MECHANICAL AND SPECTRO-RADIOMETRICAL PROPERTIES OF THE RECYCLED AGRICULTURAL PLASTIC FILMS

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Abstract: Intensive use of plastic in horticulture around Europe is causing the creation of the large amount of plastic waste that need to be dealt with. One possible way to control the amount this waste is its recycling. In this paper the results of a survey investigating the possibilities to producing a new regenerated film through mechanical recycling, from post-consume agricultural plastic films are analyzed. Four recycled films, different in composition, have been extruded and subsequently characterized by mechanical tests and spectro-radiometric analysis. Tensile tests were done in order to define the maximum strength and percentage elongation at break of these new materials while spectro-radiometric analysis allowed the definition of the optical properties, specifically with regard to the transmittance of radiation in the PAR and long IR radiation. The results allow the definition of the main engineering properties of these materials, and the possibilities for further investigation in order to have new products as an economic efficient and environmentally friendly alternative.
Key words: *plastic films, mechanical recycling, new film properties*

1. INTRODUCTION

A plastic material is any of a wide range of synthetic or semi-synthetic organic solids used in the manufacture of industrial products. Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce production costs. The word plastic is derived from the Greek word meaning capable of being shaped or molded. It refers to their malleability, or plasticity during manufacture, that allows them to be cast, pressed, or extruded into a variety of shapes—such as films, fibers, plates, tubes, bottles, boxes, and much more.

Due to their properties, plastic materials have a wide range of implementation in industry. Concerning the agriculture, especially horticulture, an extensive and steadily expanding use of plastic films is reported world-wide since the middle of the last century. Some of the reported benefits of using plastic materials in agricultural fields result from increased yields, earlier harvests, less reliance on herbicides and pesticides, frost protection and water conservation. It has also provided a more efficient use of farm land, higher quality of crops and a resultant healthier environment. Furthermore, plastics-based agricultural systems provide effective solutions to crop growing in many ways: in arid regions, for example, plastics piping/drainage systems can cut irrigation costs by one to two-thirds while as much as doubling crop yield. In particular, the market of plastics used for these purposes in Europe involves hundreds of thousands of hectares and thousands of tons of plastic films per year.

Apart from their diverse use and contribution to a significant increase in productivity 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 Italy, with the respect to an average annual consumption of more than 350,000 t of agricultural plastic, it is estimated a corresponding flow of post-consume material of about 200,000 t/year. Approximately, 55% of this quantity (Scarascia-Mungozza et al, 2008) comes from protected cultivation (greenhouse claddings, soil mulching, vineyards nets, etc.).

There are many studies that consider the mechanical recycling an appropriate system for recovery of post consumer agricultural plastic film. It is the reprocessing of end-of-life plastics into a re-usable material through a physical rather than a chemical process. The mechanical recycling process starts form the collection and removal of plastic waste from the field, its transportation to a storage point from where it is conveyed to the recycling plant for the cleaning and recycling into pellets. Pellets are introduced to an extruder that, through the thermal process shapes the new material.

The recycling of plastic films of agricultural origin is a technique technically, economically and environmentally practicable, although some difficulties may always negatively affect the process such as the price of crude oil which can sometimes make the new material less profitable, the continuous evolution of the legislation on the matter, the influence exerted by the external factors that determine a general worsening of the secondary raw material. To solve the last problem, new mixtures of plastic films obtained by recycling agricultural granules were formulated.

The aim of this paper was to presents some research results in the area of plastic materials mechanical recycling. The paper gives the basic mechanical and spectro-radiometrical characteristics of the new materials as well as the possibilities for the future research.

2. MATERIAL AND METHOD

Materials that were tested and analyzed were used as cladding materials for low tunnels and greenhouses in Almeria and Huelva region (Spain). Materilas were collected and recycled by the INSERPLASA S.A. company. Four films, different in composition but all extruded from recycled agricultural granules were extruded and subjected to mechanical testing and spectro-radiometric analysis. The four different transparent films (Fig. 1) were characterized with the following mixtures:

- G1 - recycled film obtained from regenerated granule of greenhouse film (50%) and low tunnel film (50%);
- G2 - recycled film obtained from regenerated granule of greenhouse film (75%) and low tunnel film (25%);
- G3 - recycled film obtained from regenerated granule of greenhouse film (25%) and low tunnel film (75%);
- G4 - recycled film obtained from G1 (25%), G2 (25%), G3 (25%) and HDPE, from agrochemical packaging, (25%).

Figure. 1 Granulated material and new, regenerated films

These films were subjected to mechanical test in the Laboratory of Material Testing of the Technical-economic Department of the University of Basilicata, Italy. The 10 specimens were cut (Fig. 2) according the Italian Rule (UNI 5819, 1966). Five specimens were taken along the parallel direction of the extrusion and five specimens in the transverse direction. The tensile tests were conducted, using a computerized universal machine Galdabini PMA 10 (Fig. 3), according to the Italian UNI 8422 Standard (UNI, 1982), at constant deformation velocity of 200 [mm min^{-1}]. Each test concerned 10 specimens, so expressing the results in terms of average value and bilateral confidence interval with 95 % probability (UNI 5309, 1966). The results obtained from tensile tests were reported in terms of maximum resistance (σ_{max}) expressed in [MPa] and percentage elongation at break (ε) expressed in [%].

Figure. 2 A sample for the tensile test

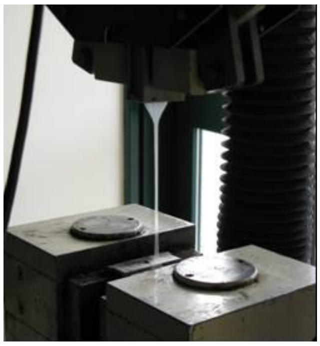

Figure. 3 Tensile test in progress

The spectro-radiometric analysis, aimed to the definition of the optical properties of the four regenerated films, has been realized in the Laboratory of Spectro-radiometric Analysis of the PROGESA Department of the University of Bari - Italy, using the spectro-photometer Perkin-Elmer FT-IR 1760X (Fig. 4).

Figure. 4 Spectro-photometer Perkin-Elmer FT-IR 1760X

The transmittance to radiation in the wavelength range from 190 nm to 25000 nm was determined. An integrating sphere was used to evaluate the diffuse fraction of the transmitted radiation in the PAR range.

3. RESULTS AND DISCUSSION

3.1 Mechanical properties of the new materials

The results of the tensile test obtained for the regenerated materials, show that there are differences in the terms of maximum resistance (σ_{max}) and percentage elongation at break (A). The values of the maximum resistance varied in the range of 12.38 – 40.45 N mm^{-2} (table 1). The lowest resistance was observed for the material G3 and it was similar in both directions. Material G2 had the highest maximum resistance regardless the tension direction. These results would suggest better behavior of the material that was mixture of 75% greenhouse covering and 25% of the tunnel covering.

Table. 1 Results of the tensile tests on the recycled films

Type of the material	Tension along the parallel direction		Tension along the transverse direction	
	A (%)	σ_{max} (N mm^{-2})	A (%)	σ_{max} (N mm^{-2})
G1	252.51	20.82	240.98	20.38
G2	270.30	30.97	350.72	40.45
G3	279.77	12.38	244.13	12.69
G4	196.70	29.38	298.67	30.48

The values of the elongation at break suggested which of the four materials is the most elastic. Values of this parameter varied significantly in a wide range of 196.7 to 350.72%, confirming the considerable un-homogeneity of the blends obtained by using recycled agricultural films. In particular, the lowest value was recorded for the G4 material when tensed in parallel direction while the highest value was observed for the material G2 in the same direction. In the case of tension along the parallel direction the range of elongation at break was narrower compared to the testing in the transverse direction. The lowest value was observed for the material G1 and the highest for the material G2. Based on the tensile test it can be concluded that the G2 material has a high resistance in both directions and best elasticity when tensioned in transverse direction. The lowest maximum resistance was observed for the material G3 in both directions.

However, concerning the minimum limits for the good mechanical properties of the cladding materials of the Italian UNI Regulation ($\sigma max \geq 17$ MPa, $\varepsilon \geq 400\%$) it can be concluded that all materials have good properties regarding the maximal resistance except G3. As for the elasticity none of the materials showed satisfying properties.

3.2 Spectro-radiometrical properties of the new materials

All regenerated film showed spectro-radiometric characteristics quite similar between them (Fig. 5). Analyzing the behavior of the 4 films in the solar wavelength range, and specifically in the P.A.R., it is possible to note that materials G1, G2 and G4 had a transmittance greater than 80% while G3 film was characterized by a total transmittance less than 80%. In any case, this value was not so low and it is possible to assume that transmittance of the G3 material can be improved by adding special additives to the blend.

Table.2 Results of the spectral analysis for the new materials

Wave length range	Measured parameter		G1	G2	G3	G4
Solar (200-2,500 nm)	Transmission	Total (%)	84.7	84.0	79.1	82.8
		Direct (%)	59.4	60.2	54.1	59.6
		Diffuse (%)	25.3	23.9	25.0	23.2
	Reflection		8.0	8.6	8.0	11.3
PAR (400-700 nm)	Transmission	Total (%)	84.1	83.2	76.3	81.5
		Direct (%)	51.7	52.1	42.2	50.1
		Diffuse (%)	32.4	31.1	34.1	31.4
	Reflection		8.4	9.2	8.4	12.7
Solar IR (700-2,500 nm)	Transmission	Total (%)	85.6	85.1	81.9	84.3
		Direct (%)	66.7	67.8	65.1	68.5
		Diffuse (%)	18.9	17.3	16.8	15.8
	Reflection		7.6	8.1	7.5	10.1
UV (280-380 nm)	Transmission	Total (%)	76.4	74.8	74.7	67.1
		Direct (%)	38.4	36.1	38.4	29.3
		Diffuse (%)	38.0	38.6	36,3	37.8
	Reflection		9.9	10.1	9.9	11.0
Long IR (7,500-12,500nm)	Transmission	Total (%)				
		Direct (%)	63.2	78.4	64.9	73.3
		Diffuse (%)				
	Reflection		9.7	5.1	12.3	8.7

Concerning the fact that material G4 was made as a mixture of greenhouse claddings and agrochemical plastic packaging it is interesting that transmittance is higher than 80%.

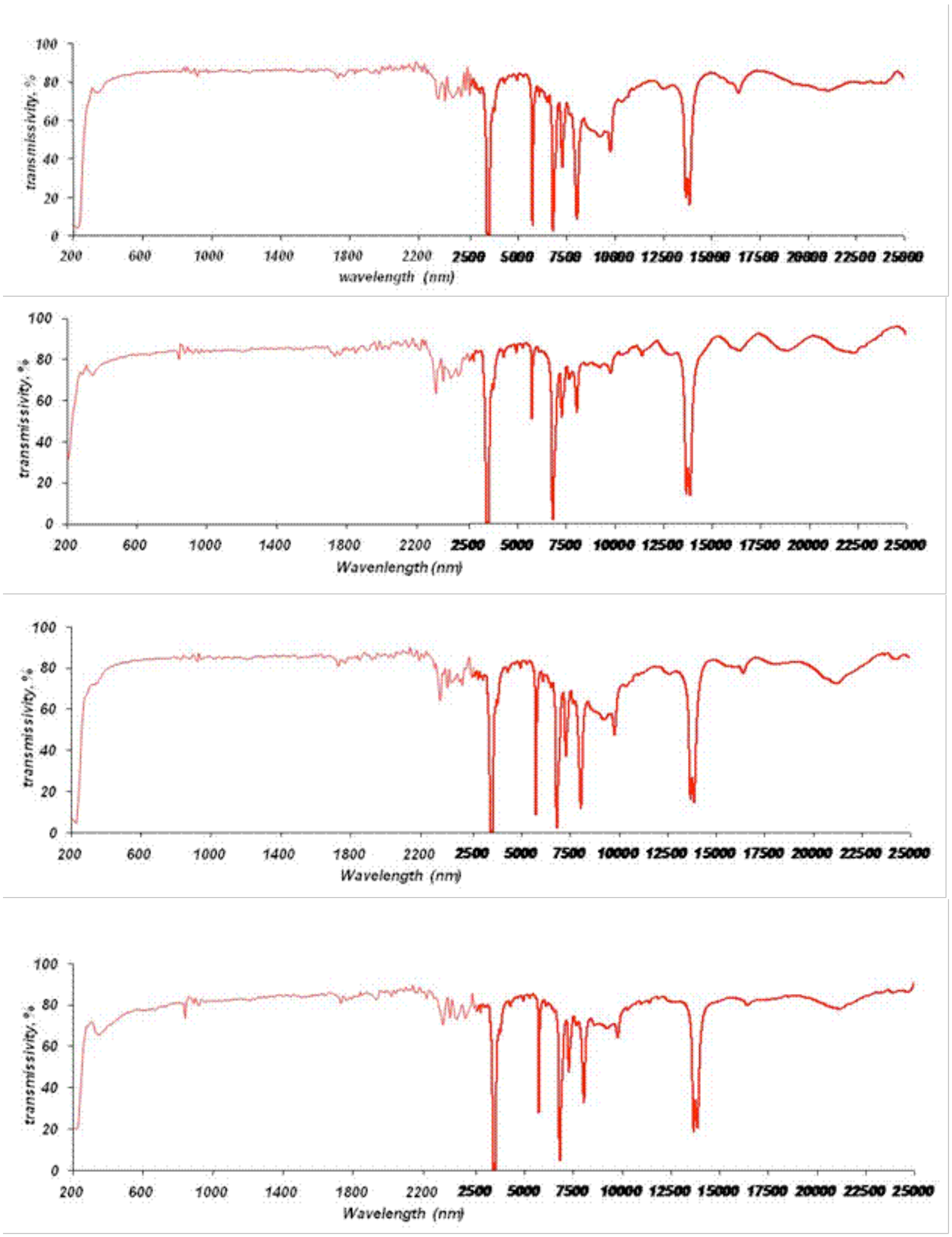

Figure. 5 Transmittance of the G1-G4 material analyzed in the whole wavelength range

In the long IR wavelength range, all films were characterized by higher transmittance values than optimal value of a covering film ($\zeta \approx 0{,}35\text{-}0{,}40$). This is the reason why they can't generate a sufficient "greenhouse effect" and act as good greenhouse covering material. A reason for such high IR transmittance can be material thickness that was 0.04 mm.

The final properties of the blend depend on the amount of degraded polymer but mainly on the extent of degradation. When the degradation of the polymer is limited, good properties can be achieved, but if the degradative effects are more pronounced, there is a general worsening of all the properties (Scaffaro & La Mantia, 2002). For this reason, it is very important to introduce into blends

4. CONCLUSIONS

The strategic contribution of plastic materials to the development of the agricultural sector is testified by their increasing use, stimulated by a constant research of new polymers and blends by the chemical industry, in protected cultivation, pasteurization of soil, irrigation and drainage, and packaging for harvest, transport, storage and sale of agricultural products.

The solution of the problem of agricultural plastic waste passes through the research of new applications of the recycled material. One of the most interesting ways appears to be the re-utilization of the agricultural wastes in the same sector, through the realization of cheap and effective products able to improve agricultural production.

Mechanical recycling represents the simplest way of managing plastic waste and, in the same time obtaining new plastic materials that can be re-used in agricultural sector. By recycling the different mixtures of cladding materials for low tunnels and greenhouses, new materials, having satisfying optical characteristics and mechanical ones in terms of resistance can be made.

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