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RESEARCH ARTICLE

Upcycling of polymer waste from automotive industry

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Abstract

The recycling methods of polymer fraction from wrecks are not solved in the automotive industry. If the manufacturers want to meet the EU directive, 95% of the car wrecks must be recycled from 2015. In order to reutilization polymer waste the upcycling is very important. Considering economic aspects, the aim is to manufacture a product of two components where the shell structure consists of low density polyolefin fraction, while the core can be developed by high density mixed waste polymer materials. Afterwards, the mechanical and flame-retardant properties of the two-component injection molded product can be examined.

Keywords

recycling · co-injection molding · car waste · fiber reinforcement · fire retardancy

Acknowledgement

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1 Introduction

The desired sustainable development can only be maintained if the increasing number of waste can be recycled, thereby the demand for primary raw materials can be reducing. The recovered waste from car wreck must be recycled, considering that the process does not require more energy at the manufacturing as a new raw material [1]. In Hungary 3 million cars ran on the roads at the end of 2010, according to the Hungarian Central Statistical Office's data bank [2]. Annually about 80 to 90 thousand vehicles were withdrawn from circulation in Hungary. The recycling of metal parts is solved in the automotive industry, and 85% of the parts of car wrecks can be recycled, so they can meet the 2000/53/EC directive now. But the recycling methods of light polymer fraction are not solved yet. However, if the car manufacturers want to meet the EU directive, 95% of the car wrecks must be recycled from 2015 on it is essential to recycle the polymer fraction, which is neglected currently [3].

The recovered polymer fraction can be processed immediately, but the product quality would be low with this method. Another way is the upcycling, where the polymer fraction can be added with fiber reinforcement and quality improver additives. Thus high quality technical products can be reproduced by appropriate technology – like co-injection molding, filmstacking process and coextrusion - [4–6].

The goal of this paper is to reveal mixed plastics fraction after shredder operation will be almost totally recyclable considering economy aspects too. Therefore, the light fraction must be separated and needed to establish one dividing line. In this way the shell structure consists of low density polyolefin fraction while the core can be developed by high-density mixed waste polymer materials.

2 Experimental

In the RECYTECH project - called "Elaboration of Recycling Technologies for nonmetalic automotive and electronic wastes avoiding further deposition of organic materials" - the polymer waste streams separated by specified increments. It sets that under 0.92 g/cm^3 density PP, between 0.94-0.97 g/cm^3 polyethylene and between these two intervals mixed polyolefin waste can be extracted. Nearby 1 g/cm^3 density PS and ABS can be found in the waste, while more than 1.1 g/cm^3 PA and rubber fraction can be detached [7].

Considering economic aspects can be used only one demarcation in the industry. It would be advisable to choose 1 g/cm^3, but in this case other polymer fractions appear in the raw material, which cause a significant declension in the quality of the product. Thus the selection fallout of 0.97 g/cm^3 density in alcohol-water emulsions, so the core- and the shell materials can be separated into two parts.

2.1 Materials and equipment

At the experimental of the shell and core structure Tipelin H949A polypropylene was used as matrix. The flame retardant was Exolit ammonium polyphosphate by Clariant GmbH.The glass fiber (type: DS 2200-13P GF-2) was produced by Fibreglass Company. Two different types of compatibilisator were used, PP-g-Ma (polypropylene-grafted maleic anhydride) and SEBS-g-MA (styrene/ethene-co-butene/styrene grafted with maleic anhydride). The matrix of the co-injected samples was separated polymer waste.

The samples of the core structure were made by Arburg Allrounder 320°C injection molding machine. The two-component injection molded products were produced with Engel ES 200H co-injection molding machine. The other samples were made with Brabender Plastograph PL 2000 internal mixer and Collin P200E plate press machine.

The tensile strength was examined with Zwick Z020 tensile testing machine. Ceast Resil Impactor Junior (with 2 J hammer) was used at the measurement of impact strength. MSZ 595/1 standard was used to determined the limiting oxygen index (LOI). The oxygenmeasuring equipment meets the MSZ 09-40041-77 standard.

2.2 Development of shell structure

During the development the goal is to establish good homogeneity and choose the best flame retardant. The shell part is consisting of polyolefin with lower density than 0.97 g/cm^3. The most important to select the best flame retardant, so three different types of foaming ammonium polyphosphate, produced by Clariant GmbH (Exolit APP), will be investigated. Each sample contains 34 wt% flame retardant (Tab. 1).

The limiting oxygen index (LOI), the tensile strength and the flexural modulus of elasticity was examined. The results show that the best two flame retardant systems are the APP 422 and the APP 766. The tensile strength and elongation are approximately the same.The LOI at APP 422 is 36 while at APP 766 is 39. Overall, it can be concluded that the primary flame retardant is the APP 766, and with this reagent can be reached the best flameretardant properties and flexural modulus.

It is important to determine which rate of flame retardant is needed to add to the polymer, because increasing the volume of flame retardant the oxygen index increased – above 26 of LOI the combustion resistance is adequate - but the mechanical properties declined. Therefore APP 766 is dosed to the polymer base 18 wt % to 50 wt% in increments of 8 wt%. The measurement data showed that the increasing amount of the flame retardant reduces the tensile strength (Fig. 1). A similar trend can be found in the breaking elongation too (Fig. 2).

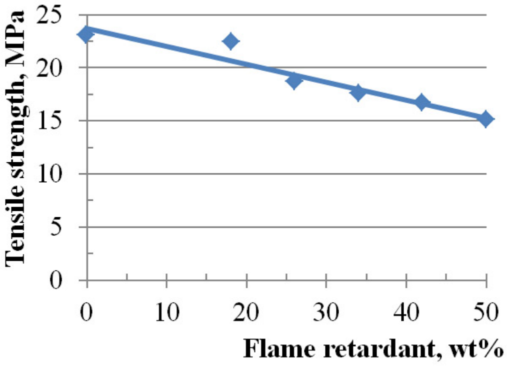

Fig. 1. The tensile strength at different content of flame retardant.

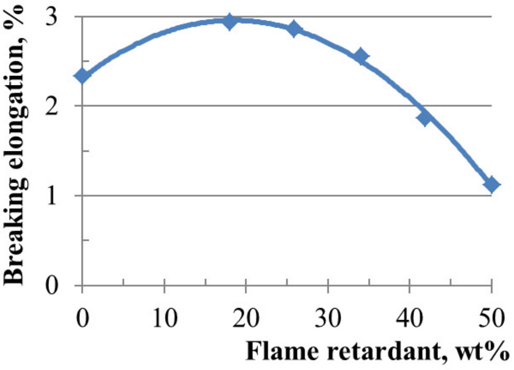

Fig. 2. The breaking elongation at different content of flame retardant.

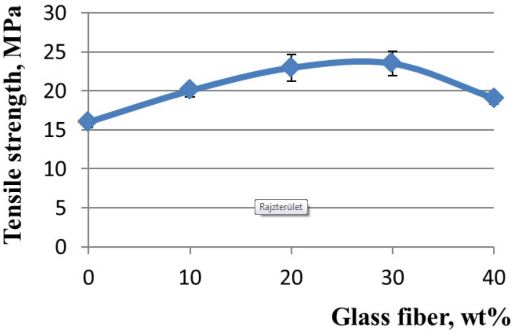

Fig. 3. Tensile strength at different content of glass fiber.

The combustion takes place at atmospheric conditions, if the LOI is less than 21. The LOI of samples without additive was only 18. At 18 wt% the LOI was 32 while 26 wt% was already 37. So it can be deducted that 18 to 26 wt% the combustion resistance can be achieved. Higher ratio of the flame retardant decreases the mechanical attribution while the further increase of this additive cannot be justified. The UL 94 test showed at 18% of flame retardant occurred longer burning than 30 seconds and melt drips can be discovered, which at 26% are no longer

Tab. 1. * Pentaerythritol tetranitrate, Composition of samples

Sample	PP	APP 422 + PER*		APP 760	APP 766	Melamine
weight=250g	[%]	[%]	[%]	[%]	[%]	[%]
Reference	100	–	–	–	–	–
APP 422	66	25,5	8,5	–	–	–
APP 422+MEL	66	20,4	6,8	–	–	6,8
APP 760	66	–	–	34	–	–
APP 760+MEL	66	–	–	27,2	–	6,8
APP 766	66	–	–	–	34	–
APP 766+MEL	66	–	–	–	27,2	6,8

appreciable. The latter case the highest V0 classification accessible, the upcycling at shell structure can be achieved.

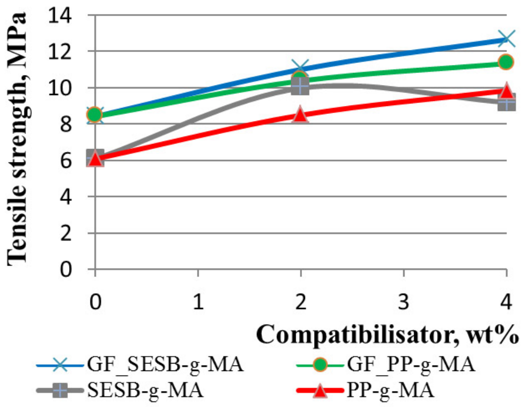

Fig. 4. Values of tensile strength.

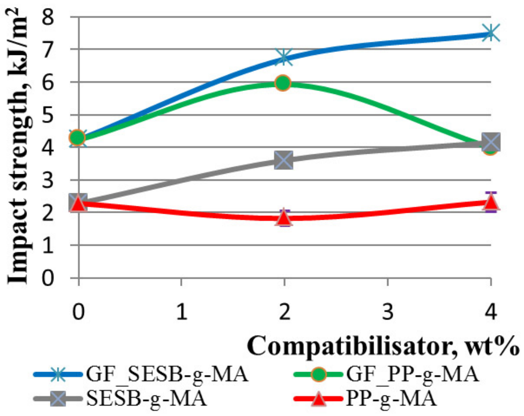

Fig. 5. Values of impact strength.

2.3 Development of core structure

The next step was to establish the structure of the core material. The samples prepared by injection molding method. The glass fiber reinforcement and the compatibilisation process are important in the core, because it consists of high density mixed polymer materials, which are immiscible with each other. The material of the matrix was Tipelin H949A polypropylene. The fiber was produced by Fibreglass Company (type: DS 2200-13P GF-2). The fiber ratio was changed between 0-40 wt% (Fig. 3). After the analysis of elongation can be stated that 10% increase of fiber volume fraction makes approximately 1% reduction of elongation. The tensile strength measurement is presented at the second figure. The tensile strength ascends close to 30 wt%, after the index decline. The reason is that in the matrix the quantity of glass fiber is too high and the fibers are not oriented so establish good formation of adhesion is difficult. The highest value observed at 30%, the measured tensile strength is 24 MPa, the mechanical properties with this condition are the best.

At the compatibility studies period two systems (PP-g-MA and SEBS-g-MA) were examined with different weight ratio in reinforced (30 wt%) and unreinforced cases. The efficacy was based on the comparison of tensile strength (Fig. 4) and impact strength (Fig. 5). The samples prepared by plate press machine. The better agents was the SEBS-g- MA system, which can be justified that in high density polymer waste the ABS content is higher, so the waste and the compatibilisator could better work together. It can be establish that between 0.97-1.3 g/cm^3 the upcycling method can be solved if glass fiber and SEBS-g-MA compatibilisator are added to the polymer waste.

2.4 Two-component injection molded product manufacturing

The two-component injection molded product (Fig. 6) was manufactured at Bay Zoltán Foundation for Applied Research Institute with Engel ES 200H co-injection molding machine. As can be seen on the figure, the mass of the core part is twice more higher than the shell. The process parameters was the can be seen (Tab. 2).

3 Results

The results of the mechanical tests can be comparable of the upcycled co-injection molded samples and the products which are made of different density fraction of polymer waste.

The tensile strength (Fig. 7) at low density polyolefin fraction is 14.85 MPa, at higher density (0.97-1.10 g/cm^3) PP, ABS and PC polymers is 16.3 MPa, at 2K injection molded product is 19.4 MPa. The reason for the high strength is the presence of glass fiber and the compatibilisator in the core. Similar trend can be observed at tensile modulus, the determined value is 2.57 GPa, which is more than one and a half time better than the value of core structure (1.51 GPa) and three times better than the value

Tab. 2. Parameters of co-injection molding

		1. aggregate – core structure	2. aggregate – shell structure
Materials		66 wt% 0.97-1.3 g/cm^3 density waste polymer, 30 wt% glass fiber 4 wt% compatibilisator	74 wt% waste polymer under 0.97 g/cm^3 density, 26 wt% flame retardant
Temperature	[°C]	260	220
Mixing head temperature	[°C]	240	240
Tool temperature	[°C]	40	40
Injection speed	[mm/s]	65	65
Injection pressure	[bar]	70	65
Holding pressure	[bar]	65	65
Weight ratio	[%]	30	70
Injection ram	[bar]	5	2
Clamping force	[kN]	400	400
Cooling time	[s]	40	40

of the shell (0.80 GPa).

The results of impact strength (Fig. 8) show that the shell structure - forming by polyolefin - is a tough material and it has a very good energy absorption capacity. The high density polymer waste is rigid. The 2K product has 11.1 mJ/mm^2 of impact strength, which is a good result. The reason is that the produced core-shell structure has a very good resistance of dynamic effects as well. More than four times increase can be achieved compared to the core material.

The APP 766 flame retardant ensures the resistance of combustion at the product, which is located in the shell structure. The measured oxygen index at 2K product is 26, while the none-flame retarded polymer waste has only 21. Although the shell structure is thin compared to the product, even it is enough that the products do not catch fire so the cost of the production can be reduced. The upcycled polymer waste is flame retardant while the natural waste from the shredder is not.

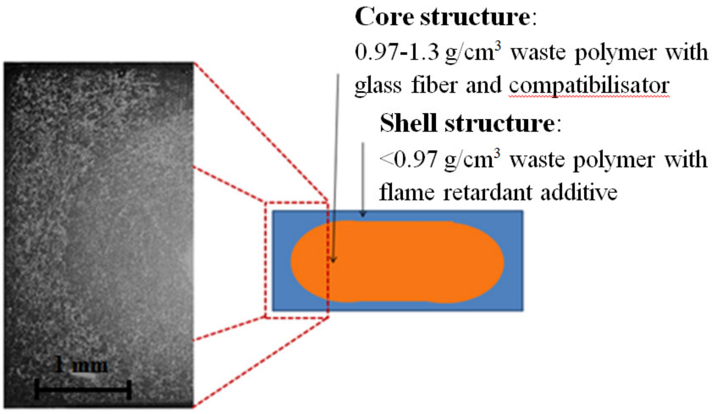

Fig. 6. The core- and the shell structure.

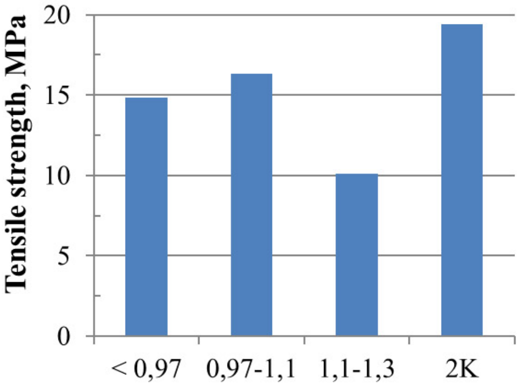

Fig. 7. Tensile strength results at different densities and the product.

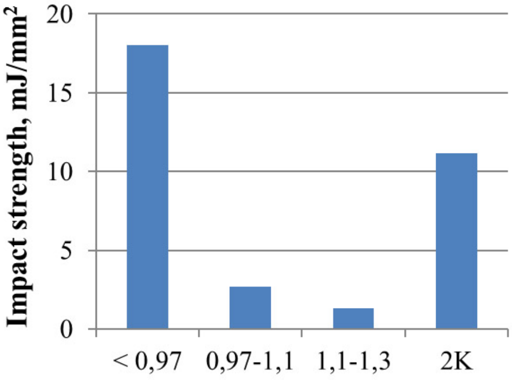

Fig. 8. Impact strength results at different densities and the product.

4 Summary

After the separation of polymer waste it can be stated that the shell structure can be developed with low density (<0.97 g/cm^3) polyolefin, till the core consists of high density mixed polymer waste. If 26 wt% of ammonium polyphosphate is added to the shell flame retardancy can be achieved. It was added 4 wt% of SEBS-g-MA compatibilisator - because of the various plastic waste - and 30 wt% of glass fiber reinforcement to the core to orient to the trends of automotive industry. Finally occurred the two-component injection molded samples manufacturing and the mechanical properties investigation.

It can be deducted that improvements of properties of upcycled products are very significant while the waste can be reused on a large scale. Thus the approach can be justified that with the right methods and technology it is possible to manufacture high quality products again from polymer waste.

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