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**MECHANICAL AND SPECTRORADIOMETRICAL CHARACTERISTICS
OF AGRICULTURAL RECYCLED PLASTIC FILMS**

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Abstract

The increasing use of plastic materials in agriculture, particularly for protected cultivation, creates at the end of their use a large amount of plastic waste that, if not correctly managed, can produce negative effects on the landscape and on the whole ecosystem; mechanical recycling appears on the other hand one of the more suitable processes for a sound disposal of agricultural plastic films.

This paper reports first results of a research project that investigates the possibility to mechanically recycle post-consume agricultural plastic films for the production of new regenerated film. Three different recycled films have been produced, characterized by mechanical tests and spectroradiometrical analysis, and compared to virgin LDPE films.

The results show that all these recycled films have worse properties than the virgin material, so confirming that, without improvements in the formulation of blends and additives, the recycling of agricultural film into new regenerated film for agricultural application would remain a solution not interesting from a technical and economical point of view.

1. Introduction

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. Plastic materials in agriculture have reached a diffusion of about 2,000,000 tons/year in the World, while in the Italian agriculture about 300,000 tons/year are employed, of which 120,000 tons/year only for protected cultivation.

This wide consumption of plastic materials produces, consequently, a rapid growth of the quantity of post-consume material (table 1), whose management and disposal have to be conducted in a correct way in order to avoid negative effects on landscape and on the agro-ecosystem (photo 1).

Table 1: Plastic waste amount (tons/year), (Pacini, 2000)

Use	Plastic material	WORLD	WESTERN EUROPE	ITALY
All applications	Consumption	153,000,000	28,000,000	6,800,000
	Wastes	75,000,000	17,500,000	3,500,000
Agriculture only	Consumption	2,000,000	560,000	285,000
	Wastes	1,200,000	327,000	165,000

On the other hand, the collection of great volumes of plastic material, relatively clean and homogeneous, is possible in the agricultural sector, where the consumption is concentrated in a well-defined number of specialized farms, located in well-known restricted geographic

areas and produced during fixed time periods, depending on the cropping activities. The estimation of waste flux, the organization of sound harvest plans for the collection of plastic waste and the transportation in specific centers for their selection, pre-treatment and disposal should be so easily possible. Nevertheless, at present, in Italy only a small percentage of agricultural plastic wastes is recovered, while the remaining quantity is burnt in an uncontrolled way – a practice that is forbidden by the Italian Law - or it is disposed in unauthorized dumping sites near cultivated areas or in drainage channels, with severe damages for the environment in all its components.

The Italian Law about wastes (D. Lgs. 22/97 – “Decreto Ronchi”) imposes that the cost for transport, storage and disposal of special wastes – like agricultural plastics - is charged to the producer, but the application of this Law to the agricultural sector is still far from realization; at present, in some Italian regions, especially in areas characterized from an intensive agriculture, harvest plans and rational disposal solutions are yet in the elaboration phase.

One of the more suitable processes for the reuse of this material is mechanical recycling, that consists in producing, through adequate mechanical and thermal treatments of plastic waste, new manufactured products that may be usable in agriculture - such as regenerated film (mulching film, nets against the wind or hail, nets to pick olives, etc.), pipes for irrigation or containers (pots, bags, baskets, etc.) -, in building - moulds for concrete and other uses alternative to wood - and in urban health and fittings - garbage bags and containers, benches, fences, etc. (Picuno and Scarascia-Mugnozza, 1994).

The mechanical recycling process starts from the collection and removal of plastic waste from the land, and its transportation to a storage point, from where it is conveyed to the recycling plant for cleaning and recycling into pellets; pellets are then introduced in an extruder that, through thermal processing, shapes the new product.

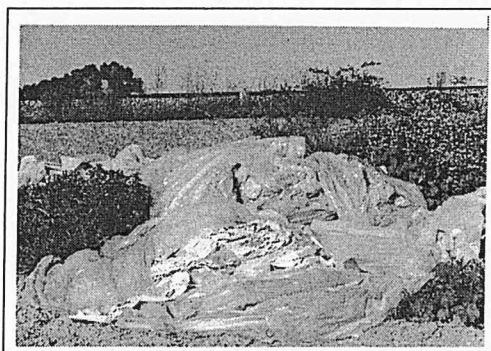


Figure 1 – Used agricultural plastic films abandoned in the countryside

The recycling of plastic films of agricultural origin is a technique of low environmental impact, well appreciated by the public opinion, because it doesn't origin harmful substances as it happens during other disposal techniques, i.e. the incineration. It may also lead to interesting advantages, from technical and economical point of view, through the creation of new products, the improvement of those existing and the development of new applications, with decreasing costs of the whole process if it is possible mechanical recycling of heterogeneous plastic material, where the need to separate different polymers is avoided.

The characteristics of the recycled material depend on those of the virgin material and on the level of dirtiness of the post-consume(used) material. Regarding this latter aspect, an adequate cleanness is usually necessary in order to obtain good properties of the recycled material: during their working life, plastic films are in fact subjected to expansion, due to thermal variations, so that particles of dust, soil or chemical products may dirty the material not only superficially, but also penetrating into the molecular structures of the polymers. The presence of such impurities can render their mechanical recycling technically complicated, and it may lead to films with low mechanical and spectroradiometrical properties. The level of chemical impurity is usually rather low, because treatments are turned to the crops and not to the plastic film, and chemical products have a safety time of 20-30 days, a time period lower than which passing between the removal of the film and its recycling; repeated and energetic washings are therefore enough.

The influence of the virgin material of the post-consume plastic film on the properties of new recycled films was analyzed formulating different blends of virgin and used materials (Tzankova Dintcheva et al., 2001; Tzankova Dintcheva et al., 2002). 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. Other studies showed that the addition of different percentages of EVA to LDPE increases not only maximum strength resistance, hardness and resistance to laceration of the recycled film, but EVA may improve its optical characteristics too (Abdel-Bary et al., 1998).

Tzankova Dintcheva et al. (2001), comparing the results of the chemical analysis and of the mechanical tests on specimens of recycled films with those obtained in the virgin material, concluded that the recycled material can be used again in a lot of applications even if its optical characteristics decrease with the number of the extrusive passages, especially due to oxidative degradation. Mechanical characteristics, instead, even worse than the virgin material, remain relatively good after a lot of extrusions; the addition of suitable stabilizers before every extrusion during the recycling process appeared anyway essential in order to obtain improved properties (Tzankova Dintcheva et al., 2002).

Considering the wide spreading of EVA film as cladding material for protected cultivation thanks to the good mechanical and spectroradiometrical characteristics of this film, that is progressively replacing other polymers traditionally used, its recycling constitutes an interesting opportunity. The mechanical recycling of 100% EVA agricultural film for the production of square-shaped bars showed however that they have a deformability that makes them incompatible with an ordinary use (Manera et al., 2000; Sica, 2000); they showed also a lower tensile strength if compared to bars realized with mixture of other polymers, like LDPE and PET (Poly-Ethylene Terephthalate), respectively obtained from agricultural film for protected cultivation and liquid containers (Manera et al., 1997; Scarascia Mugnozza et al., 1997). It was concluded that an improvement of the properties of the recycled material may be obtained only mixing EVA film with other polymers, according to formulation and blends that have to be investigated.

In the present paper the mechanical and spectroradiometrical characteristics of films usable for application in protected cultivation, obtained by mechanical recycling of post-consume agricultural plastic film, are reported.

2. Materials and methods

The recycled film to reemploy in the protection of the crops was obtained in an Italian centre of plastic waste collection, selection, pressing and granulation (ECOPLAST s.r.l., located in Melfi – Italy). Here used LDPE agricultural films were adequately cleaned and granulated (fig 2).

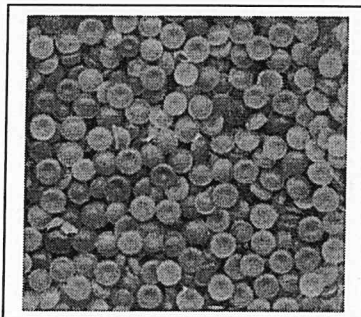


Figure 2 - Regenerated granule of LDPE

Three different transparent films, characterized with the following mixtures, were then extruded:

(A): recycled film obtained exclusively from regenerated granule of LDPE agricultural films, extruded in a thickness of 240 μm , usable as cladding material for protected cultivation;

(B): recycled film obtained from regenerated granule of LDPE agricultural films with additives, extruded in a thickness of 180 μm , usable as cladding material for protected cultivation;

(C): recycled film obtained from agricultural film (40% LDPE) and other industrial plastic waste (60%), extruded in a thickness of 60 μm , usable for soil mulching or soil solarization.

In order to compare these recycled films with the traditional ones, the two following virgin films were also tested:

(D): virgin LDPE film, thickness of 180 μm ;

(E): virgin LDPE film, thickness of 50 μm ;

Regenerated films were then subjected to mechanical test and spectroradiometrical analysis in the Laboratory of the Technical-economic Department of the University of Basilicata (Potenza, Italy). Here, tensile tests were conducted, using a computerized universal machine Galdabini PMA 10 (photo 3), according to the Italian UNI 8422 Rule (UNI, 1982), at constant deformation velocity of 200 [mm min^{-1}]. Each test concerned 10 specimens, in order to express the results in terms of average value and bilateral confidence interval with 95 % probability (UNI, 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 [%]. The spectroradiometrical analysis enabled the determination of transmittance to radiation in the PAR band [400-700 nm] and in the IR band [7500-12500 nm]; it was performed with a Jasco modular spectroradiometer, operating in direct (perpendicular) and diffused light, in a continuous wavelength range from 190 nm to 25000 nm.

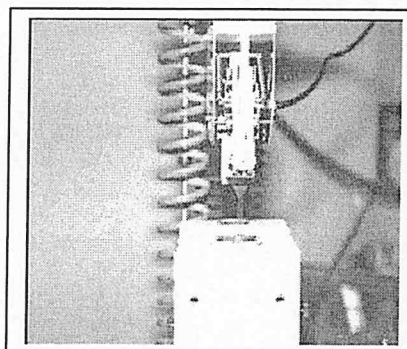


Figure 3 – Tensile test

3. Results

3.1 Covering films

The results of the laboratory tests show that the recycled film without any additive (A) has rather satisfactory mechanical characteristics (table 2), because the minimum limits of the Italian UNI Regulation ($\sigma_{\max} \geq 17 \text{ MPa}$, $\epsilon \geq 400\%$) are nearly satisfied.

The results of the tensile tests on A and B films are compared in Table 2 with the average values of a typical virgin LDPE film employed to cover greenhouse and tunnels (material D in table 2). From these results it's possible to conclude that materials A and B are rather similar between them, material B showing, despite a lower thickness than film A, better mechanical properties, probably caused by the introduction of additives. Comparing the values of recycled films (A and B) with those of the virgin LDPE film (D), it is evident that percentage elongation at break is heavily worsened by the new extrusion, and that the breakage of the polyethylene chains by the UV radiation during the exposure of the film limits the possibility to recycle agricultural film in new regenerated film only to application where good mechanical characteristics are not essential. Further improvements of the mixtures appear therefore necessary in order to make recycled films really competitive materials.

Table 2: Results of tensile tests on films for covering

Material type	Thickness (micron)	σ_{\max} (MPa)	ϵ (%)
A	240	$17,96 \pm 2,28$	$395,52 \pm 65,43$
B	180	$20,18 \pm 3,56$	$458,22 \pm 165,89$
D	180	20,00	1190,00

Film A shows spectroradiometrical characteristics quite interesting (table 3), considering that it's a rough material, not adequately manipulated like material B, where, in order to improve the tensile resistance and the transmittance in the PAR, some specific additives were added to the polymeric base. The optical characteristics of these two recycled films for covering uses, rather different from those of the virgin LDPE film (material D in table 3), are similar between them, the additives and the different thickness in material B having not influenced the results again.

Table 3: Results of spectroradiometrical analysis on films for covering

Material type	Thickness (micron)	τ PAR (%)	τ IR (%)
A	240	70,00	42,00
B	180	70,33	42,24
D	180	80,00	45,00

3.2 Film for mulching or soil solarization

The results of tensile tests on the C film are reported in table 4, where a comparison with the experimental values of a virgin LDPE film employed for soil mulching, that was also tested as reference (material E in table 4), is possible. As table 4 shows, material C doesn't have satisfying mechanical characteristics.

Table 4: Results of tensile tests on films for mulching

Material type	Thickness (micron)	σ_{\max} (MPa)	ϵ (%)
C	60	14,30 \pm 1,77	350,97 \pm 136,36
E	50	28,5 \pm 1,69	459,24 \pm 209,04

Table 5, finally, shows that material C is not able to exploit solar radiation, because the transmittance in the IR band is very high, and thermal radiations are then dispersed, so frustrating the energetic effect of the mulch and/or soil solarization.

Table 5: Results of spectroradiometrical analysis on films for mulching

Material type	Thickness (micron)	τ PAR (%)	τ IR (%)
C	60	88,00	83,89
E	50	87,00	55,00

4. Conclusions

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.

The recycled films that were tested may be considered as interesting materials, but they must be improved if new applications in protected cultivation have to be investigated; the competitiveness of the recycled material must be of course appraised from an economic point of view, in order to make it really desirable in the market.

At present, new regenerated films obtained by recycling post-consume agricultural plastic films seem do not satisfy the properties requested for protected cultivation. In particular, the recycled films, examined in this work, may be considered as interesting materials to be used in application where good mechanical properties are not essential and provided that an improvement in the formulation of blends and/or the use of appropriate additives is pursued.

The contribution to programming and executing this research must be equally shared between the Authors.

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