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Recycled agricultural film as an alternative material for rural construction

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Abstract

The use of plastic materials in agricultural applications, like protected cultivation (about 112.000 tons in Italy and 1.200.000 tons in the World in 1994), creates an increasing amount of plastic waste that may cause environmental hazard if not treated in controlled way after its use; an environmentally sustainable solution able to contribute to a sound disposal of post-consume agricultural plastic film is the realisation, by mechanical recycling, of new plastic bars that may be used as constructive elements of light rural structures like fences, vineyard pergola, little shelters, etc. In this paper the results of mechanical tests by bending, compression and tension on square-section bars obtained by recycling 100% agricultural EVA film are reported; from these tests it was possible to determine the principal mechanical characteristics of these new rods in terms of strength (unit breaking stress) and strain (Young modulus, Poisson coefficient and shear modulus in the elastic phase, together with the maximum elongation at yield). From the obtained results it is possible to observe that 100% EVA bars have a higher deformability and a lower tensile strenght if compared to those realised with mixture of other polymers, like LDPE and PET, employed for the realisation of agricultural film for protected cultivation or of liquid containers; this conclusion suggests 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.

Keywords: EVA films, plastic wastes, mechanical recycling, alternative material

1 Introduction

Materials that may be used in rural construction could have, owing to their destination to house biological productions, specific characteristics generally different, and even more restrictive, if compared with those usable for civil or industrial buildings. Materials for rural construction have to be characterised by good mechanical properties if used as structural frames, and at the same time by physical properties that let to maintain appropriate environmental conditions for growing and production of animal and crops.

Materials for rural construction could so be inert to chemical agents from manure, pollutant gas and dust of animal buildings as well as from pesticides used in protected cultivation; moreover they could have a limited thermal expansion coefficient and favourable thermal conductivity characteristics; finally, they could be low-cost, light-weight, long-lasting and suitable to properly settle in the agricultural landscape.

Widely diffused for protection of flower, fruit and vegetable cultivation, plastic materials are progressively used all over the World: in Italy, in 1999, about 122 000 tons of plastic materials were used in the agricultural sector for protected cultivation (Pacini, 2000). On the other hand they constitute, at the end of their useful life, an environmental problem if collected and disposed in a not correct way.

Mechanical recycling of plastic wastes, through the realisation of new recycled plastic products like panels, corrugated sheet for shelters, flooring and stable-rails for animal buildings, benches for soilless cultivation, containers and pots, rods for fences or plant stakes, etc., may allow to re-use as rural construction elements this new alternative material, contributing at the same time to solve a serious environmental problem.

Some research works and studies have been carried out trying to optimise the conditions for a profitable recovery of plastic wastes. La Mantia (1991) prepared products using mixtures of LDPE and heterogeneous municipal plastic wastes and he subjected them to mechanical tests to check their resistance properties.

Scarascia Mugnozza et al. (1997) carried out some experimental trials on manufactured products, commercially known as *Synplast*, consisting of 85% recycled HDPE and LDPE materials resulting, respectively, from containers for liquids and films used in agriculture, of 10% PET derived from containers for liquids, and 5% ABS resulting from motor-car wastes; for such products, produced by extrusion in the form of square section bars, the mechanical resistance characteristics were determined. They proved that these plastics could be proposed for use in agriculture as supporting elements of light structures for specialised arboreal cultivation, for instance.

The same Authors (Manera et al., 1997) continued their investigation by commissioning the manufacture of similar square section bars consisting, in a first case, of 100% recycled LDPE exclusively coming from post-consume agricultural films and, in a second case, of a mixture of 70% LDPE from post-consume agricultural films and 30% PET originated from containers for liquids. The results obtained showed that interesting mixtures could be prepared in which post-consumption polymers of agricultural origin can be used for manufacturing products having sufficient mechanical characteristics to support simple structures not subjected to heavy loads.

Finally, in view of the recent diffusion in agriculture of EVA films and for scarce knowledge and specific studies made on such polymer, experimental trials were made (Manera et al., 2000) on bars, obtained by recycling 100% agricultural EVA film, to investigate the resistance properties of these products, to identify their main mechanical characteristics and to propose recovery and re-use techniques.

In the present paper the strength and strain characteristics of these bars obtained by recycling 100% EVA film are exposed and critically evaluated also in comparison with other recycled plastic materials.

2 Materials and methods

Recycled EVA manufactured products (rEVA) were obtained by recycling 100% agricultural EVA film previously used for covering tunnel-greenhouses in a farm located at Nova Siri (Southern Italy); they were recycled by an Italian factory for the stockpiling, selection and mechanical recycling of heterogeneous plastic wastes (Alfa Edile - Brindisi) and subsequently tested in the Laboratory for Material Test of the Technical-Economic Department of the University of Basilicata.

At the 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 side equal to 48.5 mm. From these products, specimens were obtained and submitted to tensile, compression and bending tests using a computerised universal Galdabini PMA 10 type press. The results obtained in the case of rEVA were then compared with those obtained in previous studies (Manera et al., 1997; Scarascia Mugnozza et al., 1997).

The environmental conditions during the trial were: average temperature 18°C, relative humidity 70%. For each type of test 10 specimens were brought to breaking in order to express the corresponding resistance characteristics in terms of mean and corresponding bilateral confidence interval with a probability of 95% (UNI, 1966).

Tensile tests were made on specimens obtained from recycled bars, of a width of 48.5 mm, with a free length between vices of 70 mm and a thickness of 5 mm with constant deformation speed equal to 200 mm/min, whereas compression tests until break were made on cubic shaped specimens of a side of 48.5 mm, taken directly by cutting the draw pieces, at a constant deformation speed of 10 mm/min (Manera et al., 2000).

During these axial tests it was also calculated (Sica, 2000) the value of Young modulus by measuring at the end of the elastic phase the tension value in the same direction of the application of the load (σ), and the corresponding deformation (ε), as:

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

On the other hand bending tests, at a strain constant speed of 70 mm/min, were performed on 1.00 m long elements in conformity with the Italian Regulation (UNI, 1972), through the application of a load in the mid-span. In this case Young modulus was calculated by the formula

$$E = \frac{PL^3}{4bh^3f} \qquad (1)$$

where:
L = distance between the supports [mm]
b = width of the specimen [mm]
h = height of the specimen [mm]
P = load corresponding to the end of the elastic phase of the stress-strain curve [N]
f = deflection corresponding to the end of the elastic phase of the stress-strain curve [mm].

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

$$\frac{1}{m} = -\frac{\varepsilon_y}{\varepsilon_x}$$

where:
ε_x = load-direction strain [%]
ε_y = cross-direction strain [%].

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

$$G = \frac{E}{2(1 + 1/m)}$$

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

$$A = \Delta l / l_0 * 100$$

where:
Δl = maximum elongation at yield [mm]
l_0 = free length between vices [mm].

3 Results and discussion

The results obtained from the bending, compression and tensile tests, expressed in terms of maximum resistance (σ_{max}) and Young modulus (E), are reported respectively in tables 1 and 2 where they are compared with the corresponding values obtained in previous studies on other recycled plastic bars (Manera et al., 1997; Scarascia et al., 1997).

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

Test	σmax (N mm^{-2})			
	rEVA	100% LDPE	70% LDPE + 30% PET	Synplast
Tensile	7.8 ± 0.29	9.34 ± 0.45	7.90 ± 0.59	21.60 ± 2.47
Compression	29.6 ± 2.55	17.11 ± 1.13	13.25 ± 0.25	27.51 ± 3.24
Bending	Not measurable	17.08 ± 0.50	15.66 ± 0.41	32.30 ± 0.81

In terms of tensile strength recycled agricultural films give similar values, whereas the behaviour of Synplast is considerably better. In terms of compression strength rEVA and Synplast are approximately equal, significantly better than bars obtained by recycling 100% LDPE film and 70% LDPE + 30% PET film.

From bending tests of rEVA no significant results were detected because, due to its high deformability, the maximum travel stroke of the device used was not sufficient to cause breaking of the bars; this result may find a possible explanation by the analysis of the E values reported in Table 2 for the rEVA, where it is evident that rEVA shows a very high flexibility, with its Young modulus considerably lower than other recycled plastic materials, and this aspect probably makes rEVA not suitable for an use as support frame also in the case of simple and light structures.

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

Test	E (N mm^{-2})			
	rEVA	100% LDPE	70% LDPE + 30% PET	Synplast
Tensile	70.91 ± 2.62	189.20 ± 23.17	157.24 ± 6.93	977.76 ± 130.49
Compression	46.25 ± 4.57	188.58 ± 7.55	169.15 ± 16.04	384.31 ± 39.98
Bending	141.20 ± 6.03	431.51 ± 44.25	409.20 ± 25.81	1248.72 ± 123.86

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

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

	rEVA	100% LDPE	70% LDPE + 30% PET	Synplast
Maximum elongation at break [%]	368 ± 2.32	19.45 ± 2.96	14.19 ± 2.02	7.12 ± 1.45
Poisson coefficient	0.45	–	–	0.35
Shear modulus in the elastic phase [N mm^{-2}]	15.95	–	–	142

From the analysis of the tensile test curve (Figure 1) it is also possible to observe that, after a first linear elastic phase, rEVA exhibits a high plastic deformation before breaking, that is reached for a maximum elongation at break of almost 400%, more close to an ordinary LDPE film (about 600%) than to rigid plastic materials (e. g. equal to 20–50% for PVC).

This result is completely different from the case of bars produced with other recycled films; the flexibility characteristics of the material obtained from pure recycled EVA probably determine also the excessive deformability observed during the bending tests. This phenomenon is still under study, both from the theoretical point of view, in terms of analysis of the modulus of elasticity and its influence on the mechanical behaviour of such a material – probably also far from the ideal model of a homogeneous and isotropic solid – and the experimental point of view, through the formulation of different mixtures based on EVA and other recycled polymers, capable of giving the bars not only resistance but also deformability characteristics that make them adequate for use as frames of simple and light structures.

Also the results of the compression tests show that rEVA has a limited elastic phase, with significant increased resistance only immediately before breaking (Figure 2). In conclusion, also from this point of view, it seems that the material obtained from the extrusion of pure recycled EVA grains exhibits excessive deformability when subjected to load, and this makes it, just as it is, inadequate for structural applications.

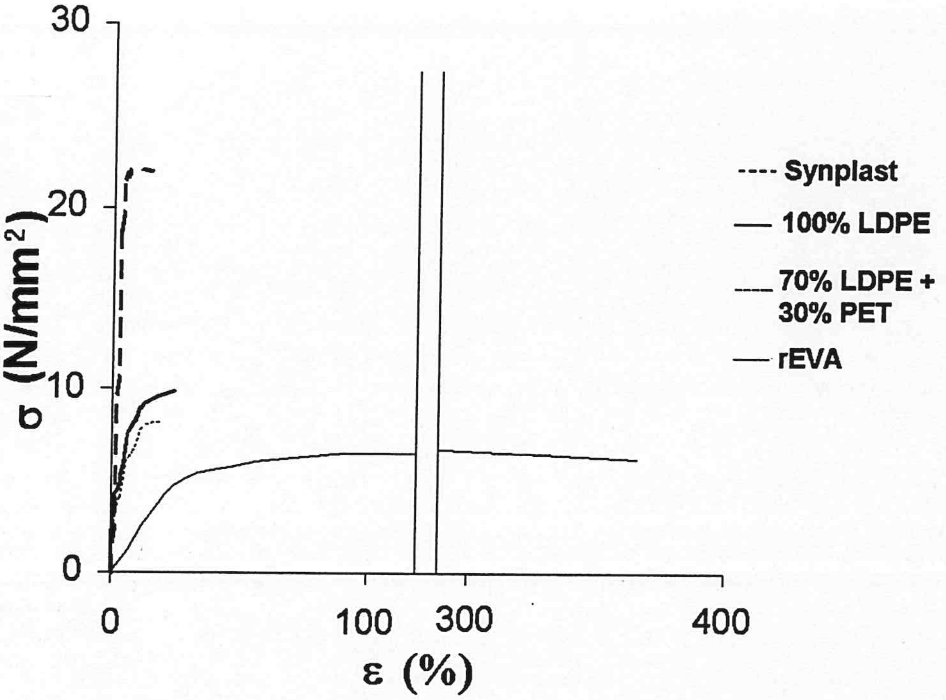

Figure 1 — Stress-strain diagram of four recycled plastic materials subjected to tensile test

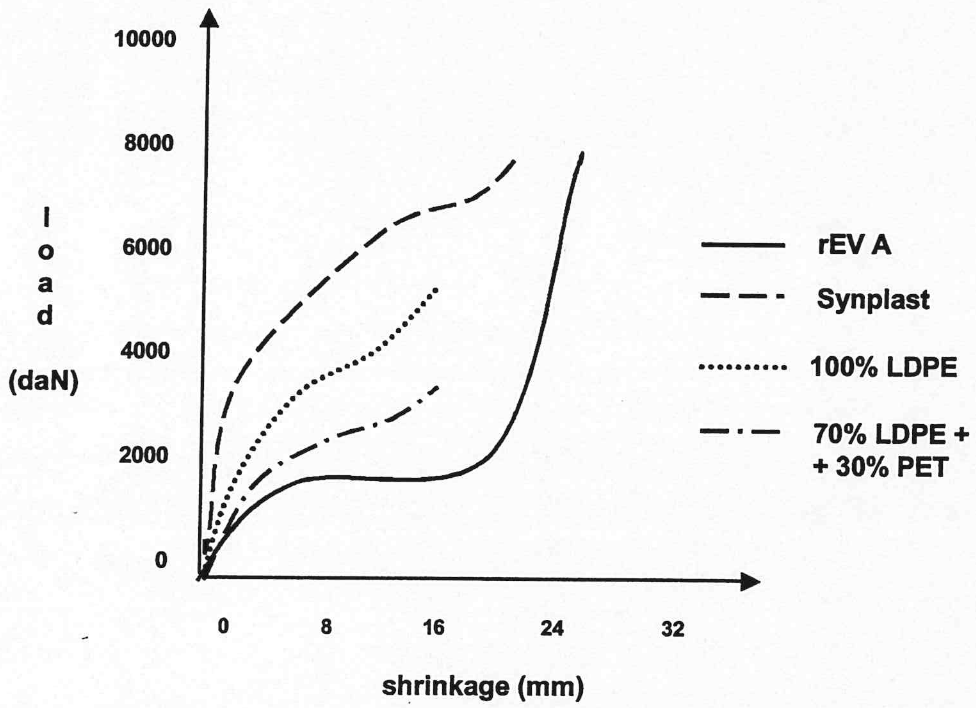

Figure 2 — Load vertical displacement diagram of four recycled plastic materials subjected to compression test

4 Conclusions

The fast evolution that rural construction are undergoing, due to considerations about environmental protection, animal welfare, workers' health, production quality and safety and traceability process (de Alencar Nääs, 2001), is leading also toward the research of alternative materials that, in addition to productivity and cheapness, enable to further optimise agricultural production cycle. On the other hand, the sound disposal and subsequent re-use of agricultural plastic wastes is a serious problem that producers, consumers and legislators have to tackle to preserve environment. In this sense, special attention has to be focused on recycling of more largely used polymers as EVA is becoming.

The experimental tests performed gave evidence of a high deformability of the material obtained from pure recycled EVA though it shows sufficient mechanical resistance properties; the study is still continuing to investigate how to optimise the characteristics of this material by producing manufactured products obtained from EVA-based mixtures with other polymers.

5 Bibliography

de Alencar Nääs I. (2001) – *Precision animal production.* CIGR Electronic Journal, vol III, January 2001;

La Mantia F. P. (1991) - Urban solid waste recycling: PE mixtures (in Italian). In: *Proceedings of the 10th Italian Congress of macromolecules science and technology*, 937–940. Ferrara (Italy), 6–11 October 1991;

Manera C., Margiotta S., Picuno P., Scarascia Mugnozza G. (1997) – 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;

Manera C., Picuno P., Sica C. (2000) – Mechanical characteristics of manufactured products obtained from recycled EVA films (in Italian) In: *Proceedings of the Italian Congress on: "New biodegradable plastics for agricultural use in soil solarisation"* – Matera (Italy), 14–15 June 2000, (in printing);

Pacini L. (2000) – Applications of the plastic materials in agriculture, Italy – year 1998. *News Bulletin of IIP (Italian Institute of Plastics)*; n°13 – July 1999, 7–9;

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

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

UNI (1972) – Tests on plastics. Determination of flexural properties of rigid plastics. UNI Italian Standards, 7219–73, Milano;

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