Mechanical characterization of recycled agricultural plastic materials

Sica Carmela [1)], Picuno Pietro [2)], Scarascia Mugnozza Giacomo [1)]

[1)] University of Bari - PROGESA Dept, via Amendola, n°165/a - 70126 Bari, Italy, scarasci@agr.uniba.it

[2)] University of Basilicata - DITEC Dept., Via dell'Ateneo Lucano n°10 - 85100 Potenza, Italy, picuno@unibas.it

Abstract

The use of plastic materials in the European agriculture is continuously increasing; as a direct consequence, large amount of plastic waste are generated, and they should be disposed in a correct way. The material reutilization through its mechanical recycling is an environmentally friendly alternative for the plastic waste disposal, that should be resolutely pursued. With this aim, a significant improvement of the technical characteristics of the recycled products is necessary too. During the recycling process the polymers are in fact subjected to manufacturing phases that may introduce thermal and/or mechanical degradation, so altering and worsening some of their chemical, physical and mechanical properties and determining a lower quality of this "secondary raw material" if compared with the original products.

With the aim to evaluate the mechanical and physical characteristics of plastic products obtained by recycling different polymeric mixtures of agricultural plastic film, experimental tests were performed on different blends of heterogeneous material. Profiles of bars with prismatic shape from recycled agricultural plastic film were produced through mechanical recycling, adding in some cases specific additives in the waste stream, like talc and calcium carbonate. In this paper the results of mechanical tests on these regenerated profiles are reported and discussed.

Introduction

The use of plastic materials in the European agriculture is continuously increasing. In Italy the annual consumption exceeds 300,000 tons (Tab. 1). The management of these materials after the end of their useful life represents an important economic and environmental issue (Picuno & Sica, 2004).

The material reutilization (mechanical recycling or energy recovery) is one of the best environmentally friendly alternative for the plastic waste disposal (Picuno & Scarascia, 1994). The main typical prerequisites for mechanical recycling are homogeneity, relatively high cleaning, and time constancy in the production of the waste flow. Therefore, agricultural plastic waste, especially mulch and covering film, is a good input for mechanical recycling, as it is constituted by a limited range of plastics, mostly polyolefin (Low Density PolyEthylene - LDPE, Linear Low Density PolyEthylene - LLDPE and High Density PolyEthylene - HDPE). The volumes are relatively small (considering even that agricultural use covers about 2% and 3,5% of the total plastic consumption, respectively in the Western Europe and in Italy). On the other hand, the waste fluxes are usually produced in specific restricted geographic areas, in a well-defined number of specialised farms, and during certain time periods of the year depending on the cropping activities (Scarascia-Mugnozza et al., 2006).

Table1 –Consumption of plastic material in the principal agricultural applications in Italy

Main applications	**Consumptions [tons/year]**		
	1999	**2002**	**2005**
Greenhouse film	53,700	55,000	58,000
Low tunnel film	27,700	30,000	31,200
Mulching film	40,000	43,200	42,000
Silage film	8,000	8,500	8,500
Irrigation pipes	67,000	78,000	83,000
Other (sheets, nets, bags, containers, pots, string, etc.)	80,000	85,000	89,000
TOTAL	**276,400**	**299,375**	**311,700**

Mechanical recycling enables an easy re-use of the same material, but some loss of properties must be taken into account, since there are some factors having a negative influence on the quality of this “secondary raw material”, when the polymers are reprocessed, so some of their chemical, physical and mechanical properties can worsen.

The mechanical recycling of plastic material

Agricultural plastic films, like other plastic materials, are subject to many and different degradation factors during their manufacture, processing and use. The polymer is exposed during processing to temperature and stresses which may cause chemical reaction, under conditions of limited oxygen access while stresses are often worse in recycling operations where high shear mixing may be required to induce good homogeneity of the final product (La Mantia, 2002). Many polymeric materials are characterised by a favourable combination of properties as: remarkable mechanical properties, comparatively high thermal and hydrolytic resistance and, in many case, outstanding resistance to chemical agents

(Gaztelumendi et al., 2002). Particular attention must be paid to the blends to recycle, since the final properties are strongly dependent not only by the raw polymers but also by the structures and morphology of the post-consumed component. Some problems may be even encountered when the collected post-consume agricultural plastic waste is constituted by different polymers recycled all together. Recycling of plastics with different chemical composition, or of plastic containing contaminants, may greatly deteriorate the properties of the final material if compared with those of the virgin one, due to the usual incompatibility of polymer blends (Gaztelumendi et al., 2002). The consequence of this heterogeneous recycling may give difficulties in the processing phase, and results in lower mechanical properties, above all if these materials were subjected to other previous recycling process. Ramirez-Vargas et al. (2004) observed a decrease in molecular weight after the first three reprocessing cycles, while the Melt Flow Index (MFI) increased with the number of processing cycles of different blends of polypropylene hetero-phasic copolymer (PP/EP) and polyethylene-co-vinyl-acetate (EVA).

Some scientific efforts conducted so far agreed about the conclusion that recycled materials are usually characterized by weak mechanical properties if compared to those of the raw material. 100% EVA recycled bars showed (Sica, 2000) a higher deformability and a lower tensile strength if compared to those realised through the recycling of mixture of different polymers, like LDPE and PET, employed for the realisation of agricultural film for protected cultivation or for liquid containers. This suggested the need to mix EVA film with other polymers before its recycling, in order to obtain mechanical characteristics of recycled plastic posts sufficient for their use as structural elements.

The antioxidants, widely used to prevent thermal degradation of the agricultural film, work essentially by stopping the peroxides formation (Scott, 2000). Mariani et al. (2003) showed that the presence of antioxidant in a LDPE changes the kinetic both of long chain branching formation/cross-linking and chain scission.

The mechanical properties of the recycled material may be also influenced by the presence of other factors, such as additives: *e.g.*, the addition of starch to LDPE blends increases the tensile strength and the elongation at break and reduces the MFI values (Pedroso et al., 2004). In particular, the MFI measurement is considered an useful indication for the analysis of the degradation of some polymers as a consequence of reprocessing (Gaztelumendi et al., 2002). Even the common contaminants (agrochemicals, soil, metals, moisture, etc.) may dirty the plastic material during the useful life and hamper the recycling process.

In this paper experimental tests were performed on bars obtained through the mechanical recycling of agricultural plastic films, adding in some cases specific additives in the extrusion process, analysing their principal mechanical characteristics through laboratory tests.

Materials and Methods

Recycled manufactured products were obtained through the mechanical recycling of agricultural plastic films previously used for covering tunnel-greenhouses in a farm located in Lecce (Southern Italy). The plastic recycled bars were produced by an Italian manufacturer for the stockpiling, selection and mechanical recycling of heterogeneous plastic wastes (Alfa Edile, Brindisi). After the collection and transportation to the recycling factory, the plastic films were granulated, melted at about 220 °C and introduced into the extruder to produce 1.5 m long square section bars with the average side equal to 49,4 mm.

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

(B): recycled bars obtained exclusively from regenerated granule of Agricultural Plastic Waste (APW), density 0.95 g*cm^{-3};

(C): recycled bars obtained from regenerated granule of APW (70%) and Calcium Carbonate - $CaCO_3$ (30%), density 1.09 g*cm^{-3};

(D): recycled bars obtained from regenerated granule of APW (70%) and talc (30%), density 1.14 g*cm^{-3}.

The mechanical properties of these bars were analysed in the Laboratory for Testing Material of the Technical-Economic Department of the University of Basilicata (Potenza), by using a computerised universal press machine Galdabini PMA 10 type. The environmental conditions during the trial were: mean room temperature 20 °C, mean relative humidity 70%.

From the recycled bars, specimens were obtained according the following dimensions:

1) Tensile test: strip-specimen, height 190 mm, length 49.4 mm, thickness 5.85 mm;
2) Compression test: cubic-specimen obtained directly by cutting the bars, side = 49.4 mm;
3) Bending test: bar-specimen, height 49.4 mm, length 1,100 mm, thickness 49.4 mm.

Tensile tests were performed, according to the Italian UNI 8422 Standard (UNI, 1982), with a length between vices of 70 mm and a constant deformation speed equal to 10 mm*min^{-1}.

Compression tests were performed at a constant deformation speed equal to 10 mm*min^{-1}. During these axial tests it was also calculated the value of Young modulus by measuring at the end of the elastic proportional phase the tension value (σ), and the corresponding deformation (ε), as follows:

$$E = \frac{\sigma}{\varepsilon}$$

Bending tests were performed at a strain constant speed of 70 mm*min^{-1} according with the Italian Standard UNI 7219-73 (UNI,1972), through the application of a load in the mid-span of a free length of 1.00 m between the supports. In this case, considering three recycled material as homogeneous and isotropic bodies, the Young modulus was calculated through the formula:

$$E = \frac{PL^3}{4bh^3 f} \tag{1}$$

where:

L = distance between the supports [1000 mm]

b = width of the specimen [mm]

h = height of the specimen [mm]

P = concentrated load in the mid span [N]

f = deflection in the mid span corresponding to the elastic phase of the stress-strain curve [mm].

In order to completely assess the strain properties of this new alternative material, by the compression tests the value of Poisson coefficient 1/m was also obtained through the measurements of the strain in the y cross-direction of application of the load, as:

$$1/m = \varepsilon_y / \varepsilon_x$$

where:

ε_x = load-direction strain [%]

ε_y = cross-direction strain [%].

Therefore also the value of the shear modulus G was obtained from measured values of E and 1/m, as:

$$G = E / 2(1 + 1/m)$$

A complete information about strain behaviour of the three recycled materials was finally obtained by calculating, from the tensile tests, the percentage elongation at yield as:

$$A = \Delta\ell / \ell_0 \cdot 100$$

where:

$\Delta\ell$ = maximum elongation at yield [mm]

ℓ_0 = free length between vices [mm].

Results and discussion

The results obtained from the tensile, compression and bending tests, elastic resistance (σ_e) and Young modulus (E), are reported respectively in tables 1 and 2 in terms of average value and bilateral confidence interval with 95% probability (UNI, 1966).

Table 1 — Values of the maximum resistance of four recycled plastic materials

Test	APW (B)		APW + $CaCO^3$ (C)		APW + talc (D)	
	σ_{max} (N mm^{-2})	σ_e (N mm^{-2})	σ_{max} (N mm^{-2})	σ_e (N mm^{-2})	σ_{max} (N mm^{-2})	σ_e (N mm^{-2})
Tensile	10.60 ± 0.42	6.31 ± 0.64	11.90 ± 0.45	6.91 ± 0.60	13.08 ± 0.84	5.03 ± 0.37
Compression	___	5.17 ± 0.14	___	6.04 ± 0.33	___	7.26 ± 0.35
Bending	—	5.45 ± 0.35	—	6.75 ± 0.74	—	7.01 ± 0.73

In terms of tensile strength the recycled bars give similar values of the maximum resistance, even if the behaviour of material D is better, but the resistance at the end of the elastic linear phase (σ_e) of this material is less than the other two recycled plastics.

On the contrary, as for compression strength material D shows an higher value at the end of the elastic linear phase.

From bending tests no significant results of the maximum resistance were detected because, due their high deformability, the maximum travel stroke of the device used was not sufficient to cause the breaking of the bars. This result may find a possible explanation by the analysis of the E values reported in Table 2 for the three recycled materials, where it is evident that B, C and D materials show a very high flexibility, with their Young modulus considerably lower than other recycled plastics (Picuno et al., 2001).

Table 2 — Values of the Young modulus of four recycled plastic materials

Test	E (N mm^{-2})		
	APW (B)	APW + $CaCO^3$ (C)	APW + talc (D)
Tensile	114.54 ± 23.16	193.41 ± 27.76	303.90 ± 90.65
Compression	119.90 ± 11.47	151.13 ± 12.88	158.81 ± 9.39
Bending	141.98 ± 9.10	175.72 ± 19.31	195.70 ± 16.92

By the analysis of the E values, it is evident that the tested materials are significantly flexible; in particular, material B is more flexible than the other two materials, with its Young modulus lower than C and D materials. Besides, it is possible to compare the tensile and compression resistance of the recycled materials to wood mechanical characteristics in the direction parallel to the fiber (20 – 40 N mm^{-2}), while the Young modulus of wood (10,000 – 15,000 N mm^{-2}) is much higher than the one of recycled plastics. The higher resistance value of the material D, during tensile test, suggests that it is lightly more fragile than the other two materials; this fragility emerges also during the tensile test, by analysing the break of the specimen (Fig. 1).

Figure 1. Specimen of recycled material D (APW + talc) broken by tensile stress.

Table 3 shows the values of the other two elasticity parameters (G and 1/m) and the percentage elongation at yield of the three examined recycled plastic materials.

Table 3 — Values of strain characteristics of three recycled plastic materials

	APW (B)	APW + $CaCO^3$ (C)	APW + talc (D)
Maximum elongation at break [%]	394.10 ± 99.38	181.68 ± 16.23	78.98 ± 46.56
Poisson coefficient	0.09	0.08	0.10
Shear modulus in the elastic phase [N mm^{-2}]	55.01	69.89	71.99

From the analysis of the maximum elongation at break, it is possible to affirm that material B is characterized by an higher elongation value while material D has the lowest value; this result, considered in connection with the values reported in table 3, confirms that material D is the most fragile, while material B is the most elastic among the tested recycled materials. Material C is characterized by an intermediate behavior.

Conclusions

The principal mechanical characteristics of the recycled plastic bars that were tested, in terms of resistance (maximum strength and elongation at break) and elasticity characteristics (Young modulus, Poisson coefficient and shear modulus in the elastic phase) could enable an estimation of their possible use in some industrial and/or agricultural sectors, as constructive elements of light structures like fences, vineyard pergola, little shelters, etc.. The tensile and compression resistance of the recycled materials are in fact comparable with building materials, like wood.

The results that were obtained allow for an improvement about the possible re-employment of these recycled materials. In order to better characterize them, analysing their behaviour both in the proportional elastic phase and plastic phase, cyclic mechanical tests should be performed.

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

Acknowledgements

The present research has been carried out under the project "LABELAGRIWASTE - Labelling agricultural plastic waste for valorising the waste stream" funded by the European Commission (Contract No. COLL-CT-2005-516256).

The Authors wish to thank Confagricoltura Puglia for the collection of agricultural plastic waste by its associated farm in Lecce, Alfa Edile S.p.A. that kindly recycled agricultural plastic waste, and Mr. Cosimo Marano of the DITEC Dept for his technical advice in the experimental tests.

References

Gaztelumendi M., Eguiazabal J. I., Nazabal J. Recycling of Engineering thermoplastics. In *Handbook of Plastic Recycling*, **2002**, Rapra Technology.

La Mantia F. Handbook of Plastic Recycling, **2002**, Rapra Technology.

Manera C., Margiotta S., Picuno P., Scarascia Mugnozza G. Recycling of post-consume plastic films for the realisation of structures for agricultural purposes (in Italian). In: *Proceedings of the National Congress of AIIA (Italian Association of Agricultural Engineering)*, 53–64. Ancona (Italy), 11–12 September **1997**.

Mariani P., Carianni G., La Mantia F. P. The antioxidant effect in controlling thermal degradation of a low density polyethylene blown film. *Polymer Degradation and Stability* **2004**, 85, pp 1003-1007.

Pedroso A. G., Rosa D. S. Mechanical, thermal and morphological characterization of recycled LDPE/corn starch blends. *Carbohydrate Polymers* **2005**, 59, pp 1-9.

Picuno P., Sica C. Mechanical and spectro-radiometrical characteristics of agricultural plastic films. *CIGR E-journal* **2004**, VI, manuscript BC 04 001.

Picuno P., Sica C. Recycled agricultural film as an alternative material for rural construction. *Proceedings of the AgriBuilding 2001*, Campinas, SP, (Brazil), 3-7 September **2001**, 242-248.

Picuno P., Scarascia-Mugnozza G. The management of agricultural plastic film wastes in Italy. *Proceedings of the International Agricultural Engineering Conference*, Bangkok (Thailand), 6-9 December **1994**, 797-808.

Ramirez-Vargas E., Navarro-Rodriguez D., Blanqueto-Menchaca A. I., Huerta-Martinez B. M., Palacios-Mezta M. Degradation effects on the rheological and mechanical properties of multi-extruded blends of impact-modified polypropylene and poly(ethylene-co-vinyl acetate). *Polymer Degradation and Stability* **2004**, 86, pp 1301-307.

Scarascia-Mugnozza G., Picuno P., Sica C. Innovative solution for the management of the agricultural plastic waste. *World Congress "Agricultural Engineering for a Better World"* **2006**, Bonn, Germany.

Scarascia Mugnozza G., Manera C., Margiotta S., Picuno P. Mechanical characteristics of recycled plastic posts in agricultural structures – *Plasticulture,* **1997**, 114, (2), 5–14.

Scott G. Green polymers. *Polymer Degradation and Stability* **2000**, 68, pp 1.

Sica C. Environmental problems connected to the use of plastic materials in protected cultivation (in Italian). Doctoral Thesis, **2000**, *DITEC Department*, University of Basilicata, Potenza, Italy.

UNI – Tests on plastics. Determination of flexural properties of rigid plastics. *UNI Italian Standard*, 7219–73, **1972**, Milano;

UNI – Statistical methods for quality control. Presentation of an average with the corresponding confidence interval. *UNI Italian Standard* 5309, **1966**, Milano.