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Properties and printability of compression moulded recycled polyethylene

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The goal of the research was the determination of the properties and printability of polymeric materials made from the recycled polymers, low-density polyethylene (LDPE) and high-density polyethylene (HDPE). From the primary (virgin) polymers and secondary (recycled) polymers that were obtained from the separately collected fractions of waste packaging, compression moulded plates were produced. The tensile properties of 1 mm and 2 mm thin plates were correlated with some structural characteristics: melting point, melting enthalpy and crystallinity degree. It was determined that the recycling process changes the melting behaviour, lowers the crystallinity and to some extent influences the tensile properties of plates. LDPE and HDPE compression moulded plates were printed with the UV inks on the large format digital UV inkjet printer Océ Arizona. To investigate the printability of plates made from the recycled materials some of their surface properties were determined. Higher optical density, area of ink coverage and dot gain of the printed HDPE plates compared to the LDPE plates are the consequence of higher roughness, higher surface energy with prevailing part of the polar component. By adding 4% of coloured master batch to the recycled polymer at moulding, the uniformity of colour is improved leading to the higher print quality. The results have shown that the digital UV inkjet printing technique could be applied for printing recycled polyethylene plastic materials, used for disposable low cost packaging products.

1. Introduction

Plastics are used in our daily lives in a number of applications resulting also in increasing waste generation rate of plastic solid waste. Recycling is one strategy for end-of-life waste management of plastic products. It makes increasing sense economically as well as environmentally [1]. Increasing cost and decreasing space of landfills are forcing considerations of alternative options for plastic solid waste. There are four main methods of plastic waste recycling [2]: energy recovery (incineration), feedstock recycling (pyrolysis, hydrogenation, gasification), chemical (de-polymerisation) and material recycling.

Material recycling is successfully applied to a single-sort industrial plastic waste. A more difficult task is recycling of post-consumer, in particular municipal, plastic waste. Post-consumer mixed plastic waste consists of a wide variety of polymer types, which originate from an almost random selection of suppliers and processes. The largest fraction of waste consists of polyolefins, such as polypropylene and polyethylene and the remaining components include polystyrene, polyvinylchloride and polyethyleneterephtalate [3]. Nowadays, the mechanical recycling of plastic waste can only be successfully implemented for homogeneous, single polymer streams or for defined mixtures of polymers that can be effectively separated into the individual polymers [4]. There are very few products made from the pure recycled polymers, partly this can be explained because little is known about the recycling process and the properties of collected materials [5]. One aspect that constrains the use of recycled materials is the eventual degradation due to reprocessing, which results in the decrease of properties, mainly mechanical ones and loss of the deformation capability [6]. It has been generally accepted that recycled polymers often show low mechanical properties and are not adequate for structural applications [7]. For this reason their use is limited.

An important fraction of post-consumer plastics discarded in urban waste consist of polyolefin materials, principally low-density polyethylene (LDPE) and high-density polyethylene (HDPE) [8]. Polyethylene is one of the thermoplastic whose reprocessing has been often studied. Earlier studies were dedicated to its degradation on reprocessing, and focused on the effect of specific stabilizers or at predicting the minimum amount of the virgin polymer that must be added to the feed in order to prevent significant loss of properties [9–11]. As polyethylene is relatively stable, degradation is only significant after a number of reprocessing cycles [12]. Study of Chemal et al., where the possibility of

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recycling of polyethylene in relation to its tensile strength exchange ratio was examined, showed that usability of recycled LDPE and HDPE is very high [13]. It was also reported that the tensile and impact strength of both LDPE and HDPE decreased exponentially with reprocessing [14]. In the case of reprocessing of greenhouse films the loss of tensile properties was much higher for recycled polyethylene compared to the virgin polymer [15]. Another study showed that both, the tensile strength and Young modulus increased with the number of extrusion cycles for HDPE and LDPE [16]. From these and other researches can be concluded that the changes in mechanical properties of polyethylene with reprocessing are the consequence of the changes in the structure; if crosslinking reaction predominates than polymer becomes a harder and stiffer material, and opposite, if the scission reaction predominates.

In the present paper some properties of compression moulded plates made from the recycled polyethylene are presented. The research was focused on determination of the printability and print quality of recycled low and high density polyethylene products. Finally, we were interested in mechanical properties of recycled materials in order to determine if the tensile properties of recycled polymers are close to ones of the virgin polymers.

2. Experimental

2.1. Materials and testing methods

Thin plastic plates were compression moulded from 100% recycled low density polyethylene (LDPE) and 100% recycled high density polyethylene (HDPE) chips, produced from the separately collected waste packaging and from the both 100% virgin polymers. Among polymers structural properties melt flow index, softening and melting point, melting enthalpy and crystallinity degree were determined. The melt flow index of resin was determined as the amount of polymer extruded at a temperature of 190 °C with a forcing load of 2160 g in 10 min. The softening and melting point were determined by the visual melting inspection with a Mettler FP84 hot-stage microscopy system. The melting behaviour of the samples in the temperature range from −10 °C to 200 °C was examined at a constant heating rate of 10 °C/min with a Perkin–Elmer DSC calorimeter. The degree of crystallinity was determined as a ratio between the heat evolved during crystallization of sample (melting enthalpy) and the heat of fusion for 100% crystalline polyethylene (293.6 J/g).

Among basic properties of polyethylene plates the thickness and mass per unit area were determined. The tensile properties were measured with an Instron 5567 tensile testing machine. Samples of initial gauge length of 100 mm were stretched at the same rate, 20 mm/min. During the stretching several load and elongation data per second were recorded until break of the sample occurred.

In the next step the printability of polymeric materials was investigated. Because the printability mainly depends from the surface properties of printing material, the surface roughness, coefficient of friction and surface energy were analysed. The surface roughness was determined with an air leak method using the Bendtsen tester (Noviprofibre). The rate at which air passes between the flat plate and test piece surface under the specified conditions is used as a measure of the roughness/smoothness of the sample surface. The profilometric parameters were measured with the Portable Surface Roughness tester TR200. For the characterization of the surface three roughness parameters were taken: the average surface roughness (R_a), root-mean-square deviation (R_q) and maximum height of profile (R_z). The dynamic and static coefficients of friction were determined on the Instron tensile testing machine equipped with the coefficient of friction test fixture testing device. The contact angle and surface energy measurements were performed on a FibroDAT apparatus. Measurements were made with two different liquids: the deionised water and formamide. The contact angles of liquids were measured after 2 s and the surface energy of the top side of plates was calculated with the known surface tension of water (72.8 mN/m) and formamide (58 mN/m).

The surface of polyethylene plates was captured with the scanning electron microscope Jeol and optical microscope Leica EZ 4D equipped with a CCD camera. With the densitometer GretagMacbeth D19C the optical density of plastic plates and with the spectrophotometer GretagMacbeth Coloreye XTH the colour of plates was measured.

2.2. Printing and evaluation of prints

Plastic plates were printed using the UV curable inks based on pigments produced by Fujifilm Sericol in a flatbed large format digital inkjet printer Océ Arizona 250 GT. Printer Océ Arizona has 8 printing heads, 2 for each colour. It uses piezoelectric inkjet technology with the Océ VariaDot™ (the drop volume from 6 to 42 pl) imaging technology. Samples are fixed with a vacuum table, which holds printing media stationary for precise printing. For printing a printing test form was prepared with the cyan (C), magenta (M), yellow (Y) and black (K) solid colour patches and the text, a number printed with the black ink.

The optical density of CMYK solid colour patches was determined with the densitometer GretagMacbeth D19C, and colorimetric properties with the spectrophotometer GretagMacbeth Eye-One (D50 standard illumination, 2° standard observer, 45/0 measurement geometry). The printed samples were evaluated first visually and then the pictures captured with the optical microscope Leica EZ 4D equipped with a CCD camera, by image analysis. For the evaluation the ImageJ program was used.

3. Results and discussion

3.1. Properties of resins

As the knowledge about resin properties is the basis of the product development, the starting point of our research was the determination of its properties: melt flow index, softening and melting temperature, melting enthalpy and crystallinity degree. Results are given in Table 1.

The melt flow index (MI) is defined as the weight of polymer extruded through a specific die in 10 min under standard conditions of temperature and pressure, and is the main rheological information of resin given by the producer. It is a measure of the ease of flow of the melt and can be identified with the manufacturing process. A lower MI value, means higher viscosity of the melt. As both tested resins, LDPE and HDPE, have low MI value this indicates that they are suitable for the blow moulding and blow extrusion, film casting and thermoforming. Knowing the MI of a polymer is vital to anticipating and controlling its processing. As both recycled polymers have the same MI values as virgin polymers, similar processability can be expected. Though, this can be misleading. Two polymers of similar MI can have different viscosities at high share rates because of different molecular weight distribution or branching and consequently their processing behaviour may be quite different [17].

The thermal behaviour of resins was examined in order to obtain further processing characteristics. For the recycled LDPE resin a higher softening and melting point with broader endothermic peak compared to the virgin LDPE resin was obtained, whereas at the HDPE resins the opposite behaviour was observed. The