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

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

[1] *University of Basilicata – DITEC Department, Potenza, Italy*
[2] *University of Bari – DISAAT Department, Bari, Italy*
[3] *University of Belgrade – Faculty of Agriculture, Institute of Agricultural Engineering, Belgrade, Serbia*

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 of this waste is its proper management and recycling. In this paper the results of a survey investigating the possibilities to producing new regenerated films 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*: agricultural plastic films, mechanical recycling, new film properties*

* Corresponding author: Pietro Picuno, Via dell'Ateneo Lucano n°10 – 85100 Potenza, Italy.
E-mail: picuno@unibas.it

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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 [2]. 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 in protection against meteorological agents such as hail, rain, wind, snow and sun. These result in increasing the yields, earlier harvests, less reliance on herbicides and pesticides [1]. 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 Europe annual consumption of plastic in agriculture is estimated to be 990.000 t.

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 a way that will not cause negative effect on the landscape and agro-ecosystem. In Italy [7], 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 [9] comes from protected cultivation (greenhouse claddings, low tunnels, soil mulching, vineyards films and nets, etc.).

Many studies consider the mechanical recycling an appropriate system for recovery of post consume agricultural plastic film [11]. It is the reprocessing of end-of-life plastics into a re-usable material through a physical rather than a chemical process [3]. The mechanical recycling process [6] starts from the removal and collection 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 (Fig. 1). 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 process 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 recycled 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 [5]. To solve the last problem, new mixtures of plastic films obtained by recycling agricultural granules were formulated [10].

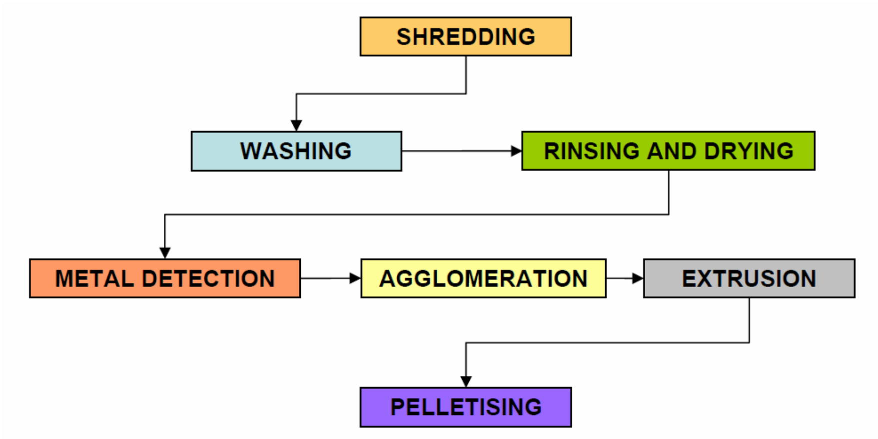


Figure 1. A typical recycling process to obtain the pallets

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 secondary materials as well as the possibilities for the future research.

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). Plastic materials were collected and recycled by the INSERPLASA S.A. company. Four transparent films (Tab. 1), different in composition but all extruded from recycled agricultural granules were extruded and subjected to mechanical testing and spectro-radiometric analysis.

These films were subjected to mechanical tests in the Laboratory of Material Testing of the Technical-economic Department of the University of Basilicata, Italy. Ten specimens were cut (Fig. 3) according the Italian Standard [13]. 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. 4), according to the Italian UNI 8422 Standard [14], at constant deformation velocity of 200 [$mm \cdot min^{-1}$]. Each test concerned 10 specimens, so expressing the results in terms of average value and bilateral confidence interval with 95 % probability [12]. 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 [%].

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 DISAAT Department of the University of Bari - Italy, using spectro-photometers Perkin-Elmer UV-VIS and FT-IR 1760X.

Table 1. Properties of the recycled materials

Material	Composition	Thickness [µm]	Type of mixture
G1	LDPE+EVA	40	regenerated granule of greenhouse film (50%) and low tunnel film (50%)
G2	LDPE+EVA	32	regenerated granule of greenhouse film (75%) and low tunnel film (25%)
G3	LDPE+EVA	77	regenerated granule of greenhouse film (25%) and low tunnel film (75%)
G4	LDPE+EVA+HDPE	30	G1 (25%) + G2 (25%) + G3 (25%) + HDPE, from agrochemical packaging, (25%)

Figure 2. Granulated material and new, regenerated films

Figure 3. A sample for the tensile test

Figure 4. Tensile test in progress

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.

RESULTS AND DISCUSSION

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} (Tab. 2). The lowest resistance was observed for the material *G3*, 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 mostly derived from the greenhouse than from the tunnel covering.

Table 2. 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 deformable. 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 deformability 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 Standard ($\sigma_{max} \geq 17$ 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.

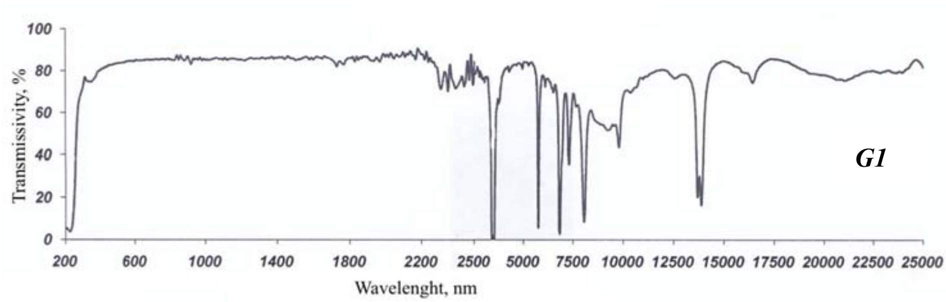
Spectro-radiometrical properties of the new materials

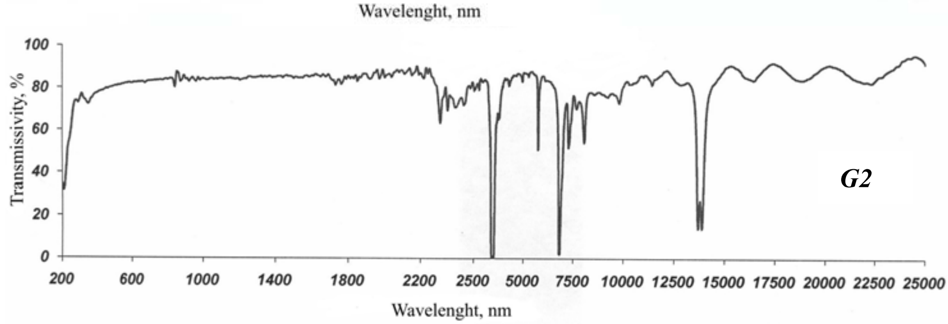
All regenerated films showed spectro-radiometric characteristics quite similar among them (Fig. 5). Analyzing the behavior of the 4 films in the solar wavelength range, and specifically in the PAR, it is possible to note that materials *G1, G2* and *G4* had a transmittance greater than 80% while *G3* film was characterized by a total transmittance less than 80% (Tab. 3).

Table 3. 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%.





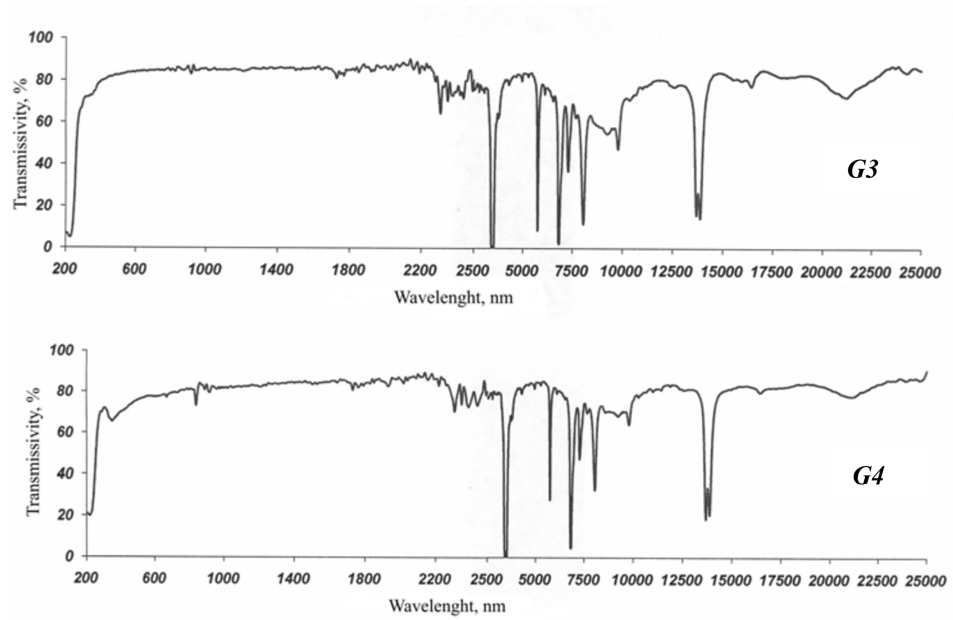


Figure 5. Transmittance of the G1-G4 material analyzed in the whole wavelength range

In the long IR wavelength range, all films were characterized by high transmittance values that are similar to the common LDPE material properties [4]. 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 could be the low material thickness (lower than 80 µm) or the absence of IRL additives.

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 [8].

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, soil solarization, irrigation and drainage, and packaging for silage 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 new recycled materials. 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, at the same time, obtaining new plastic materials that can be re-used in agricultural sector. By recycling the different mixtures of cladding materials for mulching, low tunnels and greenhouses, new materials, having satisfying optical characteristics and mechanical ones in terms of resistance can be made.

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MEHANIČKE I OPTIČKE KARAKTERISTIKE RECIKLIRANIH PLASTIČNIH MATERIJALA DOBIJENIH IZ POLJOPRIVREDE

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

[1]Univerzitet Bazilikata, DITEC Institut, Potenza, Italija
[2]Univerzitet u Bariju, DISAAT Institut, Bari, Italija
[3]Univerzitet u Beogradu, Poljoprivredni fakultet, Institut za poljoprivrednu tehniku, Beograd, Srbija

Sažetak: Savremena i intenzivna poljoprivredna proizvodnja u kontrolisanim i delimično kontrolisanim uslovima ima za posledicu velike količine plastičnog otpada koji predstavlja ekološki i ekonomski balast poljoprivrednoj proizvodnji. Jedan od načina da se kontroliše količina plastičnog otpada je njegova reciklaža. U radu su dati rezultati ispitivanja četiri tipa recikliranih folija nastalih od folija korišćenih za plastenike, niske tunele i mulčiranje zemljišta kao i od plastike od plastičnih bočica korišćenih u poljoprivredi. Nakon ekstrudiranja reciklirane folije su analizirane sa aspekta mehaničkih i spektro-radiometrijskih osobina. Dobijeni rezultati se mogu iskoristiti za definisanje osnovnih inžinjerskih karakteristika novodobijenih materijala i mogu ukazati na mogućnosti njihovog daljeg korišćenja.

Ključne reči: *plastična folija, mehanička reciklaža, novi plastični materijali.*

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