Properties of recycled plastic films obtained from protected cultivation

Carmela Sica[1], Pietro Picuno[1],
Giacomo Scarascia Mugnozza[2], Aleksandra Dimitrijević[3*]

[1] *University of Basilicata, DITEC Department,*
viale dell'Ateneo Lucano 10, 85100, Potenza, Italy
[2] *University of Bari, DISAAT Department, via Amendola 165/A, 70126, Bari, Italy*
[3] *University of Belgrade, Faculty of Agriculture, Department for*
Agricultural Engineering, Nemanjina 6, 11080 Belgrade, Serbia
**Corresponding author. E-mail: saskad@agrif.bg.ac.rs*

Abstract
Plastic materials have a wide range of application in agriculture, especially horticulture but their use causes high quantities of post-consume material that needs to be dealt with in such way that will not cause negative effect on the landscape and agro-ecosystem. In this paper the results of investigating the possibilities to produce a new regenerated film through mechanical recycling, from post-consume agricultural plastic films, are analyzed. Six recycled films made from tunnel and greenhouse covering material and HDPE from agrochemical packaging have been extruded and subjected to mechanical and spectro-radiometric tests. The results of the tensile tests show that the values of the maximum resistance varied from 12.38 to 40.45 N mm^{-2}. The values of the elongation at break varied in a wide range (144 – 350). All films showed quite similar spectro-radiometric characteristics. Transitivity of PAR radiation varied from 73.9 to 84.1%.

Key words: plastic film, mechanical recycling, technical characteristics.

1. Introduction

Apart from their diverse use and contribution to a significant increase in productivity the use of plastics causes high quantities of post-consume material that need to be dealt with. Current intensive and semi-intensive agricultural practices require the use of large quantities of plastics [Sica, 2000]; the consumption of plastic materials used throughout Europe for agricultural applications reached 615000 t in 2004 [Briassoulis & Dejean, 2010]. Most recent data suggest that agriculture and horticulture are responsible for the consumption of, approximately 1500000 t/year of all polymers in Europe. Consumption of greenhouse and low tunnel covering films in Europe amounts to 72000 and 75000 t/year, respectively. In Italy, with the respect to an average annual consumption of more than 350000 t of agricultural plastic, it is estimated a corresponding flow of post-consume material of about 200000 t/year. Approximately, 55% of this quantity [Scarascia et al., 2008] comes from protected cultivations (greenhouse claddings, low tunnels, soil mulching, vineyards nets, etc.). The intensive and expanding use of plastics in agriculture results in increased accumulation of plastic waste in rural areas. A large part of agricultural plastic waste may be recycled, especially the greenhouse films, silage films , pipes and other clean enough plastic products.

The aim of this paper is to present some research results in the area of plastic materials mechanical recycling. The paper gives the basic mechanical and spectro-radiometric characteristics of the new materials obtained from the low tunnels and greenhouses plastic film coverings.

2. Material and method

Tested plastic samples were obtained from plastic films used as cladding materials for low tunnels and greenhouses in different farms in Huelva and Almeria regions (Spain). These agricultural plastic films were collected and recycled in form of granules by the

INSERPLASA S.A. Company (Spain). After the granulation the Company extruded four transparent films (F1-F4) different in their mixtures:

-F1- recycled film (regenerated granule of greenhouse film (50%) and low tunnel film (50%));
-F2 - recycled film (regenerated granule of greenhouse film (75%) and low tunnel film (25%));
-F3 - recycled film (regenerated granule of greenhouse film (25%) and low tunnel film (75%));
-F4 - mixture F1 (25%) + F2 (25%) + F3 (25%) + HDPE, from agrochemical packaging (25%).

PATI SpA Company (Italy) has extruded two other materials, densified material (Fd5) and granulated material (Fg6) obtained from regenerated granules of greenhouse and tunnel films. Densified material (Fd5) was obtained from pellets extrusion at 180-200^0 C. Granulated material was obtained from re-extrusion of the densified.

The materials analyzed in this paper were collected and recycled, in case of low tunnels, after one production season, and, in case of greenhouse coverings, after two seasons. New recycled materials were compared with two virgin materials that were obtained from the same locations as recycled materials. Materials F1, F2, F3 and F4 were compared with a virgin LDPE film (Table 1) while materials Fd5 and Fg6 were compared with a virgin EVA film (Table 2).

Mechanical tests were carried out in the Laboratory of Material Testing of the Technical-economic Department of the University of Basilicata. The tensile tests (Fig. 1) were carried out using a computerized universal machine Galdabini PMA 10 according to the Italian UNI 8422 Standard. The results obtained from tensile tests were reported in terms of maximum resistance (σ_{max}) expressed in [MPa], percentage elongation (ε) and percentage elongation at break (A) expressed in [%].

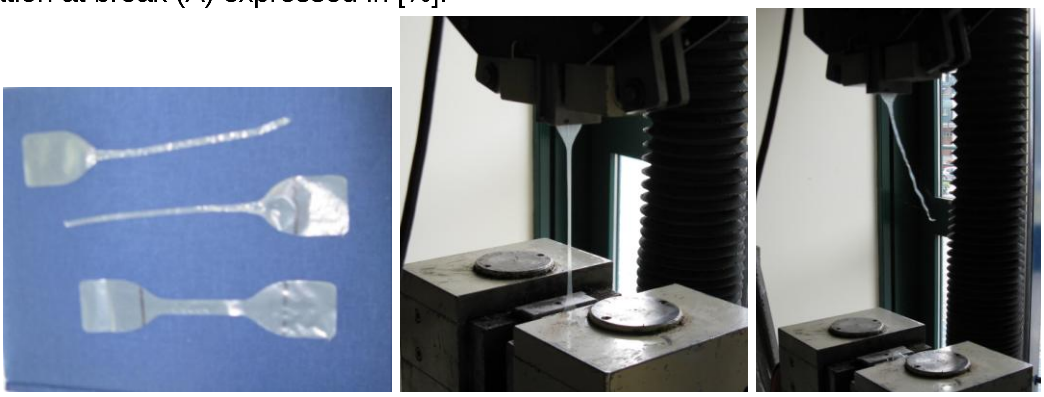

FIGURE: 1 Tensile test

The spectro-radiometric analysis has been realized in the Laboratory of Spectro-radiometric Analysis of the DISAAT Department of the University of Bari, using the spectro-photometers Perkin-Elmer UV-VIS and FT-IR 1760X [Vox & Schettini, 2007].

3. Results and discussion

3.1. Mechanical properties of the recycled materials

The recycling of homogenous polymers is a relatively easy challenge only when their structure is preserved and no significant degradation took place both during the lifetime and during the recycling process [La Mantia, 2002]. Agricultural covering and mulching films are exposed to natural weathering that influences their mechanical, chemical and optical properties in different ways leading to the significant thermal, chemical and mechanical degradation [Briassoulis, 2005]. Level of the degradation influences their post-recycling characteristic and thus determines their future applications [Ma & La Mantia, 1995].

The results of the tensile tests, obtained for the regenerated samples, show that there are differences in terms of maximum resistance and percentage elongation at break. When compared to the LDPE film, recycled samples (Table 1) show similar and higher values of the maximum resistance. According to EN ISO 527-3 standard that deals with mulching films, all these films except F3 have appropriate characteristics in terms of maximum resistance (max ≥20 MPa).

TABLE 1: Mechanical properties of all recycled materials

Material type	Thickness (µm)	σ_{max} (MPa)	A (%)
F1	40	20.60±2.75	246.75±25.58
F2	40	35.71±4.45	310.51±36.77
F3	40	12.54±4.45	310.51±36.77
F4	30	29.93±3.66	247.69±67.00
T1	**50**	**21.74±1.23**	**439.90±139.32**
Fd5	150	15.41±0.96	191.20±25.37
Fg6	70	18.72±2.51	190.87±44.34
T2	**160**	**34.54 ± 11.30**	**536.44 ± 7.56**

Concerning the percentage elongation at break there was an obvious worsening of the material properties. Only material F2 can fulfill the demands given by EN ISO Standard 527-3 (1995) for a good quality mulching film (A ≥ 300%). Mechanical properties of the recycled materials depend on those of the virgin material [Briassoulis, 2005] and the level of its degradation after the usage correlated with the ageing and the conditions of material usage, like exposure to agrochemicals, mechanical stress, etc. The mechanical degradation of plastic films can affect the recyclability of the materials making the chemical-structural changes of the polymer. Materials F2 and F4 show a certain unhomogenity of results when tensioned in the parallel and transverse direction (Fig. 2).

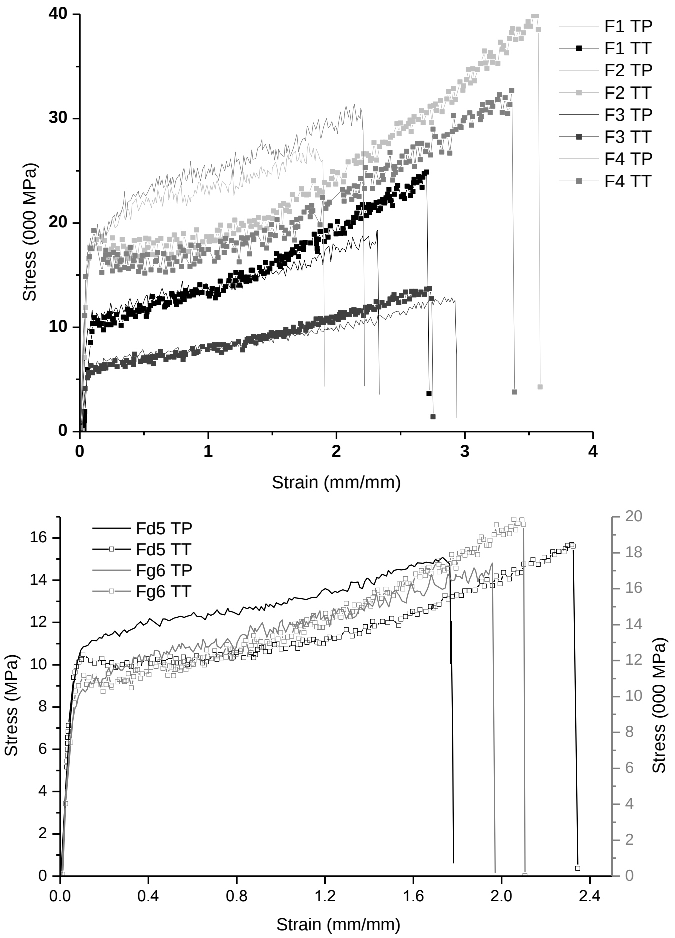

FIGURE 2: Strain-stress curves for tested materials in the parallel (TP) and transverse (TT) direction to the extrusion

Higher percentage of elongation was observed in the transverse direction for both materials. The reason can be found in the unhomogenity of the materials themselves. Based on the mechanical test results combination of 75% of greenhouse coverings and 25% low tunnel films, after recycling can give a material that fulfils the standard demands for a good mulching plastic film.

The values of the maximum resistance for the other group of materials varied from 15.41 N to 18.72 N mm^{-2} and were lower than the value obtained for the virgin EVA material as well as for the materials from the previous group (Table 1).

Material Fg6 had higher maximum resistance when tensioned in transverse direction while values for Fd5 materials were similar in both directions of extrusion. The values of the elongation at break of Fd5 and Fg6 samples were similar and very low. The tests show that both materials tensioned in transverse direction present better deformability properties compared to tension in direction parallel to extrusion (Fig. 2).

Tzankova Dintcheva et al. (2001) and Tzankova Dintcheva et al. (2002) reported the more suitable mix, obtained with about 75% LDPE (Low Density Poly-Ethylene), 15% LLDPE (Linear Low Density Poly-Ethylene) and 10% EVA (Ethylene-Vinyl-Acetate copolymer), revealed good characteristics in terms of flexibility at low temperatures, resistance to degradation, and mechanical characteristics at high temperatures. Their analysis of virgin material influence on the properties of new recycled films was analyzed formulating different blends of virgin and used materials. Other studies showed that the addition of different percentages of VA to LDPE increases maximum strength resistance, hardness and resistance to laceration of the recycled film and improves its radiometric characteristics [Abdel-Bary et al., 1998].

According to the EN ISO 527-3 standard it can be concluded that material Fg6 can be considered a covering material that fulfils the standard characteristics of a covering “normal film” because its maximum resistance is higher than 17 MPa and its elongation at break is higher than 180%.

3.2. Spectro-radiometric properties of the new materials

All the regenerated films showed spectro-radiometric characteristics quite similar among them except Fd5 and Fg6. Analyzing the behavior of the films in the solar wavelength range, and specifically in the PAR, it is possible to note that materials F1, F2 and F3 had a transmittance higher than 80% while F4, Fd5 and Fd6 films were characterized by PAR transmittance less than 80%. Lower transmittance of F4 is the result of the fact that this material in its composition had 25% of HDPE from agrochemical packaging. Material Fd5 had significantly higher thickness, contributing to the worsening of the PAR transmittance.

All the tested materials show a high UV transmittance which is related to the potential photo-degradation of the polymer by sunlight (Fig. 3). This characteristic can be appropriate if the F1, F2, F3 and F4 materials are going to be used as mulching films while it could lead to the ageing and degradation of the film during its utilization, if no anti-ageing additives are used. The highest transmittance was observed for F1 (76.4%) and the lowest for the Fd5 material (37.9%).

The more transparent the film is to NIR, the more heat will reach the protected cultivation and the soil. In the case of recycled films that were compared with the LDPE, it can be seen that all materials show the same “pattern” in transmitting NIR and that all the results are included in the range 81% - 85% except for Fd5 (77.2%) that is also much more diffusive, 37.2% in the NIR and 39.5% in the solar wave length range, compared to F1 – F4 and Fg6 samples.

The greenhouse effect of the protected cultivation technique depends on the impermeability of the covering materials to long-wave infrared radiation. As it is well known, not all wave-lengths of the infrared (IR) spectrum are equally relevant from the thermal point of view, since there are “atmospheric windows” in which the IR radiation emitted by the Earth preferentially escapes; one of these windows is located between 8 and 13 μm [Abdel-Bary et al., 1998]. In the wave range of 3000 – 25000 nm F1, F2, F3 and F4 samples show similar transmittance patterns up to 15000 nm after this value the patterns are slightly different (Fig. 4). The highest transmittance value in the long-wave IR range was observed for F2 (78.4%) throughout all the range and the lowest for F1 (63.2%). Concerning the fact that material F2 had a content made of 75% of greenhouse covering, it was expected to have a lower transmittance in the long-wave infrared radiation. In case of Fd5 and Fg6 samples, it can be seen (Fig. 3) that the lower transmittance was observed for the Fd5 material (24.1%).

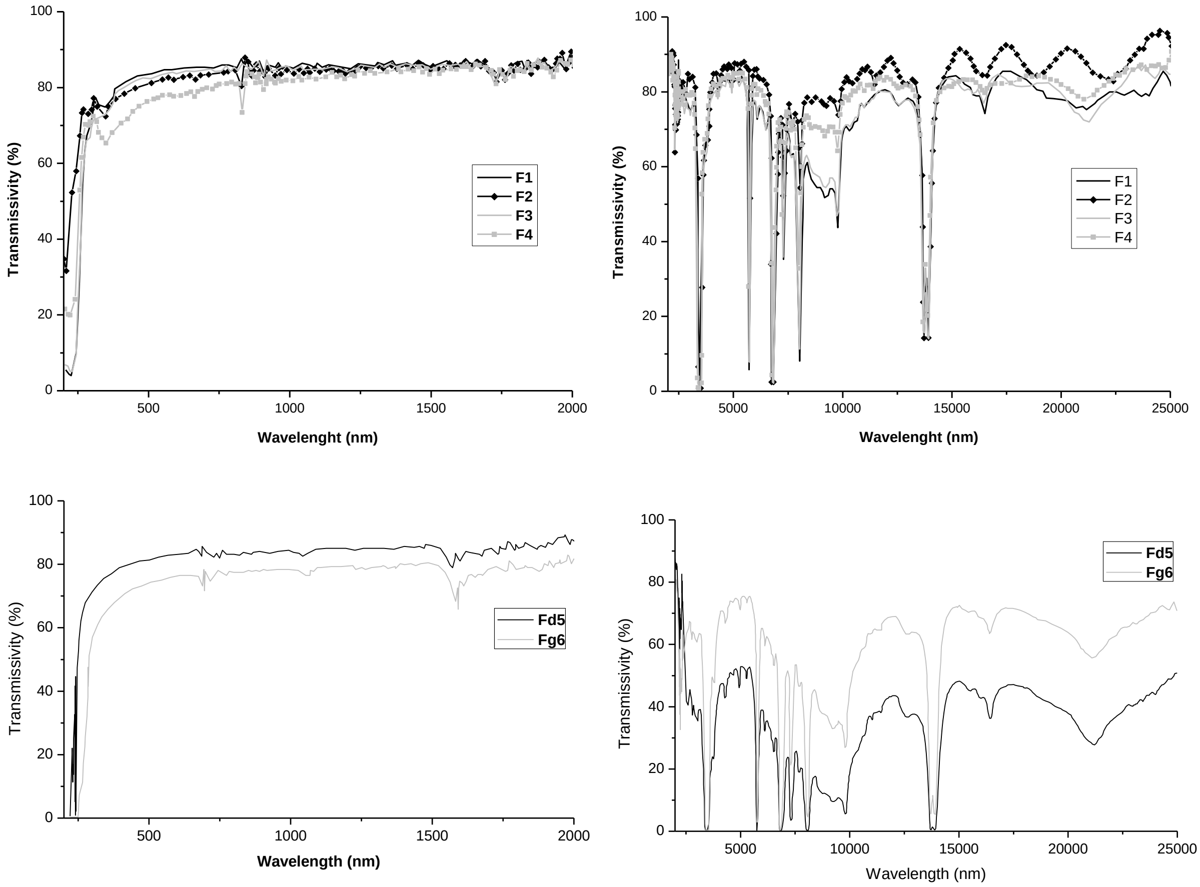

FIGURE 3. Spectral transmittance of tested materials (200-2000 nm; 2000-25000 nm)

Therefore it can be stated that in the long IR wavelength range, only the Fd5 film showed a low value while all other films were characterized by significantly higher transmittance values [Papadakis et al., 2000] than the optimal value of a greenhouse covering films (τ = 0.35-0.40).

From the spectro-radiometric analysis it can be seen that, with reference to the recycled materials composition and that the mixtures were made partially from greenhouse coverings, it has been expected that recycled materials could contain some percentage of vinyl-acetate (VA). According to the Italian Standard UNI ISO 8985, it is possible to calculate the material IR absorbance based on its IR transmittance. Since samples F1 to F4 had a thickness less than 50 µm, their content of VA was negligible while for the Fd5 material was 7.44% and for Fg6 6.44%. It is evident that the disposed plastic materials classification prior the recycling process is of high importance and that great attention should be taken when forming blends. Serranti and Bonifazi (2010) stated that no matter how efficient the recycling scheme is, sorting is the most important step in recycling loop. A good system of material traceability should be introduced into the recycling management centers.

4. Conclusion

Results show that without adding any additives materials can obtain satisfying mechanical properties if they are extruded from mixture that consists of 75% of greenhouse covering materials and 25% low tunnel coverings. Good mechanical properties were also observed with material extruded in higher thickness when combination of 25% of greenhouse covering and 75% low tunnel covering was used. Spectral analysis revealed that good PAR transmittance can't be expected in the case HDPE from agrochemical packaging is added to the blends for recycling.

Further investigation should be made on blends optimization and on improving the spectral-radiometric properties of new recycled materials.

Acknowledgement

The Authors wish to thank Mr. Cosimo Marano and Mr. Michele Cosmo, laboratory technicians, respectively for the cooperation during the mechanical and spectro-radiometric tests. In the name of the A. Dimitrijević, we wish to thank to the Ministry of Education and Science, Republic of Serbia, for funding her post-doc research at DITEC Department at Basilicata University in Italy (Grant no. 451-03-151/2011-02).

Reference list

[1] Abdel-Bary, E. M., Ismail, M. N., Yehia, A. A., Abdel-Hakim, A. A. (1998). Polymer Degradation and Stability, 62, 111-115.

[2] Briassoulis, D. (2005). The effects of tensile stress and the agrochemical Vapam on the ageing of low density polyethylene (LDPE) agricultural films. Part I. Mechanical behavior. Journal of Polymer Degradation and Stability, 88, 489-503.

[3] Briassoulis, D. & Dejean, C. (2010). Critical Review of Norms and Standards for Biodegradable Agricultural Plastics Part I. Journal of Polymers and Environment, 18, 384–400.

[4] EN ISO Standard 527-3:1995.

[5] La Mantia, F. P. (2002) .In: Handbook of Plastic Recycling.

[6] Ma, W. G. & La Mantia, F. P. (1995). In: Polymer Recycling.

[7] Papadakis, G., Briassoulis, D., Scarascia Mugnozza, G., Vox, G., Feuilloley, P. and Stoffers, J. A. (2000). Review Paper (SE—Structures and Environment): Radiometric and Thermal Properties of, and Testing Methods for, Greenhouse Covering Materials. Journal of Agricultural Engineering Research, 77 (1), 7-38.

[8] Serranti, S. & Bonifazi, G. (2010) The Open Waste Management Journal, 3, 35-45.

[9] Scarascia Mugnozza, G., Sica, C. & Picuno, P. (2008). The optimization of the management of agricultural plastic waste in Italy using a Geographical Information System. Acta Horticulturae, 801 (1), 219-226.

[10] Sica, C. (2000). Environmental problems connected to the use of plastic materials in protected cultivation (in Italian), Ph.D. dissertation. University of Basilicata, Potenza, Italy.

[11] Tzankova Dintcheva, N., La Mantia, F. P., Acierno, D., Di Maio, L., Camino, G., Trotta, F., Luda & M. P., Paci, M. (2001). Journal of Polymer Degradation and Stability, 72, 141-146.

[12] Tzankova Dintcheva, N., La Mantia, F. P., Scaffaro, R., Paci, M., Acierno, D. & Camino G.(2002). Reprocessing and restabilization of greenhouse films. Journal of Polymer Degradation and Stability, 75 (3), 459-464.

[13] UNI (1966) Italian Standard No: 5309-66

[14] UNI (1982) Italian Standard No: 8422

[15] UNI (1993) Italian Standards No: 8985

[16] Vox, G. & Schettini, E. (2007). Evaluation of the radiometric properties of starch-based biodegradable films for crop protection. Polymer Testing, 26 (5), 639-651.