Effect of Sand Wind on the Polyethylene Film used as greenhouse cover

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Abstract

This work aims at studying the degradable effect of 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 ultraviolet UV stabilizers). 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 study has been carried out over a period of eight hours of artificial ageing "Sand and wind simulation at 40°C". 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 sand wind induced the most significant degradation on the film surface and consequently a reduction in the lifetime of the material.

Keywords: LDPE; Tri-layer films; Ageing; Degradation; Temperature and sand wind.

1. Introduction

Low-Density PolyEthylene (LDPE) is one of the most used materials in plasticulture and its utilization as agricultural greenhouse cover is a common application. LDPE film is currently the most widespread greenhouse covering material in the countries of the Saharan region, as well as in many other European regions. Other important agronomical applications of LDPE film are crop mulching and soil solarization. LDPE is one the most used plastic films by farmers (Candido et al., 2007). The same Authors (Candido et al., 2011), comparing different soil solarization plastic films for weed control and yield response in lettuce, pointed out that LDPE is useful for this application too.

The exposure of LDPE film to weathering conditions, especially to solar irradiation in the range of 290–400 nm, affects its chemical structure and consequently its mechanical and physical properties (Briassoulis and Aristopoulou, 2001; Picuno P., 2014). On this subject, the useful life of a plastic covering is related to the climate and the location where the film is exposed, depending on the yearly solar radiation energy, traditionally expressed in kiloLangleys/year (kLy/year). While northern European Countries are characterized by values about 80 kLy/year, values from 140 to 160 kLy/year characterize the Mediterranean areas (Scarascia et al., 2012).

The main properties that have ensured its success are especially its lightness and transparency. Sunlight is the primary detrimental factor in the ageing of greenhouse. The antioxidants protect the film from the 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 sand wind. 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 PolyEthylene PE is yet not well understood. PE environmental degradation is a complex process, as many degradation mechanisms act together toward the total destruction of the material (Dehbi et al., 2012/b; Dehbi et al., 2015)

Briassoulis et al. (1997) 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 (Dehbi et al., 2011/a).

The qualitative and quantitative effects of the various ageing factors on the degradation of the film are usually monitored by measuring selected critical properties of the material. Chemical changes in the PE polymer structure can explain the degradation mechanisms. Changes in selected critical properties (mechanical, chemical) can be used to monitor the evolution of ageing. So far, the main property used by industry for characterizing the degradation of PE is the elongation at break. According with relevant international standards, a lowering below the limit of 50% (Dehbi et al., 2010; Carrasco et al., 2001) of this parameter compared with the value at new is the indicator that the material has finished its working life and has to be removed before that its mechanical characteristics become so poor that its removal and further mechanical recycling could be impossible (Dehbi et al., 2011/b). Sometimes the formation of carbonyl groups and/or evolution of tensile strength are also used. Many investigations have shown that the elongation at break, tensile strength, molecular weight, crystallinity, density and carbonyl index represent properties which may be connected to some extent to each other (some of them are strongly correlated, while the behavior of others is rather independent or unclear) (Yoshimoto and Takahiro, 2004; Youssef et al., 2008; Mourad and Dehbi, 2014). Carbonyl index, indeed, is an index used to express the evolution of carbonyl groups with ageing; there are several carbonyl indices reported in the literature but what is common to these is the absorbance near wave number 1710 cm^{-1} measured with respect to the absorbance at a specific wave number, taken as reference, such as 1890 cm^{-1} (Picuno P., 2014).

Therefore, more critical properties may be used as complementary indicators of ageing. A widely accepted scheme could be used then for assessing the evolution of degradation of greenhouse LDPE films in a specific format allowing for the determination of the durability of these materials for commercial purposes. Some of these properties are however covered in the work of the working group CEN-TC 249/SC3/WG 1 ad hoc "agricultural films". The recently completed preliminary draft of the European Standard for "Covering plastic films for use in agriculture and horticulture" (Dehbi et al., 2012/a) concerns, as stated therein: "transparent and diffusing plastic films based on polyethylene and its copolymers which are designed to be used as covers for permanent and temporary greenhouses for forcing and semi-forcing vegetable, fruit and flower crops" and is intended to "establish the basic requirements for the physical and mechanical characteristics of various types of film". However, the draft is still far from being adopted as a European Standard since at least 2 years are required from the time the draft is circulated to the various member states until the time of its final adoption. Furthermore, it does not cover several aspects which are critical in evaluating the overall mechanical behavior and ageing of these materials. In the meantime, most of the standards used, as well as those included in the draft of the relevant European Standard, are those pertaining to plastic films in general (*i.e.*, not specifically agricultural films). Furthermore, there is a large variety of testing methods adopted in the various standards for measuring a specific property (even several testing methods under the same standard). Some of these methods are equivalent while others are unrelated.

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 the pertinent parameters. This work has been recently done (CEN/TC n.249; Guenachi S., 2002) with a surprising result. A simple sand/wind test performed for 8 hours was found to be able to create irreversible damage of the polymeric film. The main effect of the sand/ wind is to frost the film surface and to create micro cracks by sand (silica) particle inclusions. In practice, the durability of the plastic greenhouse cover was found to depend mainly on its ability to resist to erosion and, thus, as mentioned by some Authors (Dilara and Briassoulis, 1998), resistance to erosion is one of the most important properties to be tested. The materials studied in this work were polyethylene films of low density produced in Algeria from a classical extrusion process. These were tri-layer film of low cost with some additives such as anti-UV and, anti-oxidizing agents.

The combined or respective effects of environmental pollution and the use of agrochemicals in the greenhouse affect the lifetime of the polymers as well. In this kind of degradation, for instance, hydrolysis and oxidation of the macromolecules can occur. These processes are strongly dependent on the type of bonds, the presence of catalysts and temperature (Dilara and Briassoulis, 2000). Under sub-Saharan climatic conditions as observed in south Algeria, on top of UV light, oxygen and thermal shocks, the role played by sand wind, which is known to be very aggressive in terms of erosion, must be investigated. In addition to the mechanical behavior of LDPE films observed during ageing, others properties – as, for instance, permeability to H_2O, CO_2 or O_2- must also be studied. In this work, by means of infrared and UV–visible spectrometry, interferential microscopy, the effects of sand winds on the behavior of LDPE materials used for greenhouse devices, localized in south Algeria, are investigated by following a Brownian movement of the sand particles that struck randomly the polymer surface. The sample was divided into two parts, one part exposed to the sand wind while the other remained protected during the experimental duration. Exposure to sand wind varied from 0 to 8 hours. More information concerning this simulator is given in Sebaa et al. (1993).

2. Materials and methods

The employed LDPE film was manufactured by Agrofilm SA (Setif-Algeria) using the tri-layer 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 average molecular weight is in the range 90000-12000. The melt flow index MFI of the raw LDPE is 0.33 g/10 min and the MFI with stabilizer is 10g/10min. The initial color 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 180µm, same as the overall thickness of the tri-layers LDPE film. It has been confirmed from the supplier that self-adhesion between the three coextruded layers occurs under an extrusion temperature of 70°C (Henninger and Pedrazetti, 1988).

The degradation is a complicated non-linear time-dependent process which affects directly, or indirectly, several properties of the material related to its functional characteristics. In its final stage of degradation, a material does not meet its functional requirements and is easily prone to mechanical failure. As a practical rule, the useful life of a material is considered to be reached when its initial mechanical strength is reduced by 50%**.** There are several factors to monitor and criteria to define the degree of degradation (Allen et al., 2000; Khabbaz and Albertsson, 2001).

The performance of the plastic film used as covering material in protected cultivation, as well as its service life depend strongly on (a) the original properties of the materials and (b) how these material properties are altered by the various factors which can induce ageing of the plastic film (Randy and Rabek, 1983).

The effects of sand-wind were simulated with an apparatus developed in the laboratory of the University Ibn Khaldoun Tiaret (Hassini et al., 2002). The equipment is composed by a thermo stated tube, a sand/wind chamber and a keyboard control. From an air turbine, the flux is heated up to an experimental temperature (T=40 °C), under a pressure of 100 kNm^{-2}, inside the thermo stated tube. The mass flow of air is about 2.3 m^3/min. 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 strikes randomly on the polymer surface.

UV–visible spectroscopy was achieved with a Shimadzu UV 1650 pc, in transmission mode, with a scanning velocity of 4 nm^{-1}.

Morphology and microstructure of the films were examined by scanning electron microscopy (SEM) taken by JEOL model JSM 6490 at the University of Basilicata (Potenza, Italy).

The 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–strain curve.

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 U/cm), glycerol and di-iodo-methane, were used. All measurements were carried out at room temperature (23 °C). For each liquid deposited on the sample surface, an average of five measurements was calculated. A drop of 3 ml, deposited with a micro syringe, was photographed with a black and white CCD camera (500X500).

The chamber of the sand wind (Figure 1) has been designed and manufactured in Engineering physics Laboratory of the University Ibn Khaldoun Tiaret. It consists of the following components:

1- Ventilator for source of wind

2- Input of wind for Air collection

3- Hot serpentine for heating wind

4- Filter for keeping sand in interior

5- Output of wind for wind cycle

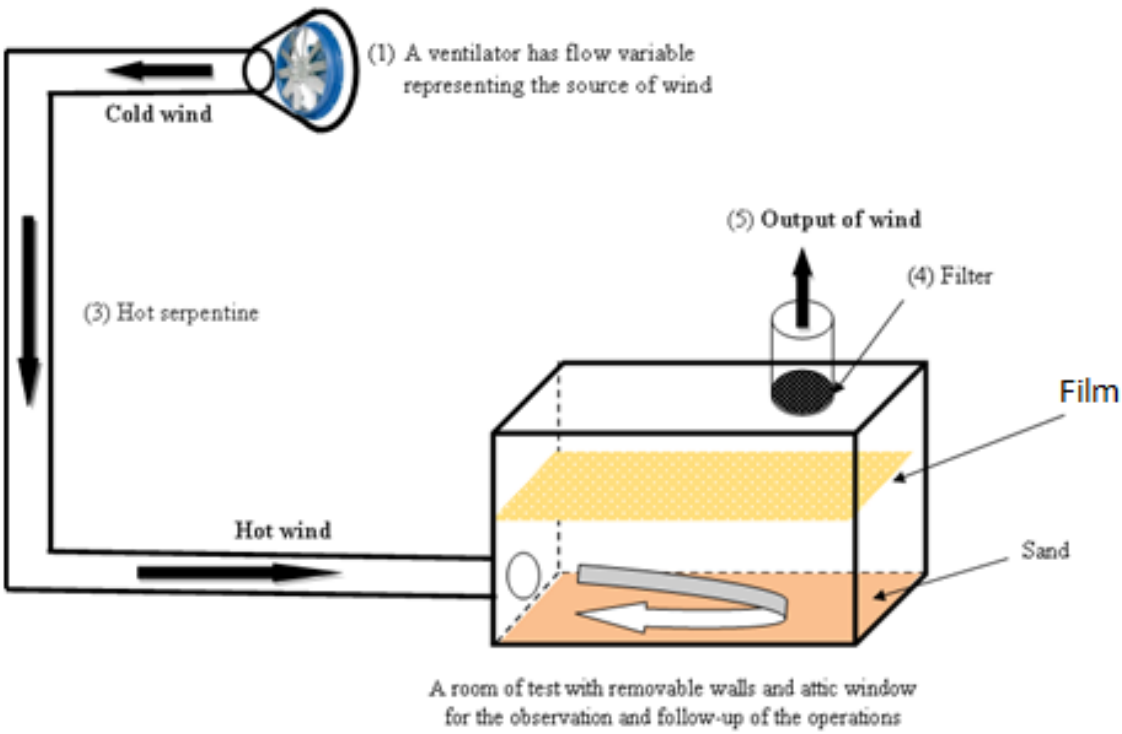

Figure 1: Equipment for simulation of sand wind.

3. Results and discussion

The measurements of UV-Visible spectroscopy (Figure 2) show the percentage of the light transmitted according to the length of vagueness for a virgin film and a sample subjected to a sand wind during 8 hours. Practically for all the wavelengths larger than 400 nm, the percentage of the transmitted light is reduced up to 0 % after a treatment of sand wind as short as 8 hours. It is a significant result, because it proves that the effectiveness of the hot greenhouse in the solar energy transformation and in the availability of radiation in the PAR – Photo synthetically Active Radiation [400 – 700] nm - wavelength can be severely reduced by a sand wind of very low duration. The inverse behavior is revealed by the increase of the light transmission after a sand/wind test performed at 40°C for 8 hours. 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.

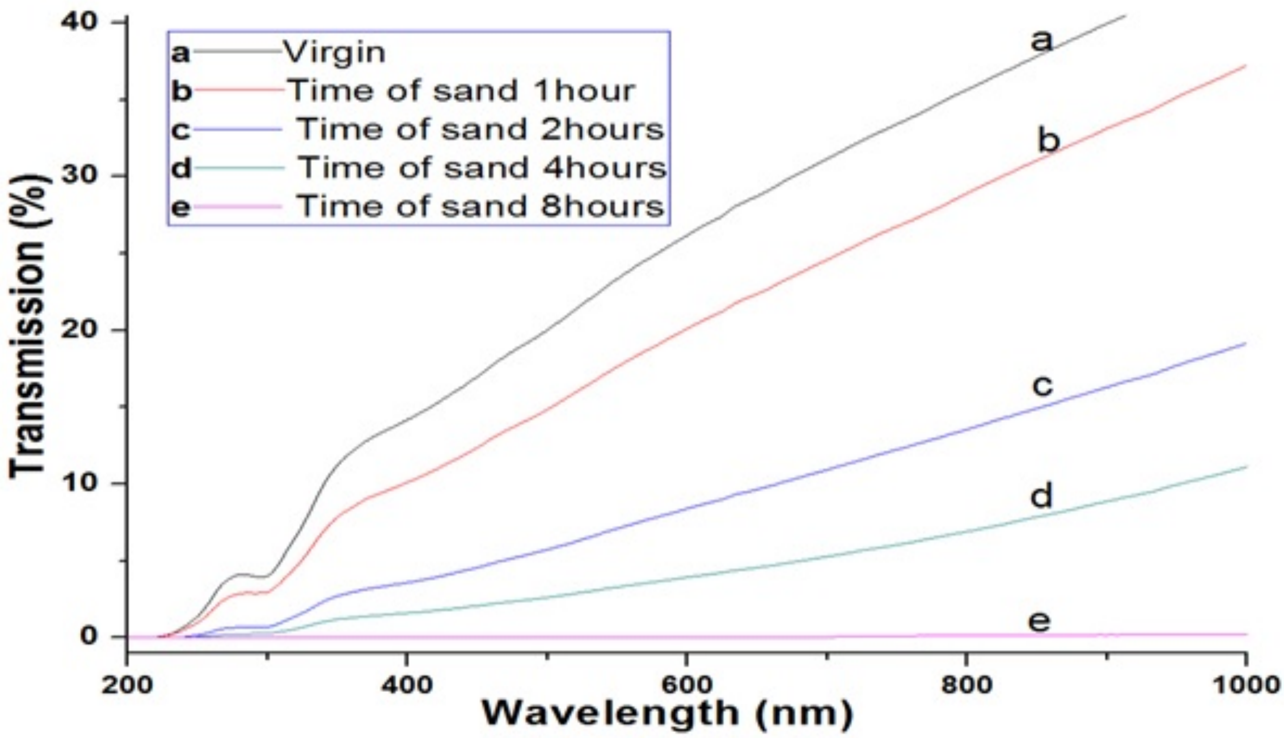

Figure 2: Percentage of light UV of transmission (T) for virgin film and film after treatment of sand wind.

The SEM micrographs in Figure 3 correspond to the surfaces of the films under study before exposure to the sand wind. Figures 3 (a) and (b), (c), (d), (e) show the micrographs obtained using the SEM signal respectively for unaged LDPE and 1hour ageing LDPE, 2hours ageing LDPE, 4hours ageing LDPE and 8hours aging LDPE. The surface of aging LDPE seems rougher than that of pure LDPE, probably due to the presence of the sand particles near that region. On the other hand, SEM micrographs (Figure 3 b, c, d and e) showed a quite uniform dispersion of sand particles (represented by the brighter domains indicative of the presence of heavier elements such as Si). However, there are some areas of variable size and shapes where aggregates seem to be present; this may be due to the high content of silicium nanoparticles in the sample (30 % wt/wt).

Before exposure to the sand wind, the topography of the films was also examined by SEM. In Figure 3, typical SEM images of LDPE and LDPE-SiO_2 samples are shown for which the most heterogeneous seems to be the later one. However, to have a clearer idea about the influence of the presence of SiO_2 particles on the topography of the films, for LDPE and LDPE-SiO2, respectively, it is reasonable to think that a rougher surface should imply more available space for attachment; therefore, after the sand and in the absence of other effects, one would expect more sand on the nanofilled polymer.

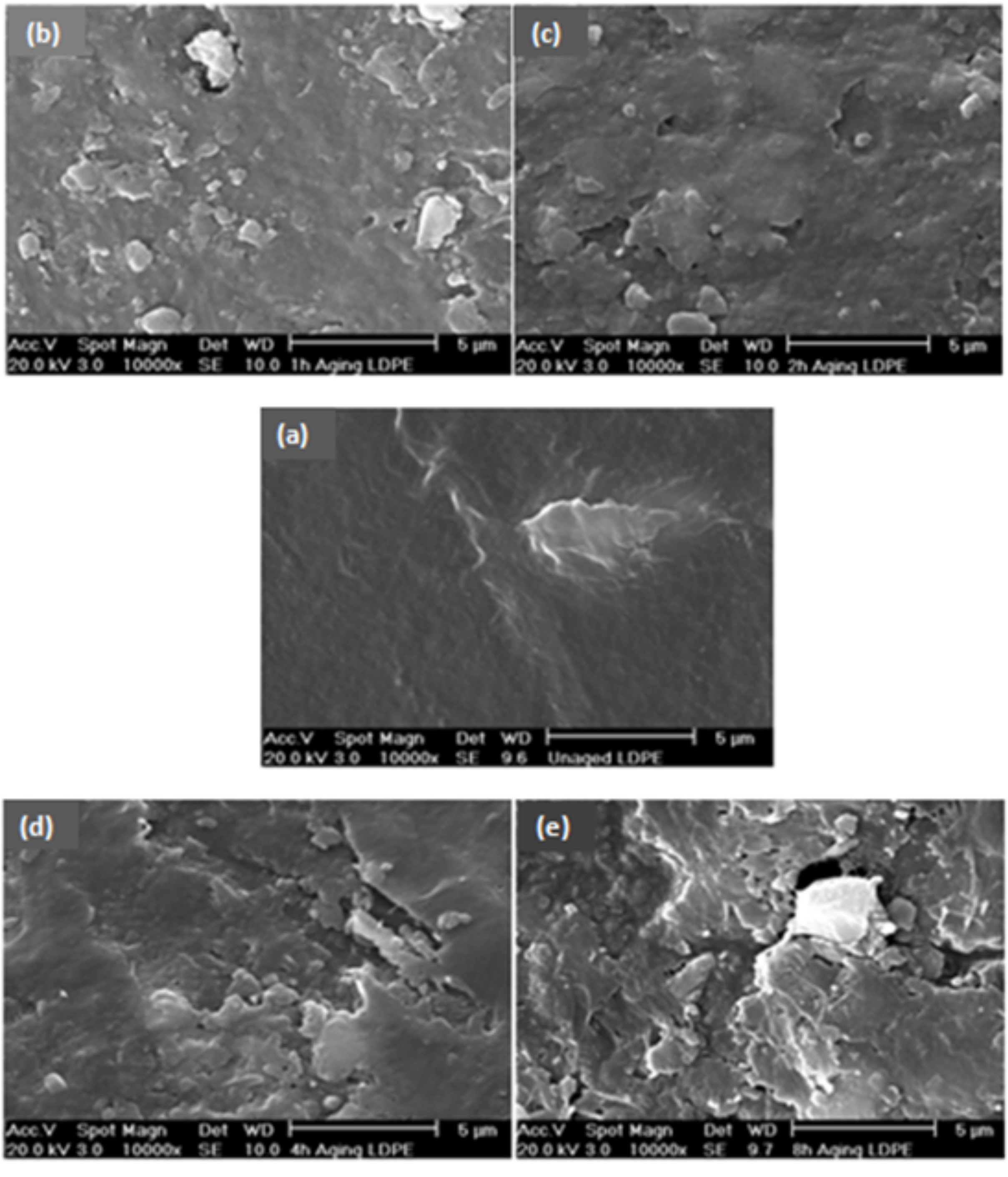

Figure 3: SEM micrographs obtained on LDPE film: virgin LDPE film (a); LDPE film after sand-wind treatment for 1 hour (b), 2 hours (c), 4 hours (d) and 8 hours (e).

The same analysis, carried out on a sample having undergone an exposure of sand wind that modifies so much severely the external roughness, gives the impression that the bearings of extrusion are practically unobtrusive. The sand impacts are well identified by large cavities shown by great black fields. Like second conclusion, we can say that a sand wind of short duration can lead to energetic erosion external of the cover of hot greenhouse covered with LDPE.

The results obtained for the tri-layer film during ageing are presented in Figure 4. It can be noticed that the free surface energy increases rapidly until 8 hours. After that the increase is slow. The increase in the free surface energy is proportional to the temperature (40°C). On the other hand, the increase is more pronounced when the film is subjected to the combined action of the temperature and the UVA radiations.

The increase in the free surface energy is the result of cuts of polymer chains CH_2–CH_2 leading to faster degradation of the film in high temperature regions than in lower ones.

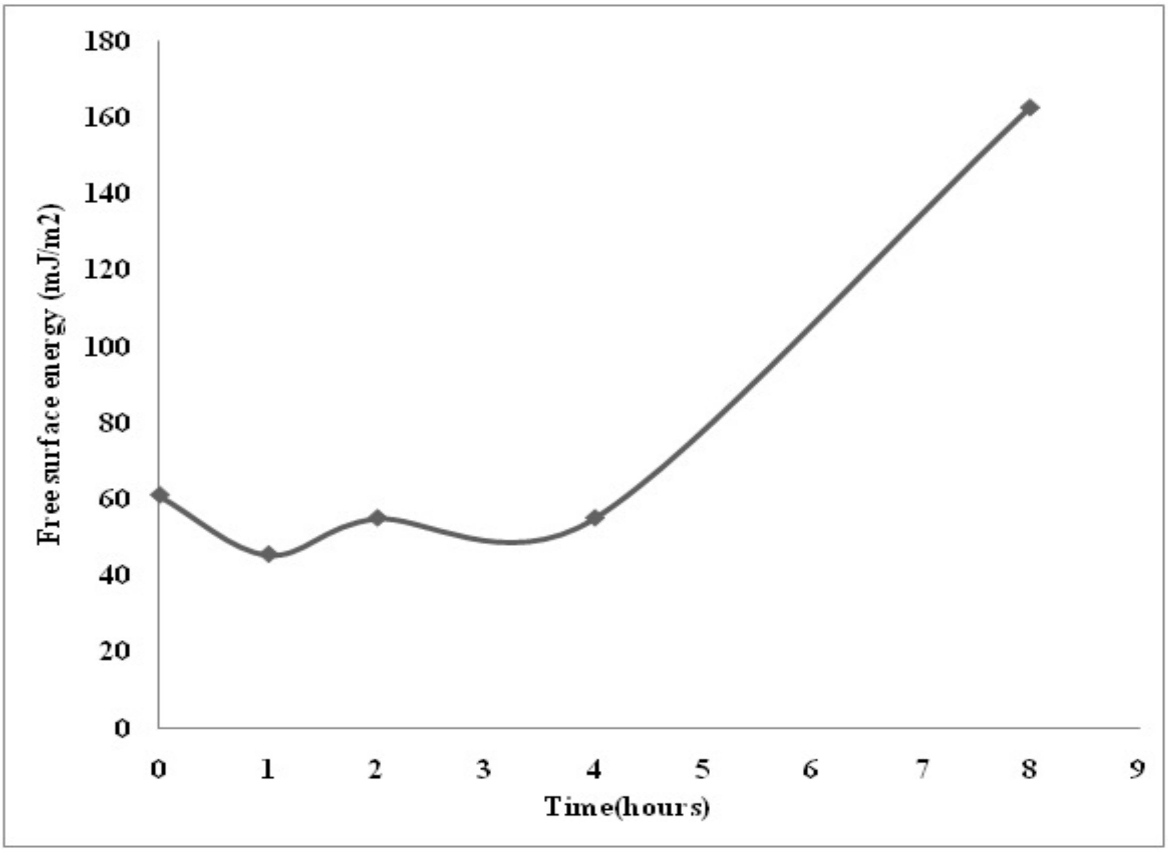

Figure 4: Variation of the free surface energy with the ageing time.

The observed increase is due to the disappearance of the additives (yellow dye). The minimum means the total loss of the additives. The increase in the yellow color is maybe due to the degradation of the film. The increase of temperature (40°C) and exposure to UV-A radiations decrease the time of passage through the minimum. This is in good agreement with the results of the free surface energy (Briassoulis D., 2006).

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 **(**Dilara and Briassoulis, 2000). 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 Figure 5, which shows a representative stress-strain diagrams for unaged (0.0-h exposure time) film and artificially aged films at a temperature of 40°C for four different exposure periods (1, 2, 4, and 8 hours) of sand-wind. In general, Figure 5 shows that the films exhibit ductile behavior, failing after extensive deformation and the ductility reduces with ageing time. The unaged specimen exhibits much enhanced yield and fracture strengths, ductility, resilience (area under the elastic region of the stress–strain curve and toughness (area under the entire stress–strain curve). The tensile properties have been firstly measured for the 180µm thick tri-layer film made of virgin material.

Generally and in the light of the results of Figure 5 the yield strength, percent elongation and fracture stress deteriorate with ageing time. Such degradation in the mechanical behavior of the tri-layer film of LDPE is due to the changes occurring with ageing in the molecular structure of the material. Polymeric molecules are very large, on the molecular scale, and their unique and useful properties are mainly a result of their size. Any loss in chain length lowers the tensile strength and is a primary cause of premature failure/cracking. The gradual changes in the molecular structure due to ageing do not allow the polymer chains to reorient as before and provide additional resistance following the initial yield of the material **(**Callister W.D., 2003).

4. Conclusions

The impacts of artificial ageing on the mechanical behavior, optical stability and lifetime of the tri-layer LDPE film performance were investigated in this study. The results revealed that the ageing conditions affected adversely the mechanical behavior of the film and the severest condition was for ageing at 40°C with sand-wind for 8 hours.

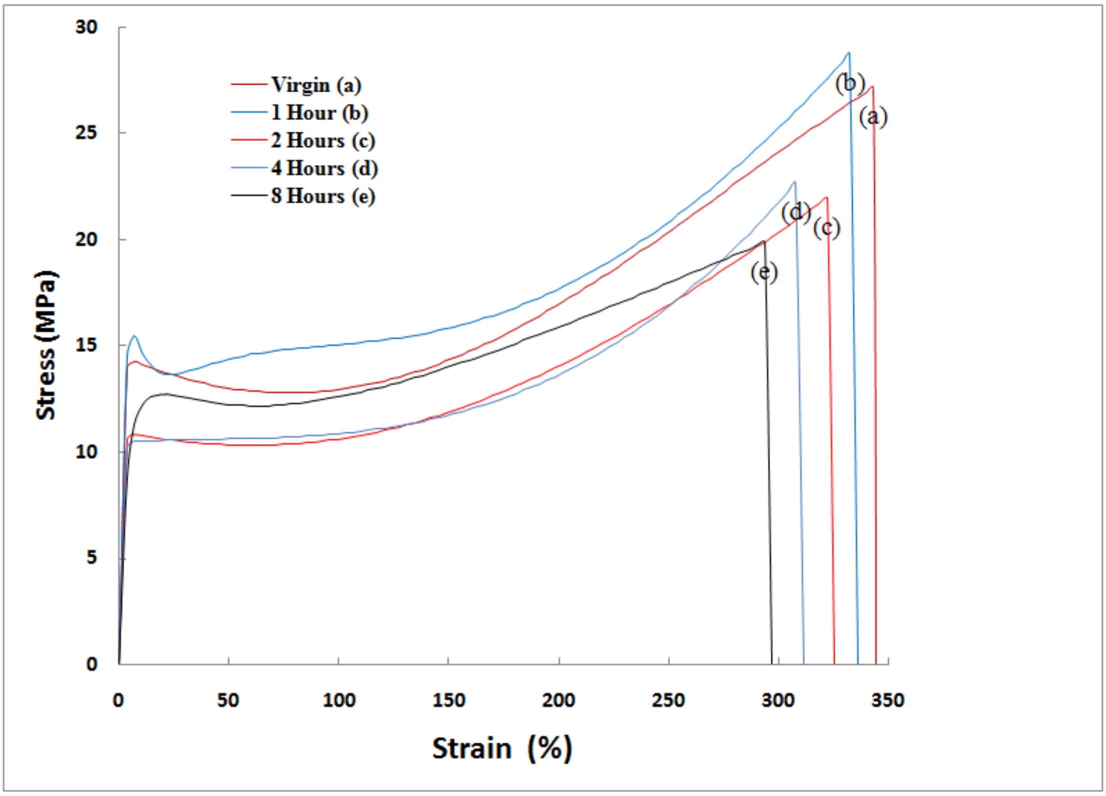

Figure 5: Stress–strain curves for unaged and artificially aged films at a temperature of 40°C for four different exposure periods (1, 2, 4, and 8 hours) of sand-wind.

Generally, the exposure to sand-wind and temperature has a remarkable deteriorative effect on the greenhouse film performance and reduces significantly its lifetime. Therefore, the sunlight radiation is the major element of degradation of greenhouse covers. This study shows clearly that the film has longer period of use in Europe (lower temperature) than in North-Africa (high temperature and sand-wind). Anyway, independently on the exposure period and climate and latitude of the site, the replacement of the deteriorated films is a crucial factor for a suitable micro-climate able to guarantee a successful greenhouse production.

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