New methods for recycling plastic materials from end-of-life vehicles

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Abstract: - The consumption of plastic materials is now 20-times greater than 50 years ago. In the car industry plastic components are increasingly used to replace metal. Recycling of plastic materials from end-of-life vehicles (ELV) is still an unsolved problem. The most delicately problem in materials recycling from ELV is the sterile recovering, which in present is sent at the municipal waste, causing environmental problems. Some experimental results for recovering plastic materials from bumpers are presented in this paper. Different samples obtained from bumpers were analyzed and mechanical characterized for the identification of polymers and their level of mechanical strength and thermal stability. The recovered materials from ELV bumpers presented a still high level of mechanical strength and a still good thermal stability. New materials with interesting properties were obtained by compounding these samples with wood flower and virgin polymers.

Key-Words: - plastic recycling, end-of-life vehicles, recycling technology, polypropylene, DSC analysis, FTIR

1 Introduction

Plastic materials have been part of our world for a century and widely used for 50 years and, in this time, they have become integral to our modern lifestyles. This is a result of their remarkable advantages over traditional materials. Plastic materials can meet almost any requirement, the many different types of plastics offering a broad range of properties. They are easy to work and can be moulded in many ways - by extrusion, injection or press moulding, thermoforming, blowing, cutting, complex products being cast as a single piece using considerably less energy than corresponding components in metal. The amount of energy consumed during the manufacture of plastic is low compared with many other materials. Besides plastic materials saves resources replacing heavy materials with lighter plastic components in cars, trains, ships and aircraft and saving fuel. Plastic materials are strong in relation to their weight, their impact resistance and bending strength are high and they are often chosen in preference to metal. This applies in the car industry for example, where plastic components are increasingly being used to replace metal. Plastic materials require minimal maintenance, tolerating the effects of water and weather, the surface being not degraded by the effects of sun, frost or chemicals. They are resistant to solvents and many chemicals. Heat insulating, low friction, low weight, dielectric properties or electric conductivity depending on chemical compositions could be other advantages of these materials [1-2].

But despite plastic's usefulness, huge amounts of plastic wastes are collected every day, most of them being landfill, where it will take hundreds of years to break down. The recycling of plastic materials represents both a national and European priority because of the annual large quantity of wastes, long-term studies showing an increase of plastic materials usage in the future. In the world, the consumption of plastic materials is now 20-times greater than 50 years ago. Sources of plastic materials wastes are showed in Fig. 1. It can be notice that plastic materials from packaging, construction, transport, electrical and electronics hold the biggest weight from all the amount of plastic materials wastes.

In 2007, more than 73 million motor vehicles, including cars and commercial vehicles were produced worldwide. In Europe, 23 million new automobiles were produced last year [3]. Environmental experts are facing a serious problem about how to manage the huge amount of end-of-life vehicles.

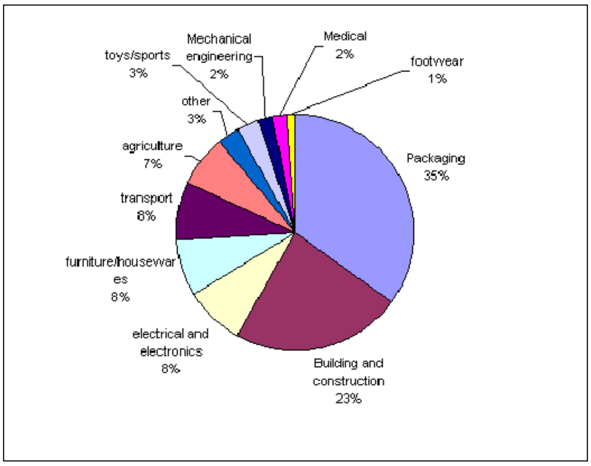

Fig.1 Sources of plastic materials wastes. (http://www.wasteonline.org.uk/resources/WasteWatch)

In the European Union who generates over 9 million tones of automotive waste each year, a high percentage of this waste is reused, recycled or recovered in a range of different applications.

Materials used in European automotive production are presented in Fig. 2 [1]. These are the components that must be recycled from an end-of-life vehicle: steel sheet, plain steel, cast iron and aluminum which give the biggest part of the car, but plastic, rubber and others (glass, textiles and fluids) are also significant. Lightweight cars today contain up to 20 % of plastic materials.

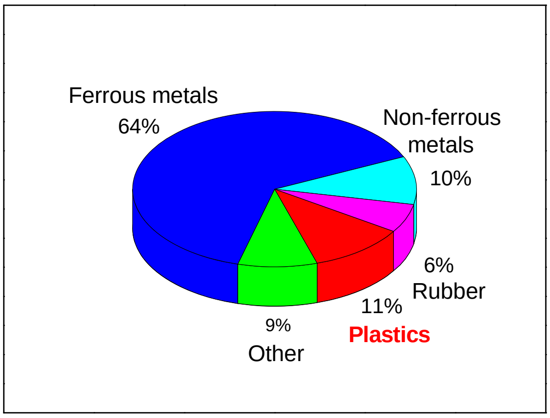

Fig. 2 Materials used in European automotive

Plastic materials are used in car manufacture for seats (eg polyurethane, polypropylene, polyvinylchloride) ~ 12%, bumpers (eg polypropylene) ~10%, upholstery (eg polyurethane, polyvinylchloride) 8%, dashboard (eg polypropylene, ABS) 14% and interior trim (eg polypropylene, ABS) 19%.

Virtually, all the materials from ELV can be recycled, but this recycling process is not always economically convenient. In present, 75% - 80% of ELV in terms of weight, mostly metallic fractions, both ferrous and non-ferrous, are being recycled.

Current recycling efforts for a vehicle consist of manual and mechanical separation (Fig. 3) [4]. Reusable components (such as engines and alternators, gearboxes, starter motors, distributors, radiators) are manually removed from the car by dismantlers. These components are resold in a market limited to other vehicles of the same model or remanufactured.

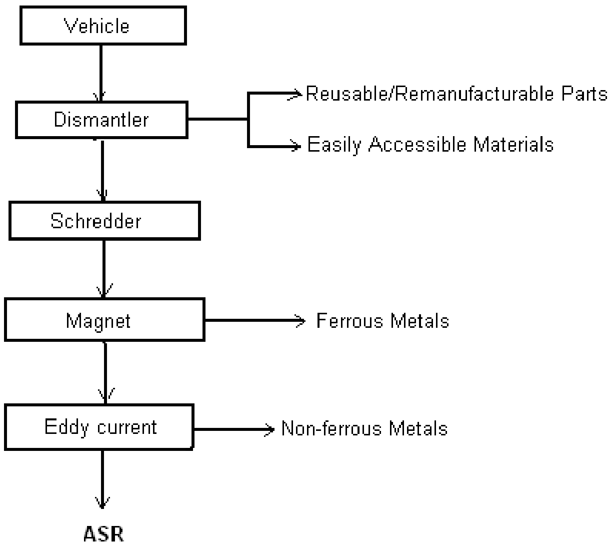

Fig. 3 Current ELV dismantling and separation process

When all these components are removed, materials with high value like aluminum, magnesium, and other large pieces of pure metal are removed by the dismantlers. Following this, the tires, the gas tank and other fluids like oils are removed and the vehicle is sent to a shredder (a hammer mill or similar piece of equipment which reduces the vehicle to fist-sized pieces), shredded, and the pieces mechanically separated based on the properties: the ferrous metals are magnetically separated into one pile, and the non-ferrous metals are generally separated using an eddy-current machine into another pile. The remainder of the car, 20% - 25% by weight currently, consisting of plastics, rubber, glass, textile, dirt, fluids, and other materials, is called automotive shredder residue (ASR) and is generally sent to a landfill [5-7].

Recycling options for plastic materials are presented in Fig. 4 [8]. Based on an eco-efficiency assessment it was theoretically demonstrated that mechanical recycling of bumper (big parts of ELV) is an efficient process [8].

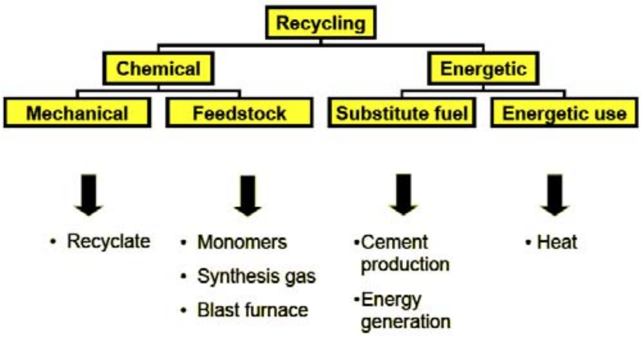

Fig. 4 Recycling options for plastic materials

Some methods concerning plastic materials recovering from ELV were experimented [9-12]. Only few successful technologies for recycling scrap automobile plastics and composites [13] and polyurethane foams [14] are signaled. Recycling thread batteries components (polypropylene auto case and lead) is already a common practice, profitable only when the two actions are coupled [15].

2 Problem Formulation

2.1 End-of-life Vehicle Legislation

In September 2000, the European Union adopted Directive 2000/53/EC, the ELV-Directive on end-of-life vehicles. First priority of this directive is the prevention of waste from ELV encouraging reuse, recycling, and other forms of recovery of end-of-life vehicles and their components. It claims:

- Until the 1st January 2006, the reuse, recycling and recovery for all end-of-life vehicles had to be increased to a minimum of 85% (by weight) per vehicle and year, 80% recycling and reuse, with a 5% allowance for energy recovery;

- From 2015, 95% (by weight) of end-of-life vehicles must be recycled, reused or recovered, 85% recycling and reuse, with a 10% allowance for energy recovery

Romania is involved through the Ministry of the Environment and Durable Development in a vast implementation process of the communitarian acquis Chapter 22, regarding environment politics. An important objective consists of supporting the research activity in order to find real methods for plastic materials recycling from end-of-life vehicles. Finding viable solutions for recycling plastic materials from ELV is the purpose of our work.

2.2 Aspects related to ELV plastic materials recycling in Romania

Romanian legislation settled the management of end-of-life vehicles by clear regulations regarding the targets for recovering and recycling, the minimum conditions that must be implemented by dismantlers and schreder installations. The schedule of industrial enterprises authorized to collect and dismantle ELV was also elaborated and approved.

In Fig. 5 - 7, the most applied technology in Romania (images from Remat Invest – Cluj – Napoca, Romania) concerning the recycling of useful materials from ELV is presented.

Fig. 5 Removal of all the fluid materials existing on VHL using a SEDA equipment

Fig. 6 Disintegration of ELV with a Schreder (Lindemann) equipment

The pictures show the most important stages: removing the fluids existing in vehicle using a SEDA equipment – Fig. 5 (the gasoline or diesel fuel, oil, wash liquid, brake fluid and the antifreeze are being soak up with an vacuum pump and decanted in special basins), disintegration of ELV with a Schreder Lindemann equipment – Fig. 6 and separation of ferrous metals from the others materials with a shredder Steinmertl equipment – Fig. 7.

Fig. 7 Separation of ferrous metals from the others materials with a shredder Steinmertl equipment

ASR or sterile consists of all the inorganic, organic and mineral scraps which remain behind recoverable metallic materials and liquids drawing from ELV. It is very difficult to extract useful plastic materials from this sterile.

Economically convenient processes for recycling plastic materials from ELV are not available in present. Applying such processes could solve many problems like reduction in landfill costs, reduction in the environmental impact of waste disposal, and re-use of a petroleum-based resource.

ICECHIM Bucharest, ICPAO Medias and some ELV dismantling companies from Romania have tried to recycle some ELV big parts made from polymers, contained in a quantity which justify this action, not only from ecologically reasons, but economically, too. Bumpers were chosen for experimental demonstration of the viability of technical solutions elaborated by the research team.

Some experimental results for recovering plastic materials from bumpers are presented in this paper.

The most important phases of the research work are presented below:

- identification of ELV bumpers suppliers;
- analysis of samples from bumpers wastes for preliminary identification of polymers;
- mechanical characterization of samples for the determination of the rezidual level of strength;
- elaboration of the characterization methodology;
- elaboration of conditioning methodology (separation, washing, milling) of plastic materials from ELV bumpers;
- elaboration of technological solutions for bumpers recycling.

To obtain samples for this experimental work, ELV bumpers were collected from 4 authorized Romanian dismantlers:

- REMAT INVEST Mediaş
- AS METAL Bucureşti
- ECOPLAST INDUSTRIES GROUP Constanța
- REMAT Craiova.

ELV brought to authorized dismantlers were manual dismantled, and, after the customary processes (removing useful parts like engine, battery, windscreen etc and fluids, dismantling wheels) bumpers were manual removed (before processing in the schredder). They were processed in the classical manner (submit to separation, washing and milling) for cleaning and grinding.

The stock of ELV bumpers from ECOPLAST INDUSTRIES GROUP of Constanța is presented in Fig. 8.

Fig. 8 ELV bumpers from ECOPLAST - Constanța

Chopped parts were rapid analyzed by DSC in order to identify the polymeric material. Samples were also analyzed by FTIR.

Different samples obtained from bumpers were mechanical and thermal characterized for establishing their level of mechanical strength and thermal stability.

New materials were obtained by compounding these samples (after adequate treatment) with wood flower and virgin polymer.

3 Experimental part

3.1 Rapid identification

Plastic materials identification before recycling is very important for avoiding the contamination of the recovered material. Differential Scanning Calorimetry was chosen to establish that the same material was used to obtain the bumpers from which samples were collected. DSC diagrams were obtained with a DSC Du Pont 2000, with 10^0C/min rate of heating using aluminium crucibles. For confirmation, FTIR spectra were performed using a Perkin Elmer - Spectrum GX FT-IR, spectral range 4000 - 400 cm^{-1}, 16 scans.

3.2 Mechanical characterization

Samples for mechanical characterization were obtained with an injection machine type Engel 22/40. Tensile properties were determined according to ISO 527 on specimens type IB (5 specimens for each test) with 50 mm/min.

3 Problem Solution

DSC diagrams of three samples from bumpers: I from REMAT INVEST Mediaş, II and III from AS METAL Bucureşti are presented in Fig. 9.

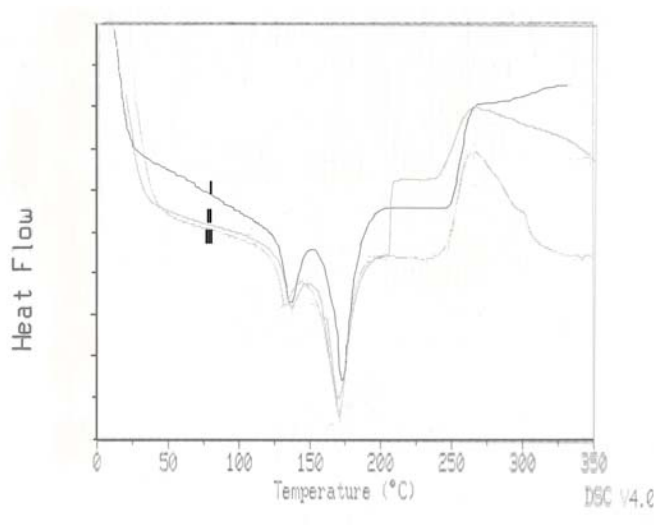

Fig. 9 DSC diagram of the plastic material recovered from bumpers (samples I, II and III)

Characteristic temperatures (melting temperatures, onset degradation temperatures) as shown in DSC diagrams are presented in Table 1.

Table 1

Sample	First melting temperature ^{0}C	Second melting temperature ^{0}C	Onset degradation temperature ^{0}C
I	136.3	172.9	247.8
II	137.2	169.9	241.9
III	133.9	171.2	246.8
C	125.1	178.8	234.0
PP		177.2	229.0

Two clear melting transitions can be observed in DSC diagrams, characteristic to the melt of 2 crystalline polymers or a copolymer. The second melting temperature corresponding to the greatest pick is of ~ 170^0C and suggests a polypropylene (typical DSC diagram of a polypropylene homopolymer is represented in Fig. 10).

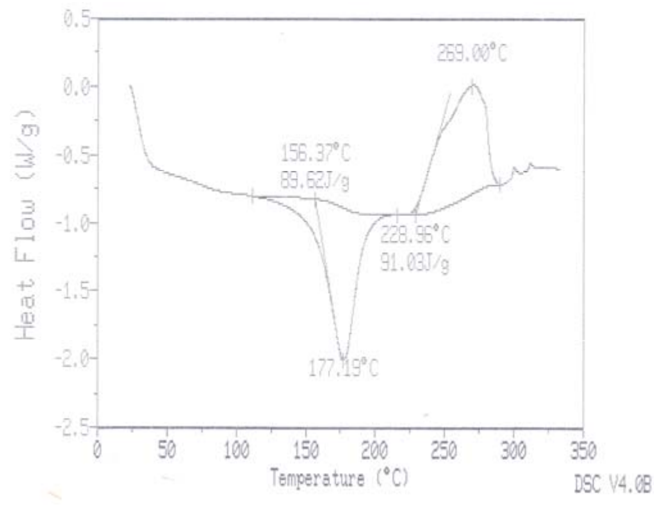

Fig. 10 DSC diagram of polypropylene HP 500 N

The first melting temperature (less intensive pick) is ~ 135^0C and suggests a polyethylene.

All samples collected from bumpers at Mediaş or Bucureşti are characterized by higher onset degradation temperatures comparatively with polypropylene. This can be caused by many factors but the presence of polyethylene could be the most important.

A sample from ELV bumpers collected at ECOPLAST INDUSTRIES GROUP Constanța (sample C) was analysed by DSC and the diagram was presented in Fig. 11 against the DSC curve obtained for the sample of REMAT INVEST Mediaş (M).

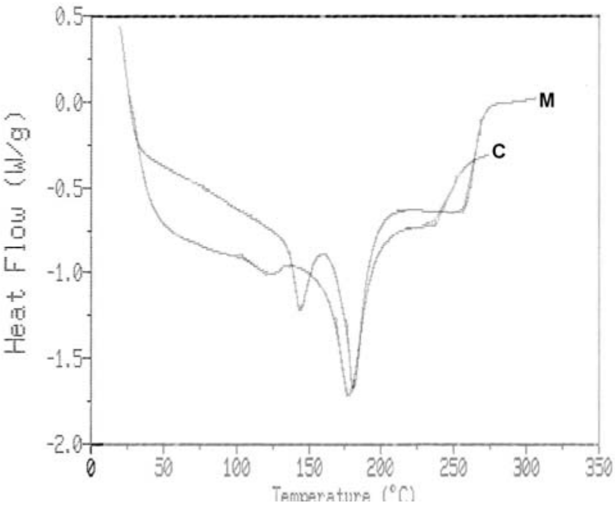

Fig. 11 DSC diagram of the plastic material recovered from bumpers
up – Mediaş bumpers; down – Constanța bumpers

Bumpers collected at Constanța are also manufactured from polypropylene as it can be seen from the DSC diagram: second melting temperature 177^{0}C. The first melting temperature is a bit lower than the temperatures observed in the case of the other analyzed samples suggesting a different polyethylene. A major degree of degradation of this bumpers suggested by the lower onset degradation temperatures could be an explanation of this behavior.

DSC diagrams of 3 samples from bumpers collected at REMAT Craiova P1, P2 and P3 are presented in Fig 12 and the characteristic temperatures in Table 2.

Samples P1, P2 and P3 show a clear transition at 171...172^{0}C, similar with the samples from Mediaş or Bucureşti, suggesting a polypropylene. The presence of polyethylene is not very clear in this case but o small deviation near 118^{0}C (the melting point of a polyethylene) is still observed.

From the curves and characteristic temperatures of all the samples it can be supposed that the same material was used by all bumpers producers and the samples contain a modified polypropylene with different proportion of polyethylene modifier and different degrees of aging. The recovered material could be a polypropylene modified or compounded with small amounts of another polymer containing polyethylene.

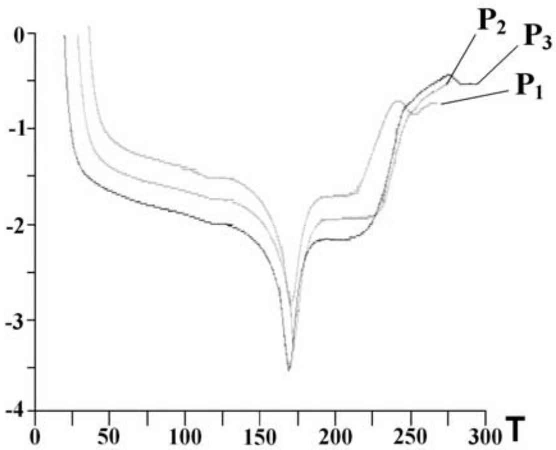

Fig. 12 DSC diagram of the plastic material recovered from Craiova bumpers

Tabelul 2

Sample	Melting temperature ^{0}C	Melting Heat (J/G)	Onset degradation temperature ^{0}C
Red M – P1	172.56	68.65	230.60
Black – P2	170.78	67.76	215.18
Silver – P3	172.05	68.14	228.71

FTIR spectra of bumper's samples from Mediaş (M), AS METAL Bucureşti (A) and Constanța (C) are presented in Fig. 13.

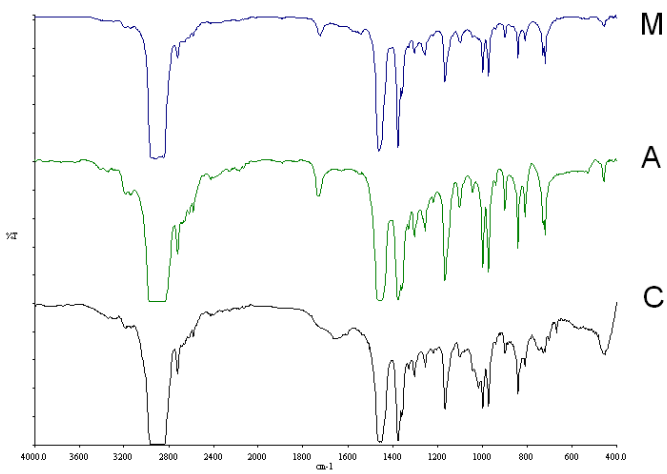

Fig. 13 FTIR spectra of bumper's samples

The analysis of FTIR spectra indicates that the most important component is a polypropylene.

In Fig. 14 superposed spectra of the sample from Mediaş - M (down) and of a polypropylene (up) are presented.

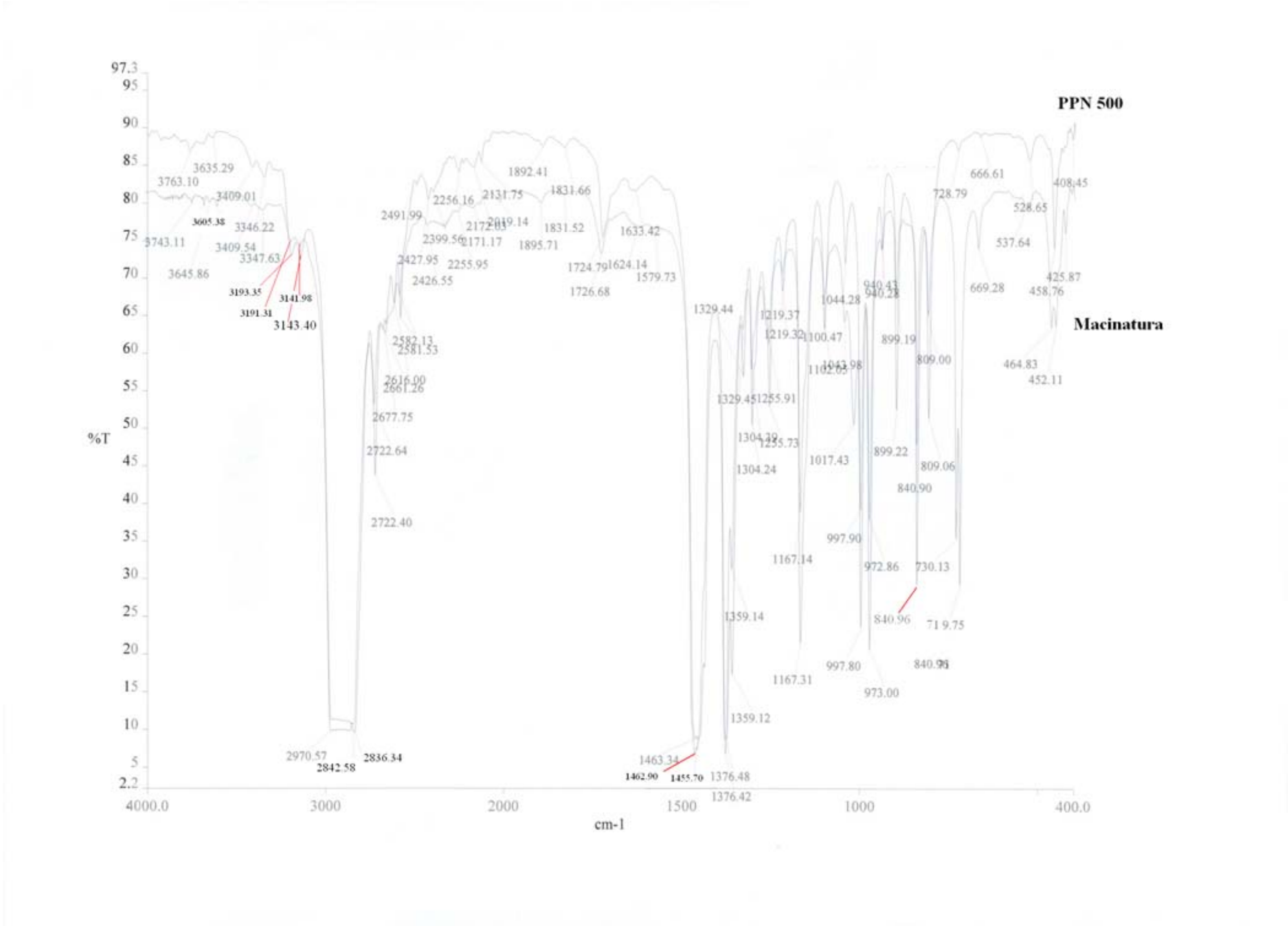

Fig. 14 Superposed FTIR spectra of samples

The resemblance of the two samples is obvious. There are still some differences which were assigned to a polyolefin elastomer.

The mechanical characterization results of the samples I, II and III are presented in Table 3.

Table 3

Characteristics	I	II	III
Izod impact strength, kJ/m^2	51.1±2.0	55.3±2.1	49,7±1.9
Tensile strength a break, MPa	14.7±0.9	19,1±0.6	16.3±0.6
Elongation at brea %	60±2	220±0.4	91±4
Flexural strength, MPa	20±2.4	21±1.1	21.2±1.3
Flexural modulus MPa	765±5	743±9	788±7

The three samples present similar mechanical characteristics, differences being related to the different stage of aging of the recovered plastic materials from bumpers.

From the level of the mechanical properties it could be assumed that the material used by bumpers producers is a polypropylene modified with a rubber for increase the impact strength.

Mechanical and thermal characterization (DSC) of the recovered materials from ELV bumpers indicates a still high level of mechanical strength and a still good thermal stability (onset degradation temperatures of the samples from DSC diagrams are 247.8^{0}C, 241.9^{0}C, 246.8^{0}C, 234.0^{0}C, 230.60^{0}C, 228.71^{0}C) as compared with polypropylene (onset degradation temperature from DSC diagram 229.0^{0}C). The recovered material from bumpers can be used in this state (without modification) for the fabrication of many parts for industrial goods (construction, auto) and domestic goods.

In Fig. 15 tiles manufactured from these recovered polypropylene (samples I, II and III) are presented. The tiles were manufactured at ROSAL srl Bucureşti in an industrial installation of extrusion and compression. In the composition of tiles beside recovered polypropylene fillers, thermal and UV stabilizers, lubricants and dye masterbach were added.

Fig. 15 Tiles from recovered polypropylene from ELV bumpers

New materials were obtained by compounding samples I and III (after adequate treatment) with wood flower and virgin polypropylene using a twin screw extruder. The results obtained after mechanical characterization of compounds containing recycled plastics from bumpers - sample I and virgin polypropylene are presented in fig 16 - 18.

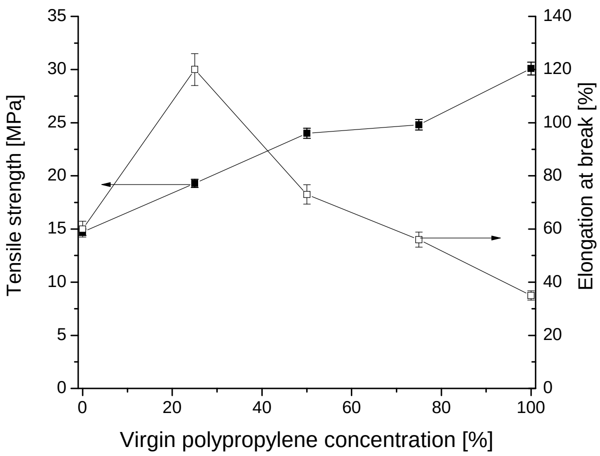

Fig. 16 Tensile properties of recycled plastics compounded with virgin polypropylene

Depending on the concentration of virgin polymer added to recycled plastics samples, new materials with new properties could be obtained. Better tensile and flexural properties coupled with good impact strength could be obtained when polypropylene 25% is added.

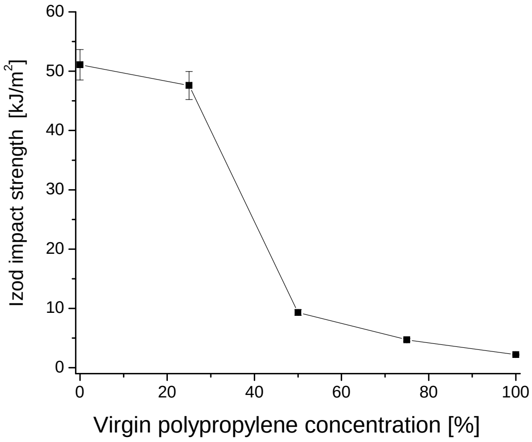

Fig. 17 Izod impact strength of recycled plastics compounded with virgin polypropylene

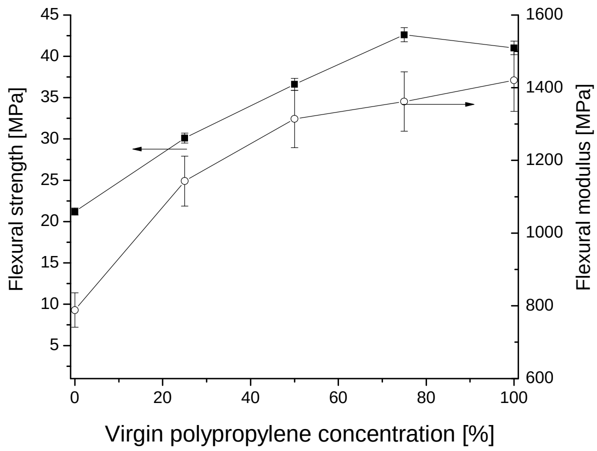

Fig. 18 Flexural properties of recycled plastics compounded with virgin polypropylene

Composites from recycled plastics from bumpers and wood flower or fibers could be another solution to this problem. Composite materials were obtained from recycled polypropylene from bumpers and wood flower in a double screw extrusion installation. The results obtained after mechanical characterization of composites (A and B) containing recycled plastics from bumpers - sample I (A) and III (B) and wood flower (WF) 40% (by weight) are presented in Table 4.

Considering the properties of recycled plastics (samples I and III from Table 3) comparatively with the mechanical properties of composites obtained from these plastics and WF (Table 4) new materials with new properties (better strength, higher rigidity) were prepared.

Table 4

Mechanical Characteristics	Composite A	Composite B
Izod impact strength, kJ/m^2	6.9±2.0	4,7±2.1
Tensile strength at break, MPa	17.3±0.8	16.0±0.9
Elongation at break, %	10±2	8±2
Flexural strength, MPa	26.8±1.8	25.4±1.4
Flexural modulus, MPa	1797±6	1674±6

These new materials, with good mechanical properties could be used in many application fields like building and construction, domestic goods, etc.

4 Conclusion

In present, 75% - 80% of ELV in terms of weight, mostly metallic fractions, both ferrous and non-ferrous, are being recycled. Recycling of plastic materials from end-of-life vehicles (ELV) is still an unsolved problem.

ICECHIM Bucharest, ICPAO Medias and some ELV dismantling companies from Romania have tried to recycle some ELV big parts made from polymers. Bumpers were chosen for experimental demonstration of the viability of technical solutions elaborated by the research team.

Plastic material samples collected from bumpers were analyzed for the identification of polymers. DSC analysis established that the same material was used to obtain the bumpers, namely a modified polypropylene. FTIR analysis confirms calorimetric results. Mechanical and thermal properties were determined in order to characterize their residual level of mechanical strength and thermal stability. Plastic materials recovered from ELV bumpers still show a high level of mechanical strength and a good thermal stability. A high level of impact strength (50 kJ/m^2), a tensile strength of ~ 15 MPa and a flexural modulus over 700 MPa are common characteristics of many commercial grades of modified polypropylene. Therefore recovered polypropylene can be used in this state (without modification) for the fabrication of many parts for industrial and domestic goods. For example, tiles were manufactured from these recovered polypropylene in an industrial installation of extrusion and compression.

New materials with interesting properties were obtained by compounding the plastic material samples collected from bumpers with wood flower and virgin polymer. Compounds from recycled and virgin polypropylene show interesting tensile and flexural properties at 75/25 ratio. High tensile and flexural strength and 100% increase of flexural modulus were obtained when 40% wood flour was added to recycled plastics.

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