12th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2008, Istanbul, Turkey, 26-30 August, 2008

PET BOTTLES RECYCLING WASTE – UTILIZATION AND PROPERTIES

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ABSTRACT
Post-consumer PET (polyethylene terephthalate) containers in the Republic of Croatia are being baled and delivered to recycling plant, where they go through various phases of cleaning and separation of PET from other materials. Waste from the recycling process consists of different materials – PET, labels and sleeves (poly(vinyl chloride), paper and polystyrene) as well as caps (polypropylene and polyethylene). The intention was to make use of this waste, so mouldings were made by compression moulding and their mechanical properties were tested.
Keywords: PET bottles, recycling

1. INTRODUCTION
By introducing the Ordinance on Packaging and Packaging Waste in the Republic of Croatia, i.e. deposit system of compensation for returned waste packaging, about 90 % packaging waste is collected in Croatia. Polyethylene terephthalate (PET) is a very wide-spread plastic packaging material which is used to manufacture containers for beverages, carbonated and non-carbonated mineral water, milk and dairy products, oil, beer and others. The containers are made in different colours (white, green, blue and brown), transparent or opaque, and single- or multi-layer. Labels, caps and sleeves are made of different plastic materials (polyethylene (PE), polypropylene (PP) or poly(vinyl chloride) (PVC)).
In the recycling system of the waste PET packaging in the Republic of Croatia, the waste PET containers are baled and delivered to the recycling plant where they pass various levels of cleaning and separation of PET from other materials. The production of high-quality recycled PET, however, requires cleaned waste PET which contains no multilayer (beer bottles), coloured and opaque containers (bottles for beer and dairy products), and PVC sleeves (containers for dairy products), and they need to be removed before starting the recycling procedure. During mechanical recycling of post-consumer PET containers, the waste that consists of various plastic materials is generated on the daily basis. The intention of this work was utilization of this waste by making new products.

2. LEGISLATION OF THE REPUBLIC OF CROATIA AND EU IN PACKAGING WASTE MANAGEMENT
The Ordinance on Packaging and Packaging Waste in the Republic of Croatia was brought on 27 July 2005. The reason for the Ordinance was to reduce the generation of the packaging waste, i.e. reduction of total mass of waste in the Republic of Croatia, by separate collection of packaging waste and its reuse as valuable secondary raw materials.
The Ordinance stipulates the method and conditions of collecting packaging waste, types of labels marking the packaging depending on the type of material, method of processing and disposal of packaging waste, and fine provisions for non-compliance to the provisions of the Ordinance. The manufacturer has to cover the costs for the collection, disposal and recycling of waste primary

packaging from the product placed on the market on the territory of the Republic of Croatia, and in the same way on one's own expense ensure marking of the packaging i.e. product placed on the market by adequate barcode in compliance with the international system of coding and product identification EAN (European Article Numbering). [1]

Everything was preceded by the European Union guidelines. The European Union, with the adoption of its Packaging and Packaging Waste Directive, 94/62/EC as amended by 2004/12/EC, is legislating for more effective recovery of used packaging and for the reduction of the impact of packaging on the environment. Recovery of PET packaging falls under the requirements for recovery and is classed together with other plastic materials in the targets laid down in directive 2004/12/EC. [2]

PET is widely recycled as a material, making a large contribution to the recycling targets required for plastics by the EU directive. When material recycling is not feasible, PET can be incinerated with energy recovery. Moreover, PET usually does not contain heavy metals and/or substances dangerous for the environment. [2]

3. PET RECOVERY PROCESSES

PET can be recovered, and the material reused, by simple washing processes to regenerate clean washed polymer flake (mechanical recycling), or by chemical treatment to break down the PET into oligomers or up to the starting monomers, terephthalic acid and ethylene glycol (chemical recycling). These intermediates are then purified and repolymerised into new PET resins. A final option, for PET that is unsuitable for material recycling (e.g., very dirty, or too contaminated to clean), is to use PET as an energy source. [2]

Purity is essential for good quality mechanical recycling. Discrete physical contamination is usually easy to remove i.e., dirt, soil, paper, glues, product residues and other plastics like PVC and PE. However, ingrained soil caused by abrasion or grinding, for example during baling, transport or handling in poor storage conditions, is difficult to dislodge and will need some filtration to ensure removal. For some low risk applications, like non-food contact and fibres, incidental product contamination is likely to be insignificant. For other uses, appearance and odour are important. The intended use of the recycled PET often determines the feedstock purity requirements. [2]

Chemical recycling processes are generally less sensitive to purity of feedstock than mechanical ones, as they include efficient purification steps.

Recovery of PET by combustion in waste-to-energy power generation plants is a useful method of utilising the high intrinsic energy content of PET (23 MJ/kg, comparable to that of soft coal). If this type of plant is not available, simple incineration is then the alternative option. Combustion of PET is perfectly safe; containing only carbon, hydrogen, and oxygen, with controlled burning its combustion generates only carbon dioxide and water. The volume of ash generated is parts per million, essentially insoluble and can be treated in the same manner as other resulting ashes. [2]

In landfills, PET is stable and inert with no leaching or groundwater risk. Bottles are crushed to very small volume, take up relatively little space, and generally add a degree of stability to the landfill.

3.1. Uses of recycled PET (R-PET)

Clean, recovered R-PET flake is virtually indistinguishable from virgin PET and can be converted into many different products competing in the same markets. It is used again in bottles for non-food end uses like household chemicals and cleaners. In countries where local laws allow it, the use of R-PET for the manufacture of new beverage bottles is growing rapidly. [2]

However, the major secondary use is for the manufacture of polyester fibres then used to make clothing, either directly or as a filling fibre in anoraks and bedding. The fibres are also used extensively for carpets and scouring and cleaning pads. Protective packaging for delicate articles, like

eggs, and plants for despatch through mail, are manufactured from R-PET using thermoforming techniques. [2]

Figure 1 shows some examples of recycled PET applications.

Figure 1: Examples of using recycled PET [3]

3.2. Design for recycling guidelines

The basic guidelines for PET bottles design suitable for recycling include the selection of additional material regarding its compatibility with PET or separability in the usual separation systems based on water according to density (Table 1). The attachments include caps, stickers, labels, sleeves, safety foils, coatings and surface layers. For efficient separation of PET from other materials, the attachments have to be made of material whose density is lower than the density of water (1 kg/m^3), since such materials float in the separation system and can be easily separated from PET. Especially undesirable is PVC, since PET and PVC have similar densities, so that both materials fall to the bottom. For the moment there is no separation method that separates PVC from PET with 100 % reliability, so that PVC sleeves on PET packaging should be avoided. [4]

The use of sleeves made of other materials is recommended. The oriented polystyrene is used more and more (OPS) and polyethylene terephthalate modified by glycol (PETG). OPS is somewhat less expensive than PETG. In Europe PVC is increasingly substituted by PETG, and in Japan sleeves made of PVC are not used any more. [5]

Table 1: Design for recycling guidelines for PET bottles [4]

	Preferred	Undesirable
Closures	PP, PE-HD, EVA	PVC, Al
Colours	Unpigmented; Green, transparent	Other colours, tinted and/or opaque
Labels/Adhesives	PP, OPP, HDPE, MDPE, LDPE and LLDPE; PS Foam only; Non-bleeding inks; Water-soluble or dispersible adhesives	PVC, Paper, Metallized
Layer/Coatings	PET compatible; easily separable from PET in conventional recycling systems	Non-PET layers and coatings
Other Attachment	Non-PET, must be compatible with, or easily separable from PET in conventional recycling systems.	

4. EXPERIMENTAL PART

The focus is on the possible material usage of waste generated during the mechanical recycling of post-consumer PET packaging at the Croatian plant for PET recycling, BBS d.o.o. Podrute. The procedure selected for the processing of the generated waste was compression moulding and the test samples were made to determine the mechanical properties in order to determine the usability of the obtained material (moulded part).

There are 2000 kg of waste generated daily at the factory. The total weight of waste (material) contains 45 % PET, 10 % labels (PVC, paper and PS) and 45 % caps (PP ≈ 32 %, PE ≈ 13 %). The share of humidity in the waste is about 19 %. Before the processing the material was dried for 1.5 hours at the temperature of 100 ^{o}C, to avoid swelling of the products (moulded parts) after processing. The specimens were cut by a circular saw from the plate made by compression moulding.

The material was processed on the daylight press Belišće. The processing parameters were:

- Temperature of plates: 220 ^{o}C
- Compression pressure: 100 bar
- Pressure time: 15 minutes
- Air cooling time: ≈ 20 minutes
- Material weight: 0.5 kg

The following mechanical properties were tested: tensile properties, flexural properties and hardness. Table 2 gives the mechanical properties of compression moulded parts of waste from the BBS Company. Values of the properties of the manufactured moulded part dissipate extensively, which is the consequence of lack of homogeneity of the product along the transversal cross-section. Polyethylene used as binding agents in the moulded part has not uniformly coated the solid particles randomly distributed.

Table 2: Mechanical properties of compression moulded parts of waste from the BBS Company

	Range of values	Average
Tensile strength (N/mm^2)	4.1 – 4.9	4.4
Tensile modulus (N/mm^2)	582 – 883	740
Flexural strength (N/mm^2)	12.1 – 15.2	13.7
Flexural modulus (N/mm^2)	433 – 660	538
Hardness (N/mm^2)	14.1 – 17.3	15.5

5. CONCLUSION

PET container recycling is a healthy industry and growing very steadily, while recycled PET is very well established in the market. During the mechanical recycling process of post-consumer PET containers, waste consisted of various materials is generated that needs to be taken care of. The procedure of compression moulding was selected and mechanical properties were tested. Application of such materials is limited due to inhomogeneous cross section and relatively poor mechanical properties, so further research will be oriented to better homogenization of the mixture, i.e. extrusion prior to compression moulding or by adding some new material (e.g. polyethylene or polypropylene) to the mixture. Possible application of this material is the manufacture of objects of art (decorations), such as e.g. plant pots, coasters, and similar, or for seats at stadiums, stationery (stands for pencils and documents), litter bins etc.

6. REFERENCES

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Acknowledgement

This work is part of the research included in the project Increasing Efficiency in Polymeric Products and Processing Development *and in the* Advanced Technologies of Direct Manufacturing of Polymeric Products. *They are included in program* Rapid Production – From Vision to Reality *supported by the Ministry of Science, Education and Sports of the Republic of Croatia. The authors would like to thank the Ministry for the financing of these projects.*