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Plastic waste management and environmentally degradable plastics in Hungary

Summary — General characteristic of Hungarian plastics industry in 2000, present state of plastics waste management and legislative issues concerning plastics waste management have been described. Wastes in majority are landfilled and only small amounts of them are incinerated or recycled. Plastics recycling is limited to post-production one. There are very few companies collecting and processing wastes from other sources (*e.g.* municipal wastes). The results of research works, carried out in several Hungarian scientific centers, on environmentally degradable plastics (EDP) have been discussed in details. These works focus on the blends of polyolefins (PP, PE) with thermoplastic starch (TPS). Data concerning the effect of compatibilizer presence on the morphology and mechanical properties of the blends have been presented.

Key words: Hungary, plastics, wastes, recycling, environment, degradation.

PLASTICS INDUSTRY IN HUNGARY IN 2000

Chemical industry has a very strong position in the economy of Hungary: it gave about 15% (1.764 billion HUF) of the total industrial production in 2000 and has occupied this position the last decade [1]. The production of plastic raw materials, as well as plastic processing form an important part of chemical industry — they represented about 7% (810 billion HUF) of the total industrial production, *i.e.* 46% of chemical production in the same year. In 2000 the growth rate of chemical industry was 43% in value [1, 2]. The plastics industry grew at a slower rate, 35% in value. The average growth rate was 23% in volume for the production of plastics, the total amount of polymers produced in the country reached 1009 kt, the majority of which (888.4 kt) consisted of four commodity polymers (PE, PP, PVC and PS). The amount of plastics processed in 2000 increased by 17% in volume in comparison to the previous year and reached the highest value ever (680 kt, including paints and adhesives) so, plastics processing develops dynamically in Hungary. Companies of all sizes operate in this field and most of them are in good and stable financial position. Prediction indicates further growth in this section of the industry.

Table 1. Manufacture of plastic products in Hungary in 2000 [1]

Product type	Amount	
	1000 t	%
Films	116.4	22.8
Injection molded parts	95.9	18.8
Pipes	56.7	11.1
Bottles and containers	44.1	8.6
Plastic fiber	24.9	4.9
Structural foams	35.3	6.9
Cable and wire insulation	20.3	4.0
Plates, sheets	13.8	2.7
Profiles (door, window, *etc.*)	13.5	2.6
Floor coverings	11.4	2.2
Molded thermosets	3.1	0.6
Synthetic leather	1.3	0.3
Others	73.6	14.4
Total	510.3	100.0

Table 1 shows the absolute and relative amount of plastic goods produced in Hungary in 2000 [1]. Films, injection molded parts, pipes and bottles were produced in the largest quantities. The high proportion of packaging materials in the total amount of processed plastics calls attention to the importance of waste management and especially to the handling of this class of materials. A large part of it appears in the municipal waste, which is usually deposited in landfills. The importance of this problem is recognized also by the Ministry of Environment and most legislative regulations focus on this issue. Recycling and the production, as well as the application of environmentally degradable plastics as packaging materials would solve the problem at least partially.

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WASTE MANAGEMENT

In 1999 approximately 72.5 Mt of waste was produced in Hungary; about 3.7 Mt from this quantity was hazardous waste [3]. 58.2 Mt of non-hazardous waste originated from agricultural, industrial or other production activities. Municipal waste can be divided into 6.3 Mt of liquid and 4.5 Mt of solid waste. Only about 83% of the solid waste is collected regularly in the form of organized services, the rest is deposited illegally somewhere in the environment.

The composition of solid municipal waste is shown in Table 2. So, plastics form only a small part of the waste — the quantity of the country average is 5—6%, and 12—15% in Budapest. The municipal waste contains a large quantity of material — like construction and building materials, large household parts, *etc.* — which should not be dumped this way, but deposited separately. Although the composition of the waste is somewhat different in Budapest from that in the rural areas, the data of the Table 2 give a good idea concerning the relative importance of plastic waste in Hungary. In spite of the small quantity, the public is very sensitive to its environmental impact today.

T a b l e 2. Composition of solid municipal waste in Hungary in 1999 (w/w%)

Material	Budapest and larger cities*)	Country average**)
Paper	18—20	16—17
Plastics	**12—15**	**5—6**
Textile	5—6	3—4
Glass	4—5	3—4
Metal	3—4	3—4
Decomposing organic waste	30—32	35—40
Inorganic waste	20—25	25—30

*) Values measured according to standard.
**) Estimated values.

About 85% of solid municipal waste are deposited in landfills. The number of official deposition sites is about 2700 in Hungary. Except hazardous materials, a large quantity of the waste produced by plants or other industrial enterprises is also deposited in landfills, either in the private landfill of the plant or it is transported to municipal landfill sites.

Only about 30% of the municipal landfills meet more or less the requirements of environmental regulations. According to present estimates, the capacity of existing landfills is sufficient for 5 years more. A significant number of the landfills represent a potential danger to the environment.

The latest data concerning plastics waste management are shown in Fig. 1. Only a very small part of the waste is incinerated (8.3%) and even this is done without energy recovery. Even less plastics waste is reprocessed (2.5%) and none is disposed by biological means. Organized selective collection of municipal waste does not exist in Hungary at the moment.

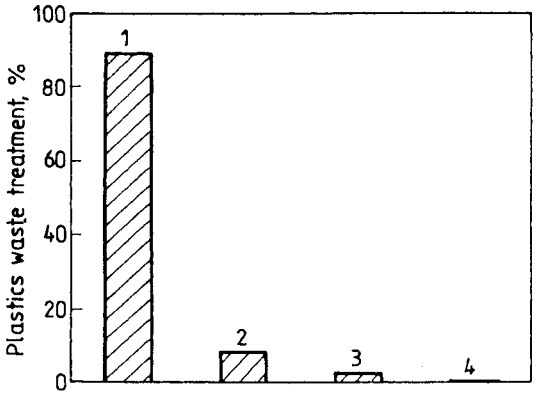


Fig. 1. Disposal of plastics waste in Hungary (1998): 1 — deposition, 2 — incineration, 3 — recycling, 4 — biological treatment

Naturally, the numbers mentioned above apply to municipal waste, since most of the plastics waste produced by the industry is recycled. Several plants buy waste from other companies. The low amount of recycled waste leads attention again to the importance of proper waste management.

REGULATIONS, LAWS

Up to quite recent years basically no regulation concerning the environment and the handling of waste materials existed in Hungary. The first act on the protection of the environment was introduced in 1995. Regulations, which control the handling of all kinds of wastes including hazardous materials are summarized in Table 3. Several regulations focus on the waste formed by packaging materials and in 1995 an act on a charge for such products was introduced. This act defines the extent of

T a b l e 3. Hungarian legislative issues related to the environment

Subject	Type	Year
Municipal waste management	ministerial decree	1986
Import of hazardous waste	governmental decree	1987
Waste management	governmental decree	1988
Emission from incineration	ministerial decree	1991
Environmental protection	act	1995
Product tax (packaging)	act	1995
Determination of environmental effects, authorization procedures	governmental decree	1995
Hazardous waste	governmental decree	1996
Waste management	act	1999

tax for each class of packaging materials and gives compulsory quotas for their recycling. In the case of plastics packaging materials, product tax and waste management quotas (in %) amount: in 2000 — 12.7 Ft/kg and 41%; in 2001 — 13.5 Ft/kg and 55%. In comparison with other kinds of packaging materials, the highest tax must be paid for plastics.

A further problem is created by the fact that the tax paid by the companies producing the packaging materials is not used for the installation of new reprocessing plants or for plastic waste management generally. The quotas given for recycling are sometimes more severe than those of the EU. The most important concern of all legislative forums, the ministries who prepare the laws and the parliament enacting it, is to create acts which harmonize with those of the European Community. However, it is questionable if the very strict recycling quotas can be met in Hungary in the near future.

RECYCLING

Only a small part of the plastics waste is recycled in Hungary. Reprocessing is hindered mainly by the usual problems: collection, separation and cleaning of municipal waste. Although authorities made attempts to convince the population to collect waste separately, this did not work even for glass or paper. As a consequence, only agricultural and industrial wastes are reprocessed and used at present. Reprocessing of plastics is carried out by 8 companies. Four of them are specialized in the recycling of films, the total amount of reprocessed material is about 18 800 t/year. All of these companies are located in the countryside and they process agricultural waste, mostly films used as greenhouses.

Naturally most plastics processing companies reprocess their own technological scraps. However, some of the companies, mostly involved in injection molding, sell their processing waste to companies, which are specialized in recycling. They handle mixed waste, mostly PE-HD, PE-LD, PS, PVC and PET. The total processing capacity of these companies is about 11 500 t/year, the largest of them is of capacity 5000 t/year, which is still negligible compared to the amount of the plastic materials processed and used in Hungary each year.

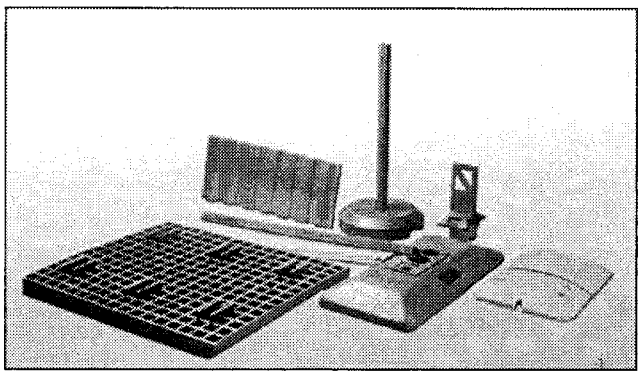


Fig. 2. Products of Recyclene Ltd.

Only a few of the companies (*e.g.* Recyclen, Holofon) manufacture end products from the waste. They process the waste into thick, low value articles, like posts and planks used as fences, banks, mooring facilities, *etc.* Several articles produced by Recyclen are presented in Fig. 2. The production of the company varies each year depending on the availability of waste and the demand for its products. However, it must be emphasized here again that these companies do not reprocess municipal, but only industrial waste. Nevertheless, the number of companies involved in recycling increases continuously.

Only rare attempts are made to produce high value products from plastic waste. One of these is the production of Syntumen, a synthetic plastic component of bitumen used in road construction. This additive is produced by the catalytic degradation of selected plastic waste, mostly polyolefins. A plant of 5000 t/year capacity is constructed by TVK, one of the large petrochemical companies, to produce this new material in the near future.

ENVIRONMENTALLY DEGRADABLE PLASTICS (EDP)

As it was mentioned above, up to quite recent time, acts and regulations concerning environmental protection were lacking in Hungary. Most of the public was more or less indifferent to this issue and companies rather paid the ridiculously low penalty for their activities endangering the environment than introduced measures which would have led to considerable expenses. However, the scientific community understood the importance of environmental protection, and research works on environmentally degradable plastics started relatively early in Hungary. First starch was introduced into polymers as a filler to promote biological degradation (Industrial Research Institute of Organic Chemistry). Similarly to other attempts in the world, these efforts were unsuccessful, they did not result in a commercial product.

In the next stage, blends were prepared from thermoplastic starch (TPS) and polyolefins (Institute of Chemistry, HAS). The research work was done in cooperation with a Swiss company, Fluntera, and it resulted in Fluntera-Plast, a compound still available on the market. Several blends were developed with excellent properties: their mechanical properties reached those of the polyolefins used as matrix materials [4].

The key issue in achieving good properties was compatibilization. Fig. 3a presents a scanning electron micrograph (SEM) taken from the fracture surface of a PP/TPS blend broken at liquid nitrogen temperature. The large spherical particles of TPS and the poor adhesion indicate the lack of interaction between the phases, as well as poor mechanical properties. Compatibilization by maleic anhydride modified PP led to a drastic de-

crease in the particle size of the dispersed phase (Fig. 3b) and to a significant improvement of properties [4].

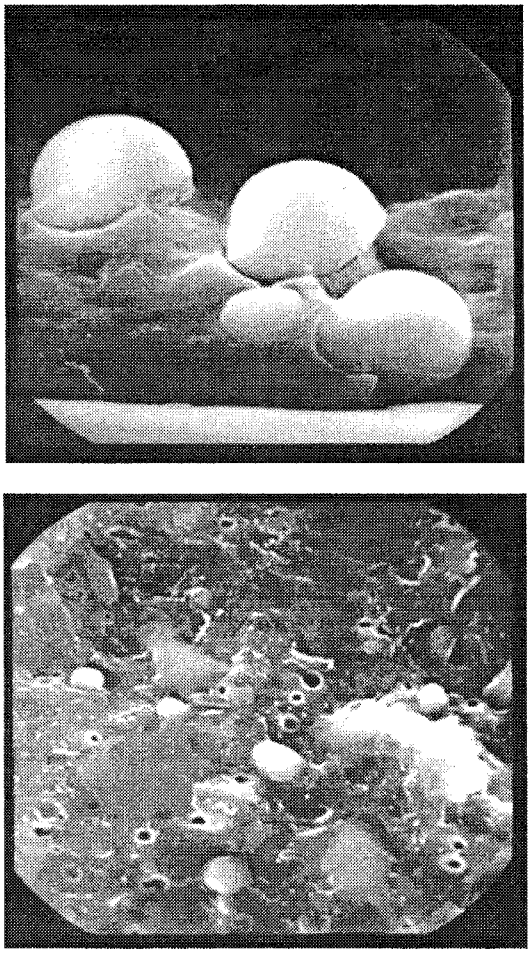


Fig. 3. Morphology of TPS/PP blends: (a) without compatibilizer, (b) with a compatibilizer [4]

The relative tensile strength compatibilized and nonocompatibilized PP/TPS blends as a function of TPS content is presented in Fig. 4. Actual, measured tensile strength was related to the values calculated by assuming additivity in order to facilitate comparison and account for the large difference in component (PP, TPS) properties. As the figure shows, the tensile strength of the blend prepared without compatibilization (curve 1) is very close to the theoretical minimum. This latter was calculated by a simple theory taking into account the influence of relative load-bearing cross-section and interfacial interaction in heterogeneous polymer systems [5, 6]. Compatibilization led to a significant improvement of tensile strength, which surpasses even the additive values at certain compositions. Similar, or even better, results were also obtained by using PE as matrix.

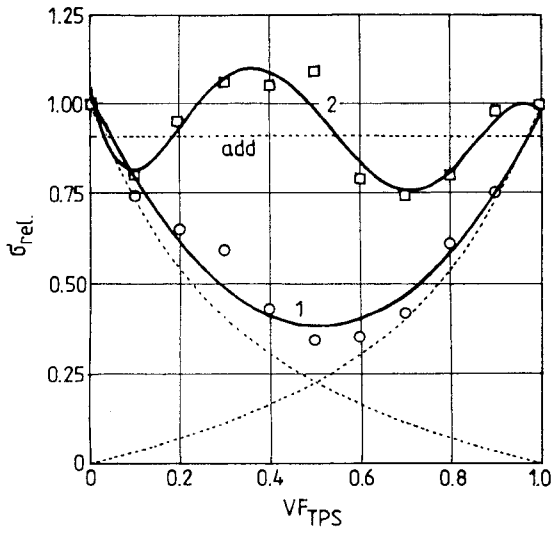


Fig. 4. Relative tensile strength ($\sigma_{rel.}$) of PP/TPS blends as a function of TPS volume fraction (VF_{TPS}): 1 — without compatibilizer, 2 — with a compatibilizer, dashed curves — additivity (add) and theoretical minimum [4]

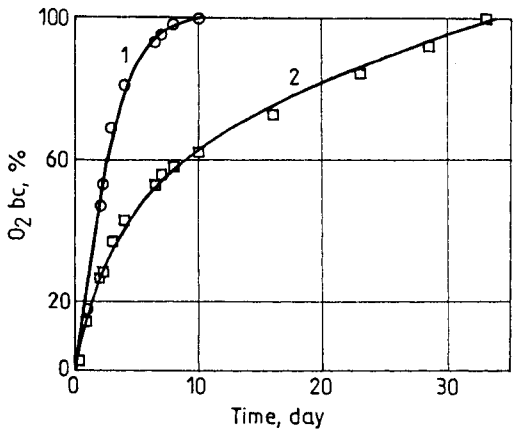


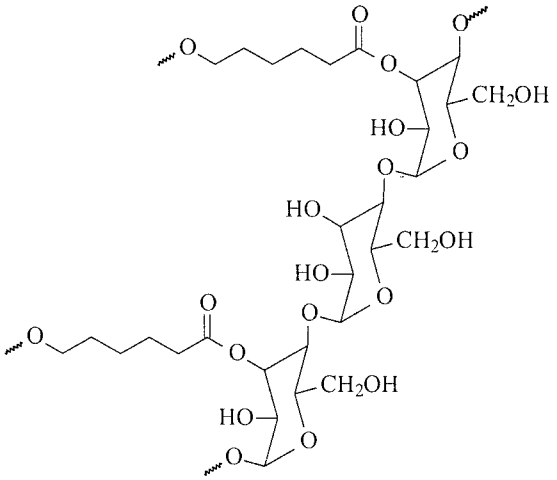
Fig. 5. Biological degradability (relative biochemical oxygen consumption — O_2bc) of TPS/PE blends: 1 — multilayer film (PE/TPS/PE), 2 — powdered sample [4]

Biodegradability of the blends was also checked. The relative biochemical oxygen consumption (OECD Method 301C, modified MITI-Test) during the biodegradation of the starch phase of a PE/TPS blend is plotted *versus* time for two different samples in Fig. 5 [4]. It is clear, that the starch phase degrades completely in less than 40 days. However, the polyolefin component does not degrade this way, which hinders the application of such blends, or even leads to their ban in many countries.

At present, research is done in several institutions to produce EDP in Hungary. At the Kossuth University in Debrecen intensive research is carried out on L-lactide and other natural materials (straw) to prepare environmentally degradable plastics [7—11]. Mostly polyure-

thanes are used in these experiments. Through the proper selection of component ratio and reaction conditions biodegradable thermoplastics and elastomers with wide range of properties can be prepared this way.

At other institutions, starch is chemically modified and the product is combined with aliphatic polyesters (Budapest University of Technology and Economics). Product prepared this way is demonstrated by (I) [12].



(I)

Such products may also characterize with widely varying properties and complete biodegradability. Moreover, direct melt processing offers an economically feasible way for their production. Since Hungary is an agricultural country, further effort will be done to produce L-lactic acid, as well as to use starch and other natural products for the preparation of environmentally degradable packaging materials.

As it was described above, governmental institutions strongly support such efforts. Both the Ministry of Agriculture and the Ministry of Environment launched projects to support such activities also financially. The National Bureau of Technical Development also finances research in this field, *e.g.* the above mentioned project on polyurethanes prepared from L-lactide is supported by this institution. The positive approach of authorities brought some results already after a short time, a few companies seriously consider the introduction of EDP type products into the Hungarian market. These intend to use raw materials available commercially, mostly Mater-Bi (Novamont) and aliphatic polyesters or their copolymers (Ecostar, BASF). Hopefully, the various ministries will coordinate research, development and production of EDPs and Hungarian products will be used by the above mentioned companies soon.

CONCLUSIONS

At present only a limited amount of plastics waste is recycled in Hungary. Mostly agricultural and industrial waste is reprocessed into granulates or low value products. Attempts are made to develop high value products and a plant is built to produce Syntumen in the near future. The other option to decrease amount of plastics waste is the production of environmentally degradable plastics. Considerable research is going on in Hungary in this field. Governmental institutions strongly support such activities, although main effort of everyone involved is concentrated on the research and development work resulting the material which can be used for the production of EDP packaging. The introduction of the tax for plastic packaging gives further impetus to this work. Several companies seem to be willing to take the risk and start the production of EDP packaging materials in the very near future.

REFERENCES

1. Wappel K.: *Műanyag Gumi* 2001, **38**, 237.
2. Szabó F.: *Műanyag Gumi* 2001, **38**, 233.
3. Homepage of the Ministry of Environment. http://www.ktm.hu
4. Tomka I., Müller R., Innerebner F., Pukánszky B., Holló J.: Thermoplastic Starch/Polymer Blends: Structure, Properties, Application in "Proceedings of the Intl. Symp. on Non-Food Industrial Valorisation of Major Crops Products", Apria, Paris 1993, pp. 309—322.
5. Pukánszky B., Turcsányi B., Tüdős F.: Effect of Interfacial Interaction on the Tensile Yield Stress of Polymer Composites in "Interfaces in Polymer, Ceramic, and Metal Matrix Composites" (Ed. Ishida H.), Elsevier, New York 1988, pp. 467—477.
6. Pukánszky B.: *Composites* 1990, **21**, 255.
7. Sipos L., Zsuga M., Deák Gy.: *Macromol. Rapid Commun.* 1995, **16**, 935.
8. Sipos L., Zsuga M.: *J. M. S.-Pure Appl. Chem.* 1997, **A34**, 1269.
9. Sipos L., Gunda T., Zsuga M.: *Polym. Bull.* 1997, **38**, 609.
10. Borda J., Bodnár I., Sipos L., Zsuga M.: *Műanyag Gumi* 1999, **36**, 252.
11. Borda J., Tesléry B., Zsuga M.: *Polym. Compos.* 1999, **20**, 511.
12. Vidéki B., Vargha V., Tomka I., Pukánszky B.: "Compostable Thermoplastic Packaging Materials", paper presented at the UNIDO Workshop on Environmentally Degradable Plastics, Łódź-Pabianice, Poland, June 4—8, 2001.