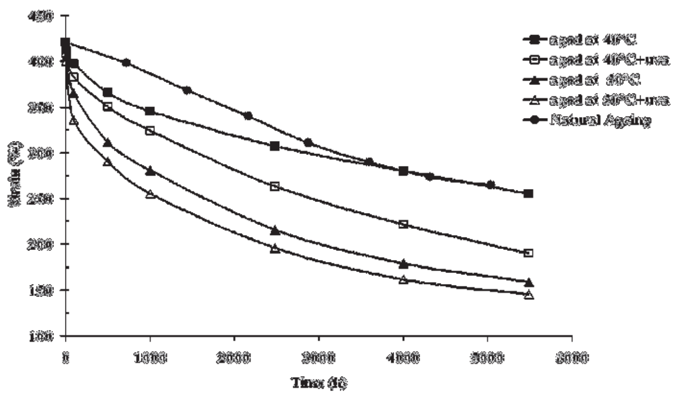


Fig.3 Evolution of the percent elongation with the ageing time (● natural, ■ 40 ° C, □ 40 ° C + UVA, ▲ 50 ° C and Δ 50 ° C+UV-A).

Generally the percent elongation and fracture stress deteriorate with ageing time. It is worth noting hear that, the apparent rise in the modulus of elasticity with ageing is considered a sort of degradation not enhancement since it its at the expense of ductility or the film becomes stiffer. Such degradation in the mechanical behaviour of the tri-layer film of LDPE could be due to the changes occurring with ageing in the molecular structure of the material gradually do not allow the chains to re-orient and provide additional resistance following the initial yield of the material [16]. In fact, changes in the molecular structure associated with the ageing behaviour are due to increased crosslinking and chain scission [1-6].

## *4. Conclusion*

The impact of natural and artificial aging on the characteristics of the tri-layer LDPE film used as a greenhouse roof has been investigated. The essential degradation in the mechanical characteristics (modulus of elasticity, fracture stress and elongation at break) has been evaluated.The study shows that natural ageing of the film in North Africa is almost equivalent to artificial aging at 40°C. Further, the sunlight radiation is major element of degradation and the anti UV additives are not optimized in this film. The combined effect of the temperature and UV-A radiation reduces the life time considerably. The data of the yellow color, correlated with the degradation in the mechanical performance of the film.

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