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Recycling of plastic car components: The case of a multilayer item based on polypropylene

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The recycling of a particular internal car component with a multilayer structure such as the dashboard has been extensively investigated. On this item, based on polyolefins, a thermal, spectroscopic, mechanical and morphological analysis has been performed. The recycled material showed a strong worsening in the mechanical and impact properties due to the occurrence of thermo-oxidative and thermo-mechanical degradation phenomena taking place during processing. A limited improvement in the mechanical behaviour has been obtained by adding, during the recycling, a suitable antioxidant and stabiliser additive. A more significant enhancement has been achieved in terms of deformation at break, impact toughness and overall morphology when an ethylene-propylene copolymer and virgin polypropylene were added to the formulation during the recycling process. By this procedure materials with properties suitable to be reused for the same or for similar applications within the car have been obtained.

1. Introduction

The steady growth in the use of plastic materials in automotive applications has promoted the leading industries to search for solutions for reducing the environmental impact of cars at the end of their life cycle. In this framework one of the primary objectives of the automobile manufacturers is to completely recover the materials present in the car [1–6]. For metallic components, which presently constitute the 75% of the car, the problem has been already solved and the attention is now focused on the plastic components, which actually represent the 12.5% and are expected to grow further in the near future. However, car recycling, besides its ecological relevance, could be also economically attractive provided that all the operations, from the dismantling part to the material pelletising, are optimised.

In the present contribution the recycling of a particular internal car component, a dashboard, has been investigated in detail. The recycling of this item is very complex because of the time required to dismantle the parts and because of the large number of constitutive elements and of the different polymeric materials, often mutually incompatible, employed in its construction. Therefore it is necessary to develop suitable design for disassembling and even more important to rationalise the choice of the constitutive materials with careful consideration of their mutual compatibility.

Actually two kinds of dashboards are commonly employed:

1. Rigid dashboard (uncovered) made by a rigid body in polypropylene with a number of parts in ABS based materials. The choice of the materials is dictated by their technological, mechanical and thermal characteristics, as well as by the geometry of the items. However, the ABS based materials are highly incompatible with the polypropylene matrix, so that the recycling is not possible without a preliminary mechanical separation of the components, which makes the entire process not economically feasible.
2. Covered dashboards, which can be of two different types: the first consists of a rigid support in polycarbonate/ABS and a leather-like covering in foamed PVC. The second type of covered dashboards is made by a rigid support in ABS reinforced with glass fibres, an intermediate layer of foamed polyurethane and a final leather-like covering in PVC/ABS.

Both types require a preliminary separation of the different layers before recycling.

In an attempt to overcome the above limitations, very recently, the automotive industries are trying to develop new dashboards in which all the components are made from a single or very similar/compatible polymeric materials (monocomponent solution).

In this contribution the recycling of a "monocomponent" dashboard based on polyolefins has been analysed. The aim has been to optimise the processing conditions and to improve the end-properties of the

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resulting materials by using suitable polymeric and/or non-polymeric additives. The objective is to obtain a recycled material with properties comparable or even improved with respect to the virgin counterparts and hence suitable to be reused either for the same or for similar applications within the car. A detailed thermal, spectroscopic, mechanical and morphological analysis has been performed on the recycled material.

2. Experimental

2.1. Materials

The multilayer dashboard based on polyolefins was kindly supplied by the Research Centre of Fiat-Elasis (Naples-Italy).

A pentaerythrityl-tetrakis [3-(3,5-di-tertibutyl-4-hydroxylphenil)-propionate] produced by the Ciba-Geigy with a trade name of Irganox 1010 and having a molecular weight (M_n) of 1176 and a melting point of 125 °C was used as antioxidant and heat stabiliser.

An amorphous ethylene-propylene copolymer (EPR), kindly supplied by Enichem Elastomeri with a C_2/C_3 ratio close to unity and $\bar{M}_w$ equal to 1.5×10^5 was employed as compatibiliser and toughening agent. An isotactic polypropylene (PP) produced by Exxon Chemical Co. with $\bar{M}_w$ equal to 1.0×10^5 was used as virgin polymeric additive.

2.2. Techniques

Differential scanning calorimetry (DSC) measurements were performed on the single layers of the monocomponent dashboard, using a Mettler TA 3000 instrument at a scanning rate of 10 °C/min, to establish the chemical nature of the constituents.

Thermogravimetric analysis (TGA) was carried out in air at a rate of 5 °C/min by means of a Mettler TA 4000 apparatus. On the same layers a spectroscopic analysis was also performed by using the FT-ATR sampling technique (KRS5 crystal) with a Perkin-Elmer System 2000 spectrometer.

The dashboards were first granulated and then the recycling process was carried out by using a HAAKE 600 internal mixer at a temperature of 200 °C and at different roller speeds and mixing times.

The premixed material was compression moulded to produce sheets of two different thicknesses (1.0 and 4.0 mm) at 200 °C and a pressure of 150 bar in a heated press. The 1.0 mm thick sheets were cut using a suitable hollow punch in dumb-bell shaped specimens on which tensile mechanical tests were performed. The 4.0 mm thick sheets were cut using a mill to obtain rectangular specimens 6.0 mm or 12.0 mm wide and 60.0 mm long for performing flexural and Charpy impact tests, respectively. For Charpy tests the specimens were notched at the middle point of their length using a machine with a V-shaped tool. The value of notch depth was measured after fracture using an optical microscope.

Tensile and flexural mechanical tests were performed using an Instron machine model 4505 at ambient temperature and at a cross-head speed of 2 mm/min. The modulus, the stress and elongation at rupture were calculated from stress-strain diagrams on an average of six specimens.

Charpy impact tests were carried out at an impact speed of 1 m/sec using an instrumented pendulum of Ceast DASWIN 4000. For all the material examined a set of eight specimens were broken at ambient temperature and with a span of 48 mm. Curves of energy and load against time or displacement were recorded for each test.

Fracture surfaces of notched specimens were examined by using a Philips Scanning Electron Microscopy (SEM) model XL2O. Prior to examination the surfaces were coated with a thin layer of a gold-palladium alloy in order to improve conductivity and prevent charging.

3. Results and discussion

3.1. Thermal and spectroscopic analysis

The DSC thermograms of the three layers constituting the dashboard are shown in Fig. 1. The rigid support (trace A) exhibits a single melting peak with a maximum at 170 °C. This thermogram is characteristic of a melting process of isotactic polypropylene (PP). The external layer (skin, trace B) shows a broad melting peak with two maxima at 110 °C and 120 °C, followed by a sharp melting peak at higher temperature close to that observed in trace A. The lower temperature peaks may be associated with a melting process of polyethylene (PE), while the peak at 160 °C is due to the presence of PP. Thus, the skin thermogram points to a polypropylene matrix containing an ethylene-propylene copolymer. This copolymer contains PE sequences long enough to produce a polyethylenic crystalline phase, although their irregular and defective structure leads to a broad and ill defined melting endotherm.

Finally, the thermogram of the intermediate layer (foam, trace C) shows two melting peaks. The first is very sharp, with a melting temperature of 120 °C, characteristic of polyethylene. The second peak at higher temperature, is very broad with a maximum in the temperature range 140–150 °C. This melting process, could be associated with the melting of long PP sequences in an ethylene-propylene copolymer. Therefore, the thermogram of the intermediate layer is consistent with a polyethylene matrix containing a copolymer whose composition is richer in C_3 than in C_2.

The FT-ATR spectra of the three dashboard components in the wavenumber range 4000–600 cm^{-1} are reported in Fig. 2A–C. The spectrum of the support (Fig. 2A) clearly reveals three peaks at 3677, 1009 and 668 cm^{-1} characteristic of magnesium silicate (talc), which constitutes the filler. The C-H stretching region is typical of polypropylene, with peaks at 2950, 2918 and 2852 cm^{-1}. The characteristic deformation modes of PP are also found at 1460 cm^{-1} (CH_2) and at 1377 cm^{-1} (CH_3).

Several absorptions are observed in the carbonyl range, and are attributed to low molecular weight additives (plasticizers, stabilizers, etc.) added to the formulation. The spectrum of the foam (Fig. 2B) is characterised by intense absorptions bands covering wide spectral regions. In particular, a peak is identified at 1728 cm^{-1}, with satellite bands at 1650 and 1536 cm^{-1} and a broad absorption centred at 1064 cm^{-1}, likely

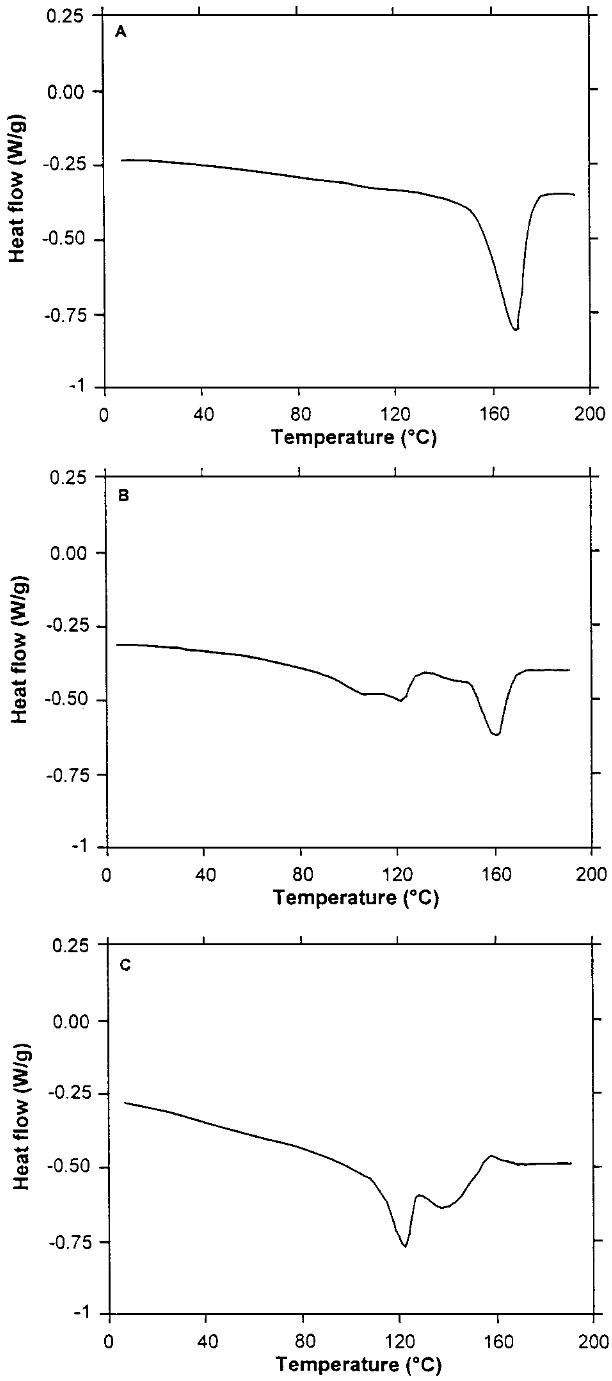


Figure 1 DSC thermograms of the various layers constituents the dashboard: trace A, rigid support; trace B, external layer (skin); trace C, intermediate layer (foam).

due to a C-O-C stretching vibration of an ester group. These features indicate the presence of a considerable amount of aliphatic ester additives which have probably migrated to the sample surface. The more diagnostic peaks for the polymeric substrate are located at 1453 cm^{-1} (a CH_2 deformation of polyethylene and polypropylene), at 1373 cm^{-1} (a symmetric deformation of the CH_3 group in PP) and at 728–719 cm^{-1} (the rocking vibration of polyethylene CH_2 sequences). In particular, the splitting of the doublet at 728–719 cm^{-1} is indicative of the presence of a well defined PE crystalline phase. In agreement with the calorimetric analysis, the above spectrum can be reasonably attributed to a PE semicrystalline matrix containing an ethylene-propylene copolymer.

The spectrum of the outer layer (skin, Fig. 2C) is again dominated by the strong absorptions of the low molecular weight additives (at 1740, 1631, 1244, 1061 cm^{-1}). The peaks of the polymeric substrate resemble those of PP both in the CH stretching region (2920, 2851 cm^{-1}) and in the CH deformation range (1463, 1380 cm^{-1}). A low intensity peak, indicative of the presence of PE, is identified at 721 cm^{-1}. Contrary to what is found in the spectrum of Fig. 2B, here the peak is not completely resolved in a doublet but displays only a shoulder at higher frequency. This indicates that the CH_2 sequences responsible for this rocking vibration are shorter and more defective than in the case of the intermediate layer (foam) and they produce a correspondingly lower and less regular crystalline phase. Also in this case, the FT-ATR results are consistent with the DSC data, and confirm the presence of a PP matrix to which an ethylene propylene copolymer has been added.

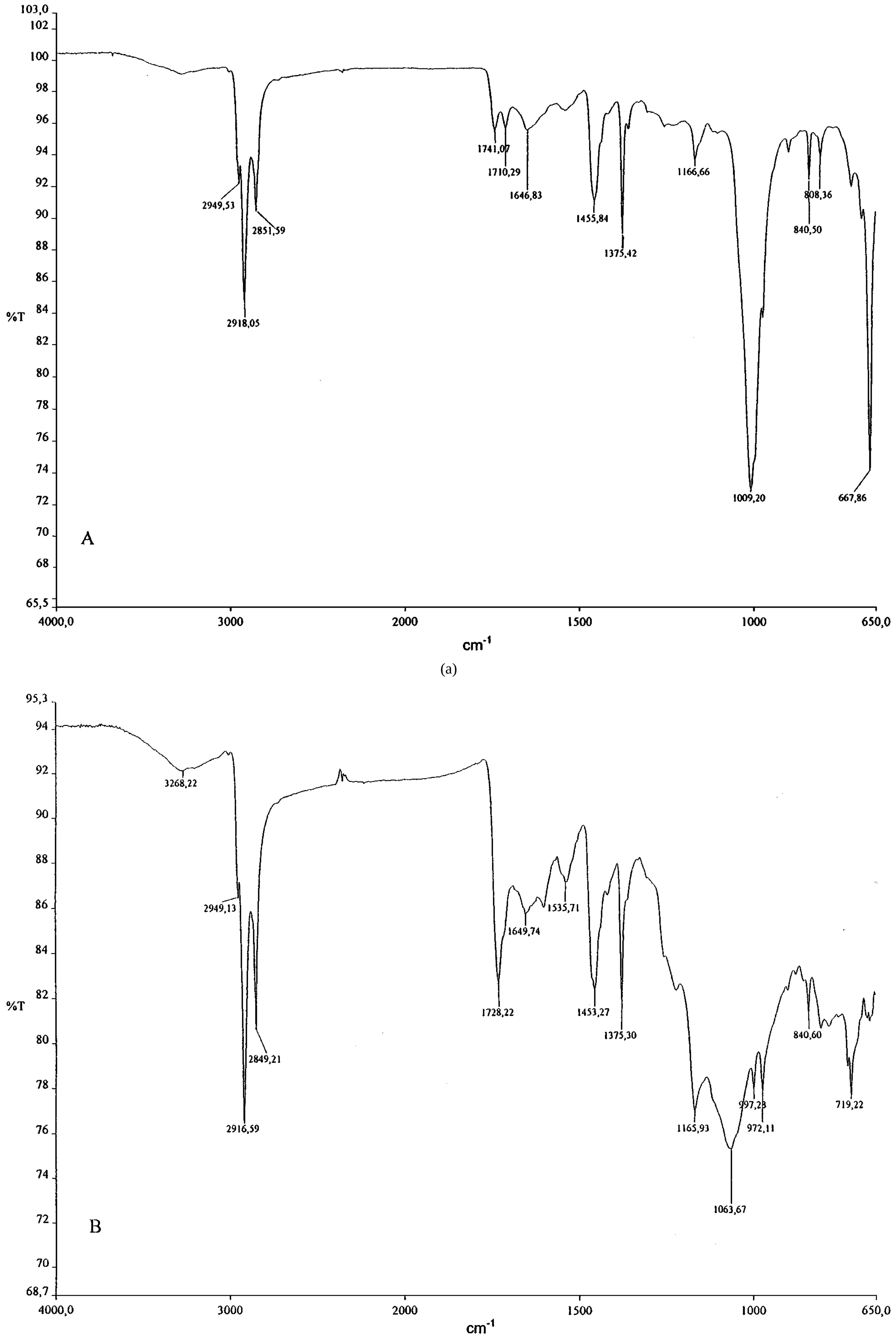
The thermogravimetric data (TGA) are reported in Fig. 3. The rigid support (Fig. 3A) shows essentially two degradative processes at 260 °C and at 400 °C, respectively. In particular, the principal degradative process is that occurring at higher temperature, at which a weight loss of about 80% of organic material (PP) takes place. At temperatures above 500 °C a residual product of about 20% is still present and can be attributed to the inorganic component added to the support as reinforcement (talc). The skin layer (Fig. 3B) exhibits a TGA thermogram more complex than that of the support. In fact, there are several degradative processes which can be attributed, to the simultaneous presence of two polymeric species, polyethylene and an ethylene-propylene copolymer. However, the maximum degradative process occurs at a temperature close to 420 °C with a weight loss of about 95%. In addition, a small degradative event appears at temperatures beyond 500 °C probably due to the dehydration of inorganic components present to aid processing. The TGA thermogram of the foam layer (Fig. 3C) seems to be very close to that of the skin layer, apart from the absence of the loss process at 460 °C. Also in this case the degradation of the organic constituents is complete at temperatures below 500 °C.

3.2. Mechanical properties

Different mixing conditions have been used to optimise the recycling process of the monomaterial dashboard.

In Figs 4 and 5 are shown the tensile stress-strain diagrams of the recycled material at different mixing times and roller speeds, respectively. On the same figures is also reported the stress-strain curve of the virgin polypropylene support, which has been taken as reference material because it was not possible to perform a mechanical tensile test directly on the starting dashboard. On the other hand, considering the chemical nature of the other two layers (skin and foam), and the fact that they constitute only about 10% of the entire weight of the dashboard, it seems reasonable to assume the support as reference material.

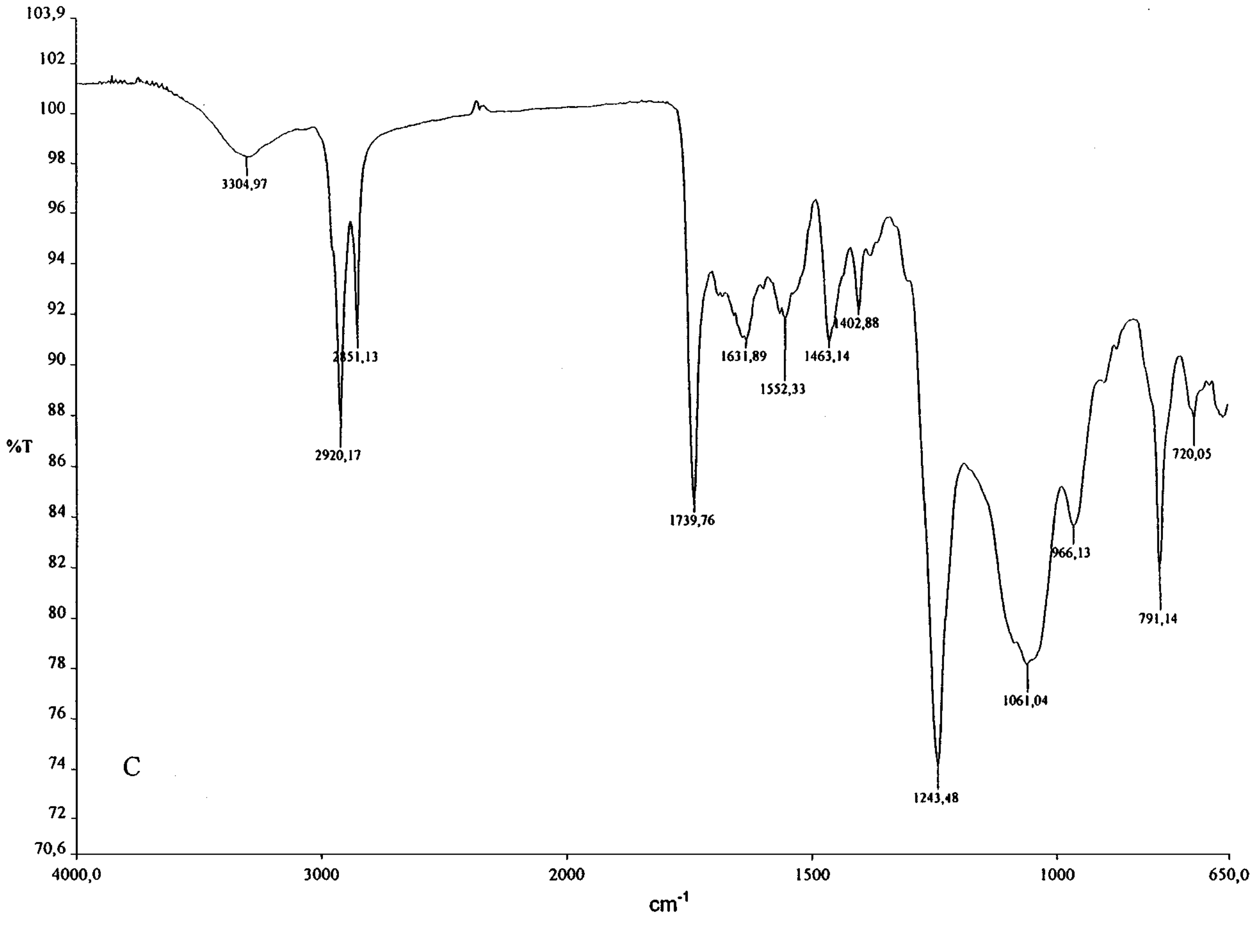
From both Figs 4 and 5, it is clear that the recycling process strongly reduces the mechanical performance



(a)

(b)

Figure 2 FTIR-ATR spectra in the frequency range 400–600 cm^{-1}: trace A, rigid support; trace B, intermediate layer (foam); trace C, external layer (skin). (*Continued*.)



(c)

Figure 2 (*Continued.*)

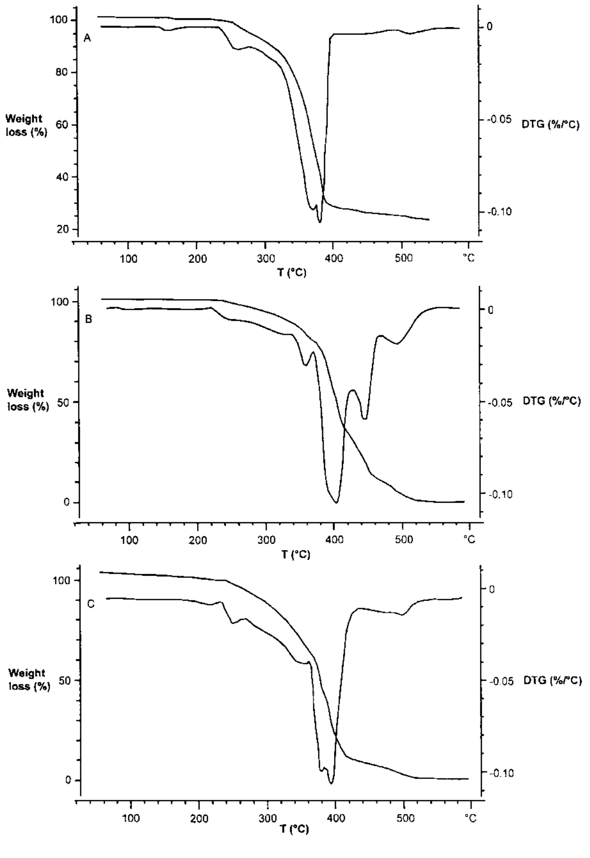


Figure 3 TGA thermograms of the various layers constituents the dashboard: trace A, rigid support; trace B, external layer (skin); trace C, intermediate layer (foam).

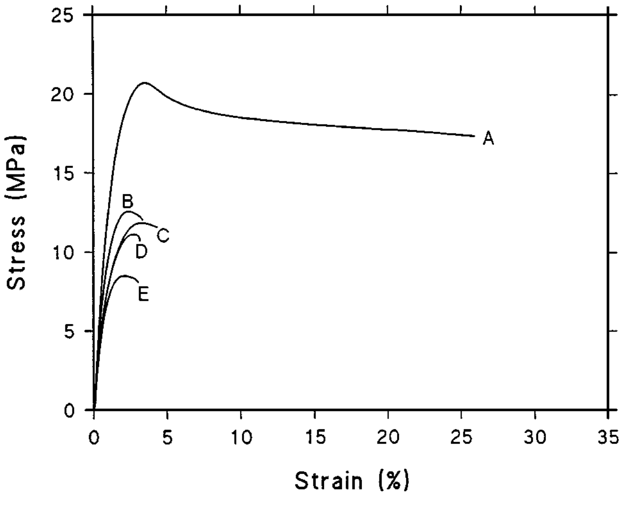


Figure 4 Tensile stress-strain diagrams of the recycled dashboard processed at 200 °C, at a roller speed of 32 r.p.m. and at different mixing times: curve A, reference material (virgin support); curve B, mixing time 5 min; curve C, mixing time 10 min; curve D, mixing time 15 min; curve E, mixing time 20 min.

of the starting resin. In fact, for all the processing conditions employed, the yielding and the cold-drawing exhibited by the reference material (curve A), tends to disappear and the mechanical behaviour of the recycled product resembles that of a brittle material.

The quantitative effect of the recycling conditions on the mechanical parameters is better seen in Figs 6–9,

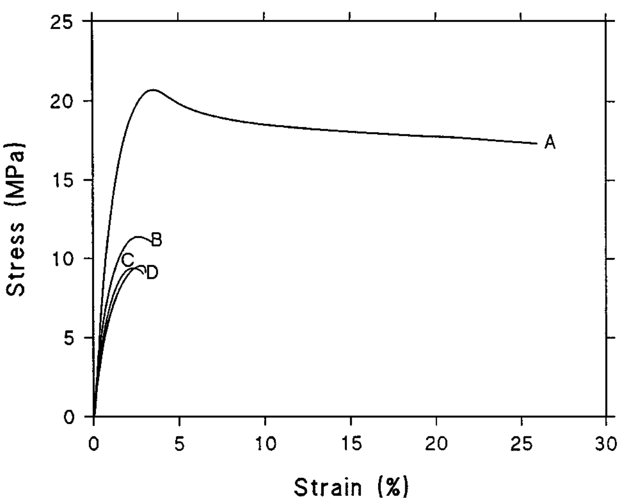


Figure 5 Tensile stress-strain diagrams of the recycled dashboard processed at 200 °C, mixing time 5 mm and at different roller speeds: curve A, reference material (virgin support); curve B, 32 r.p.m.; curve C, 24 r.p.m.; curve D, 8 r.p.m.

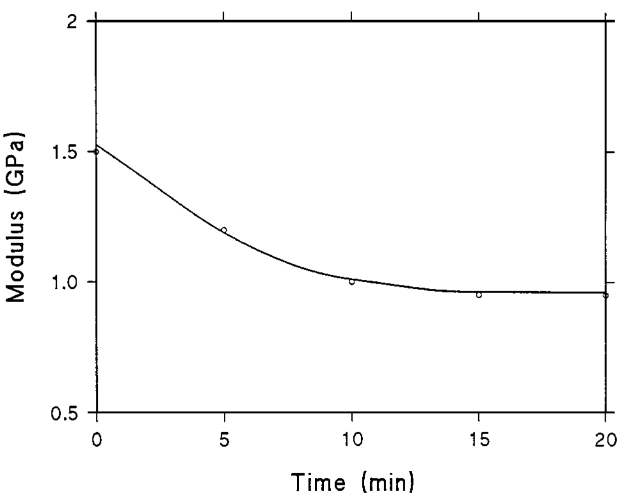


Figure 6 Tensile elastic modulus, evaluated from the stress-strain diagrams of Fig. 4, as a function of the mixing time.

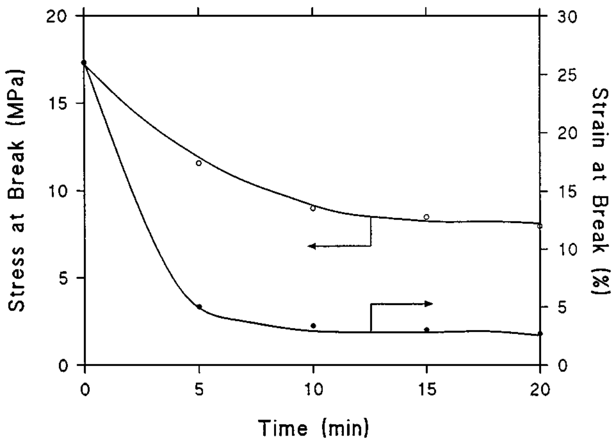


Figure 7 Stress and strain at break, evaluated from the stress-strain diagrams of Fig. 4, as a function of the mixing time.

where the elastic modulus, E, and the ultimate properties such as the stress, σ_b, and elongation at break, ε_b, evaluated from the stress-strain diagrams, are reported. In Figs 6 and 7 are collected the values of the modulus and of the stress and strain at break obtained at various

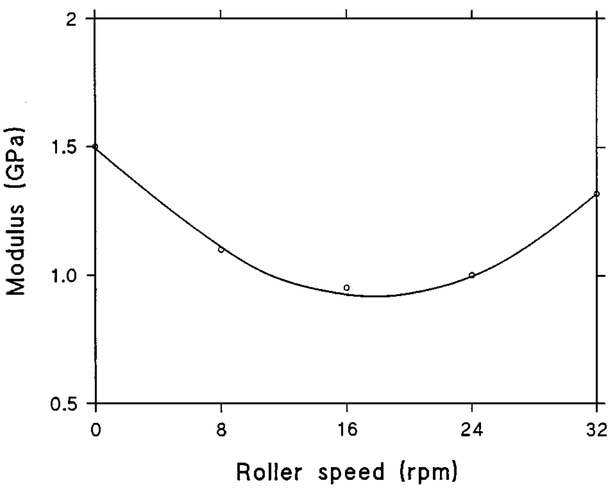


Figure 8 Tensile elastic modulus, evaluated from the stress-strain diagrams of Fig. 5, as a function of the roller speed (r.p.m.).

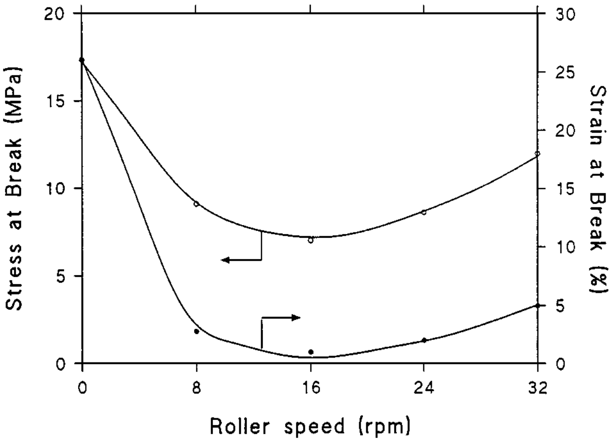


Figure 9 Stress and strain at break, evaluated from the stress-strain diagrams of Fig. 5, as a function of the roller speed (r.p.m.).

mixing times and at a roller speed of 32 r.p.m. The value of this speed is comparable to that generally used for mechanical recycling by extrusion processes.

It is found that, the modulus (Fig. 6) decreases almost linearly up to a mixing time of about 10 minutes and than levels off at higher residence times. A similar trend is found for the stress at break (see Fig. 7), while a dramatic drop is observed for the deformation at break (ε_b). The value of ε_b decreases from 25% to about 5% after 5 minutes of mixing and than remains constant around 3% for longer times.

Thermal degradation and oxidative processes are responsible of the observed deterioration in the tensile mechanical properties [7, 8].

In particular, the marked decreases of the mechanical parameters showed at low mixing times, can be ascribed to the fact that the oxidative process of polyolefins is autocatalytic and proceeds via a free-radical mechanism [9]. The primary product is a hydroperoxide which decomposes to free-radicals to initiate the chain reactions. Thus, in the early stage of the recycling process, due to the presence of heat and of a large amount of oxygen, the rate of formation of the hydroperoxide is quite high an hence a substantial reduction in the mechanical properties can be achieved. At higher residence times the rate of the oxidative reactions strongly decreases and, consequently, the effect on the mechanical performance of the material is limited.

The results of the mechanical parameters (E, σ_b and ε_b) relative to the recycled material processed at a fixed mixing time of 5 minutes and at different roller speeds are shown in Figs 8 and 9. The modulus (see Fig. 8) decreases with increasing the roller speed approaching a minimum at about 16 r.p.m. and than rises at higher roller speeds. A close behaviour is exhibited by the ultimate properties σ_b and ε_b (see Fig. 9). Also in this case, as reported in Fig. 6, the mechanical parameter that undergoes a very strong reduction is the elongation at break.

The above data can be explained considering that for roller speeds ranging from 8 to about 24 r.p.m. the shear and heat stresses acting on the material are not sufficient to achieve a homogeneous dispersion of the various layers constituting the dashboard, even though they have a similar chemical nature. Thus the item is recycled in a non optimal fashion leading, at the end of the mixing process, to a material with a high degree of inhomogeneity. This poor interconnection reduces the capability of the material of carrying the external load and hence a worsening of all the mechanical properties is the final result. At a roller speed of 32 r.p.m. a more homogeneous material can be obtained by virtue of the increased shear stress and a decreased melt viscosity. Both these parameters have a positive effect on the mechanical behaviour of the recycled product.

In Fig. 10 the modulus and the stress at break evaluated by flexural tests are reported as a function of the mixing time. Both these parameters, as in the case of tensile tests, exhibit a sharp drop at low values of the residence time and then they remain almost constant at higher times. The same parameters, obtained on samples recycled at a fixed time and different speeds are not reported, because their behaviour resemble that showed for the tensile test.

Mechanical measurements were also carried out under impact conditions in order to calculate the fracture toughness of the recycled material under rapid loading. The corresponding values of the impact strength as a function of the mixing time and roller speed are shown in Figs 1l and 12, respectively. It is observed that the different processing conditions lead to a very similar trend with the occurrence of a minimum at about 10 minutes (Fig. 11) and at a speed of 16 r.p.m (Fig. 12). Afterwards an enhancement in the impact strength is found. However, as for the other mechanical tests, the values of the recycled material are always lower compared to the reference one.

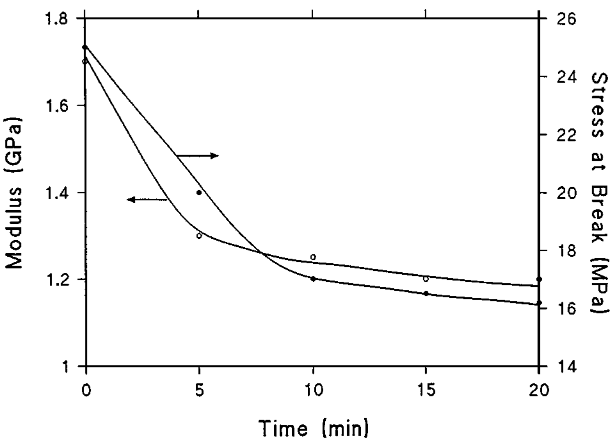


Figure 10 Flexural modulus and stress at break of the recycled dashboard as a function of the mixing time.

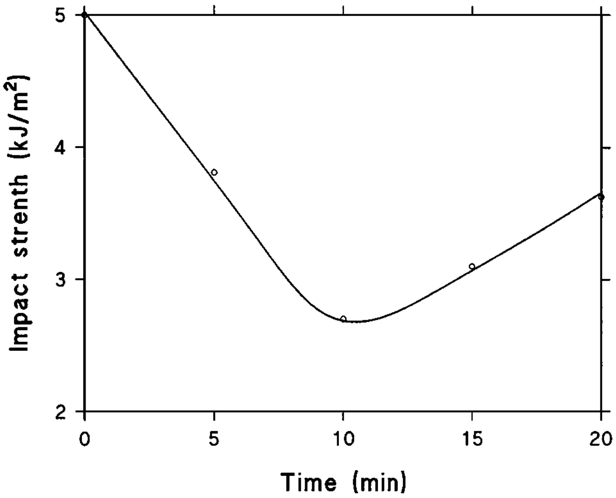


Figure 11 Impact strength of the recycled dashboard as a function of the mixing time.

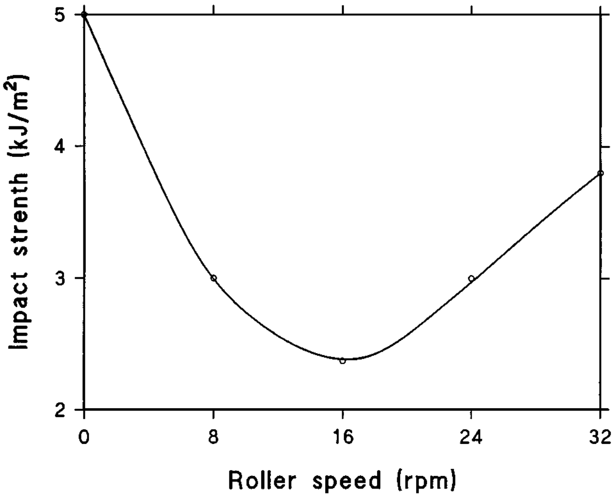


Figure 12 Impact strength of the recycled dashboard as a function of the roller speed (r.p.m.).

From the mechanical and fracture results reported so far two important conclusions can be drawn:

- The optimal processing conditions to achieve a recycled dashboard with a minor reduction of mechanical properties compared to the reference material are a roller speed of 32 r.p.m. and a mixing time of five minutes.
- The recycling process, even if conducted under the above conditions, leads to a strong worsening in the mechanical performances of the recycled material. This phenomenon is essentially due to thermo-oxidative and thermo-mechanical degradation taking place during the recycling. Both these processes may be facilitated by the presence of talc in the polypropylene support, which reduces its thermal stability, and by the morphology of the intermediate layer (foam) which incorporates a

substantial amount of air thus favouring oxidative reactions.

3.3. Influence of additives on the recycled dashboard

An attempt to reduce the thermo-oxidative degradation taking place during processing, the recycling of the dashboard has been carried out by adding a small amount (0.2 wt %) of an antioxidant specifically designed for polyolefins. This additive, acting as an oxygen-centred radical scavenger, inhibits autoxidation as soon as it starts, thus enhancing the thermo-oxidative stability [9].

In Fig. 13 are shown the tensile stress-strain diagrams of the reference material (curve A) and those of the dashboard processed with and without antioxidant (curves B and C, respectively). An overall improvement of the mechanical behaviour is found for the material recycled in the presence of the antioxidant, although its performances still remain lower than that of the reference material.

The extent of the oxidative process has been evaluated by FTIR spectroscopy [10–12]. In Fig. 14 are reported the FTIR transmission spectra, in the wave number range 1900–1500^{-1} of the dashboard processed with and without antioxidant (traces A and B respectively). It is found that the dashboard area in the carbonyl region considerably decreases in the presence of the antioxidant. Also the number of the carbonyl species produced upon oxidation is reduced. In the presence of the antioxidant the peaks characteristic of C-C double bond insaturation at 1621 and 1602^{-1} are not observed. The above spectra allow evaluation of the carbonyl index (C.I.) which represents the area under the carbonyl absorption, normalised for the sample thickness. This parameter decreases from 1.4 to 0.7 when the antioxidant is added to the formulation.

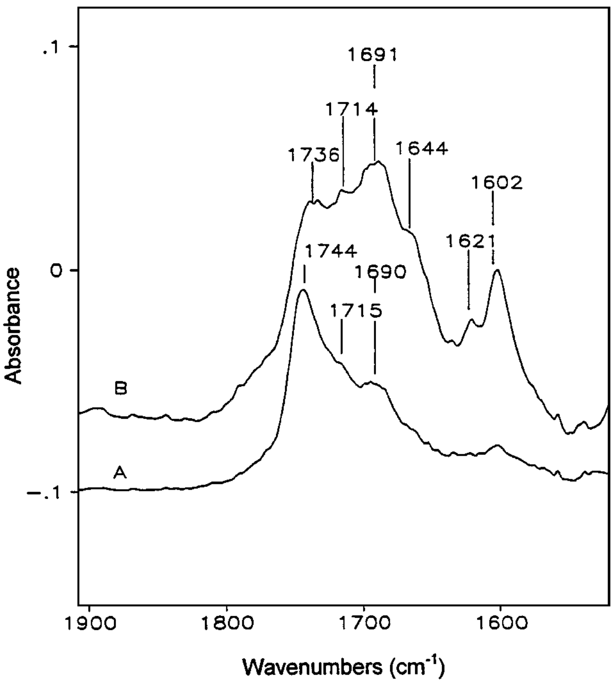


Figure 14 FTIR transmission spectra in the frequency range of 1900–1500 cm^{-1} of the recycled dashboard processed with (trace A) and without antioxidant (trace B).

The above results show that, in general, the recycled product has quite good mechanical properties. However, some parameters such as the elongation at break and the impact fracture toughness are still unsuitable for reusing the recycled material for the same or similar applications within the car.

To overcome this limitation, in addition to the use of an antioxidant, the recycling process has been conducted by adding to the formulation different amount of a random ethylene-propylene copolymer (EPR).

The use of rubber additives to improve fracture toughness of polyolefins has been largely reported. In related work, such additives have proven very effective if properly selected [13–17]. Block and graft copolymers have been especially valuable for this purpose since they can provide adhesion at domain

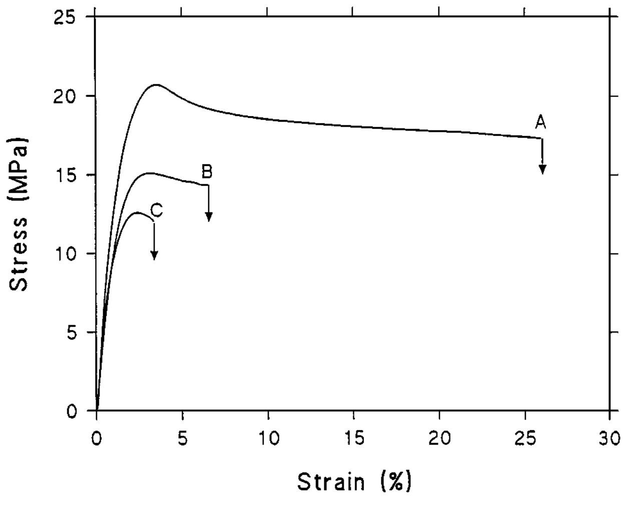


Figure 13 Tensile stress-strain diagrams of the dashboard recycled in presence of antioxidant: curve A, reference material (virgin support); curve B, recycled dashboard with antioxidant; curve C, recycled dashboard without antioxidant. The processing conditions were: temperature 200 °C, roller speed 32 r.p.m, mixing time 5 min.

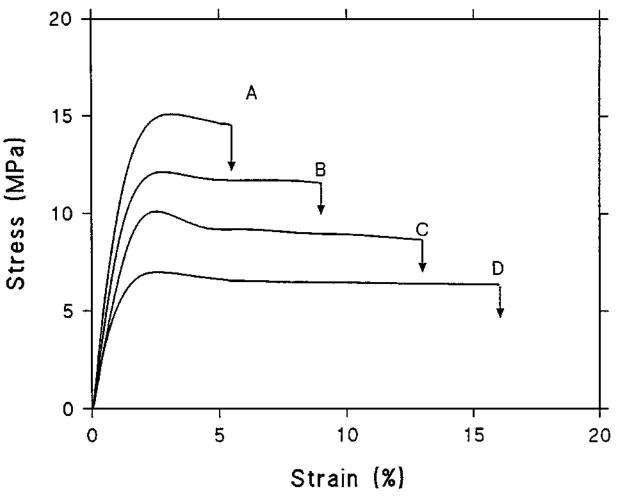
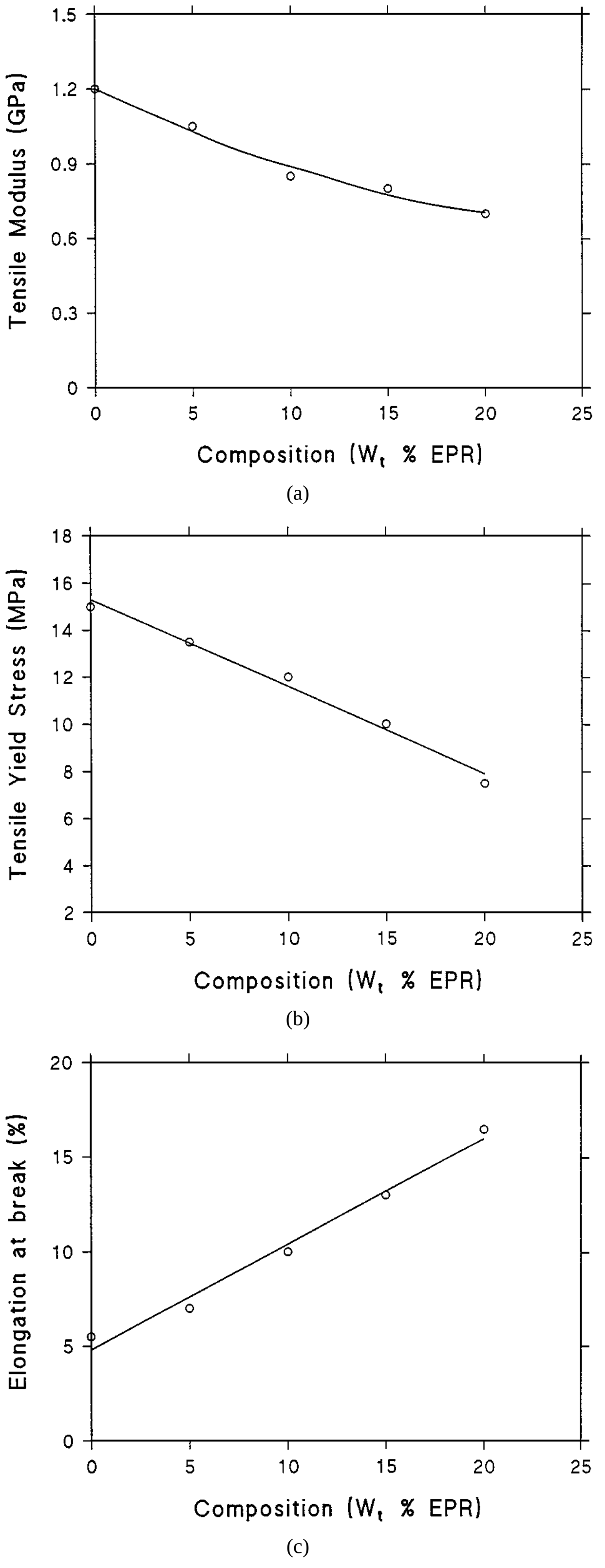


Figure 15 Tensile stress-strain diagrams of the recycled dashboard processed with antioxidant and different amount of EPR: curve A, dashboard with 0 wt % of EPR; curve B, dashboard with 10 wt % of EPR; curve C, dashboard with 15 wt % of EPR; curve D, dashboard with 20 wt % of EPR.

interfaces in incompatible systems. For polyolefins, however, there is ample evidence that toughening can be obtained by blending with certain rubbers without graft or block structures. For example, both polypropylene and polyethylene can be impact modified by blending with polyisobutylene or rubber ethylene-propylene copolymers [18–20]. Therefore, it is very reasonable to use a random EPR copolymer to improve the ultimate properties of the recycled dashboard.



(a)

(b)

(c)

Figure 16 Mechanical parameters, evaluated from the stress-strain diagrams of Fig. 15, as a function of the EPR content: Fig. 16A, Tensile modulus; Fig. 16B, Tensile yield stress; Fig. 16C, Elongation at break.

In Fig. 15 are shown some representative tensile stress-strain curves of formulations containing different amounts of EPR. A visual inspection of the samples during the test, showed a stress-whitening phenomenon due to the occurrence of shear bands across the specimen at an angle of approximately 45° to the tensile stress direction. It was also possible to observe a reduction of the cross-sectional area of the sample with the formation of a micro neck followed by a limited cold-drawing process before fracture. All these features increased with enhancing the EPR content and were almost completely absent in the unmodified dashboard.

The modulus, the yield stress and the elongation at break as a function of the EPR concentration are reported in Fig. 16 (curves A, B and C respectively). The first two parameters show an almost linear decrease with increasing the amount of EPR. This predictable behaviour is to be attributed to a softening effect of the rubber which lowers the overall crystallinity of the material. An opposite trend is observed for the elongation at break. In fact, this parameter increases linearly with increased EPR content. These tensile results and especially the remarkable enhancement observed for the deformation at break, strongly indicate that the EPR acts as compatibilizer [15]. In fact, a better homogenisation of the material is achieved which improves the flow capability of the recycled product favouring yielding and drawing processes.

Further evidence of the effect of the EPR addition arises from the fracture results performed under impact conditions. These data (see Fig. 17) show that, the impact strength increases substantiality on increasing the EPR content. In particular, a fourfold increase of toughness is found for a formulation containing 20 wt % of EPR.

These toughness results can be interpreted on the basis of the fractographic analysis performed by SEM on such materials. In Fig. 18 are reported the SEM micrographs after impact fracture of the unmodified dashboard and the modified containing 10 wt % and

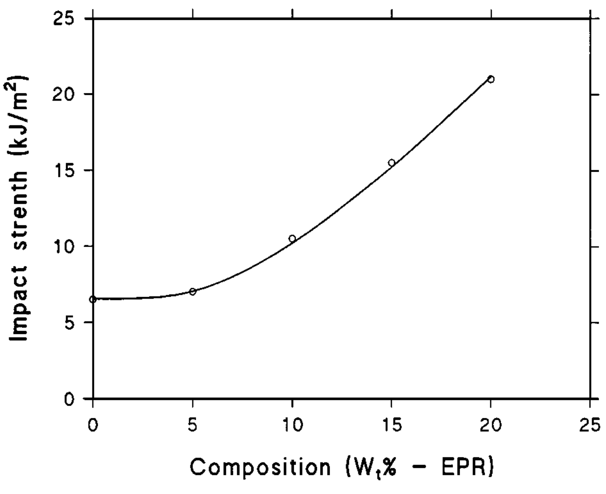
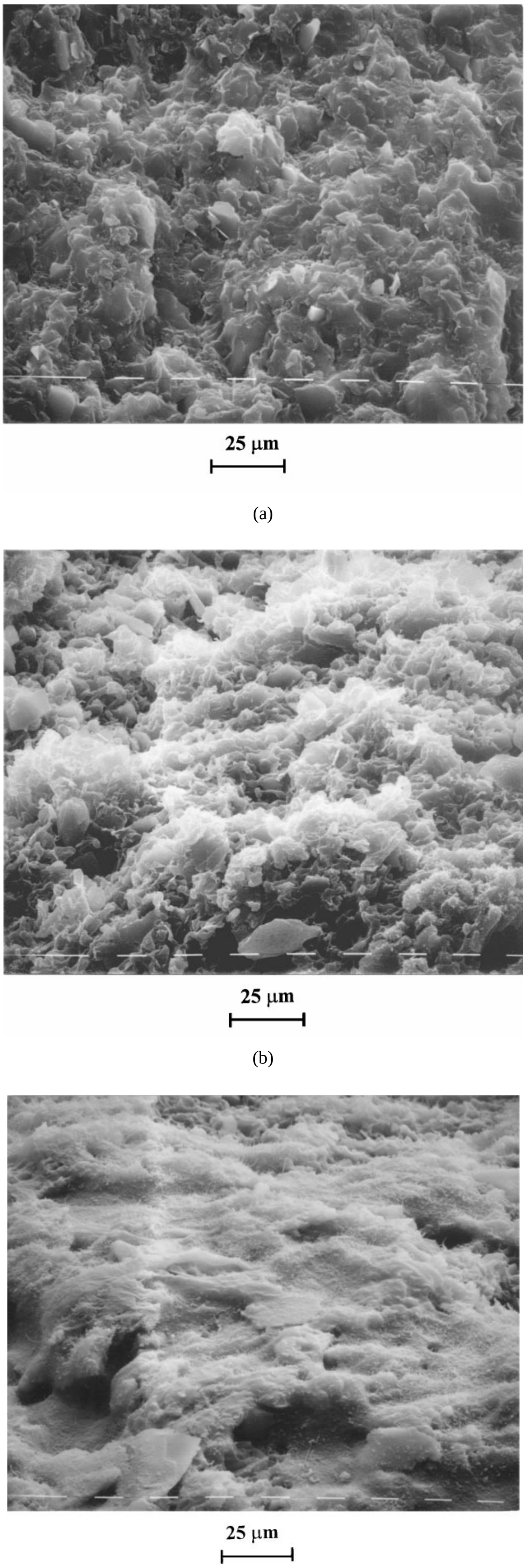


Figure 17 Impact strength of the recycled dashboard processed with antioxidant as a function of the EPR content.

20 wt % of EPR. All the pictures have been taken near the notch tip, located on the left side of the micrographs, in the region of crack initiation. The unmodified resin (Fig. 18A) shows a morphology which resembles that of a brittle material. In fact, no stress-whitening nor any feature distinctive of a plastic flow mechanism are visible. The absence of a significative plastic deformation correlates well with the observed low value of the impact toughness. The addition of EPR (Fig. 18B and 18C) changes both the fracture mode and the overall morphology. The fracture surfaces show a stress whitening phenomenon that increases with increasing the copolymer content. In particular, the fracture surface of the formulation containing 20 wt % of EPR (Fig. 18C) appears completely covered by a white layer indicative of the occurrence of an extensive plastic deformation due to a shear yielding mechanism which represents the main source of energy dissipation before fracture.

From the above analysis it may be concluded that the presence of EPR induces in the recycled material a complete ductile fracture mode whose extent is dependent on the amount of toughening agent added to the formulation during processing.

However, it must be recalled that the improvement in toughness is accompanied by an appreciable reduction of the elastic modulus (see Fig. 16A). This effect could represent a serious limitation in the end-use of the recycled product for applications where the stiffness is an important requirement. It is possible to reduce this undesired effect by replacing part of the EPR in the formulation with virgin polypropylene. In fact, as shown by the results reported in the histogram of Fig. 19, it is sufficient to substitute 5 wt % or 10 wt % of EPR with PP for obtaining materials with balanced properties in terms of modulus and toughness. This type of approach, which seems very promising to realise recycled materials with balanced properties for specific applications, is actuality under investigation also for other internal car components.



(a)

(b)

(c)

Figure 18 SEM micrographs of the impact fractured surfaces: A, unmodified dashboard; B, dashboard with 10 wt % of EPR; C, dashboard with 20 wt % of EPR.

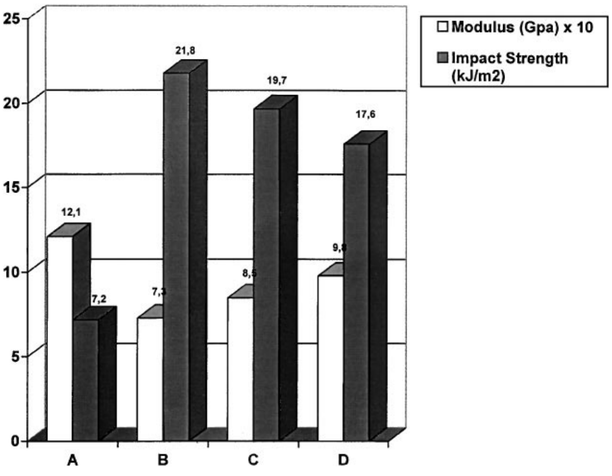


Figure 19 Tensile elastic modulus and impact strength of formulations recycled in presence of the antioxidant and containing different amount of EPR and virgin PP: A, unmodified dashboard; B, dashboard with 20 wt % of EPR; C, dashboard with 15 wt % of EPR and 5 wt % of PP; D, dashboard with 10 wt % of EPR and 10 wt % of PP.

4. Conclusions

As this contribution has shown, there has been a significant improvement in the mechanical recycling of one of the more complex internal car components having a multiyear structure, the dashboard. This result is partially due to the development of an innovative technology for manufacturing the dashboard which is based on the use, for the various layers, of very similar polymeric materials and therefore more compatible "monocomponent" approach. However, also in this case, it has been demonstrated that for a dashboard based on polyolefins the recycling, even if conduced under optimal conditions, leads to a material with very low mechanical and impact properties. This phenomenon has been attributed to the occurrence of thermo-oxidative and thermo-mechanical degradation processes taking place during the recycling.

A limited enhancement in the overall mechanical behaviour has been achieved adding, during processing, an antioxidant specifically designed for polyolefins. However, a substantial improvement, especially for some mechanical parameters such as elongation at break and impact toughness has only been possible by using suitable polymeric additives, like an ethylene-propylene copolymer and virgin polypropylene. In fact, it has been demonstrated that, by matching appropriately these additives, it is possible to realise materials with balanced mechanical properties able to be reused for the same application or for the manufacture of other internal car components such as door panels or roof covers. Finally the background developed so far will be used to optimise the mechanical recycling of other multilayer plastic items used in the automotive industry.

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