Investigation on the friction coefficient of the composite materials obtained from plastics wastes and cellulosic fibers

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The samples studied in the present paper were obtained by melt mixing different density fractions separated from Municipal Solid Wastes Plastics [MSWP] coming from Urban, Brasov, Romania collected from the central part of Romania, (Brasov County), in September 2010 – used as polymeric matrix; cellulosic fibers Chitcel [CC], purchased from Shandong Textile Sci. and Tech. Co. Ltd, China – used as filler; Irganox 1076 (Ciba) as thermal stabilizer, and PO-g-MA (Sigma Aldrich) as compatibiliser. Virgin polyolefin/CC fibers composites were obtained in the same conditions. Because these composite materials can be used in applications requiring mechanical friction, this paper presents determination of static coefficient of friction on flat surfaces. The selection of polymeric composites from waste as materials for sliding components of machines and devices is a very important aim for tribologists as well as tribological behavior of non-polymer-on-polymer tribosystems. The best tribological combination confirmed practically is steel on polymer; therefore the tests were done in this combination. The testing machine is a high precision tribometer with prisms, including two plane semi couples, one fix and the other one mobile. The tribometer worked on the principle of the inclined plane. Humidity and temperature values during determinations were also recorded. The lowest friction coefficient was obtained for the polymer material obtained from municipal solid waste recycling (23.103%PP, 72.862%PE, 1.329%PS and 0.207%PA), 2%cellulosic fibers and 0.5% Irganox. The results have led us to propose the use of these materials for industrial applications in the FP7 project "Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefins from Waste".

(Received March 25, 2013; accepted July11, 2013)

Keywords: Friction coefficient; Polyolefin composites; Tribology; Recycling

1. Introduction

Between 2009 and 2010 the global production of plastics increased by 15 million tons (6%) to 265 million tons, confirming the long-term trend of plastics production growth of almost 5% per year over the past 20 years. In 2010, Europe accounted for 57 million tons (21.5%) of the global production and China overtook Europe, as the biggest production region, at 23.5% [1]. The growth of different plastic types production varied in 2010, the first two places being taken by PP and PE. Taking into account the existing global and European data regarding the polymers production, the annually resulting polyolefin waste is impressive. Because of these reasons the authors team participate in an international project focused on building industrial equipment able to develop cost-effective and clean technology based on Magnetic Density Separation (MDS) and Ultrasound process control in order to recover and to separate high-purity secondary polyolefin from complex wastes (PP and PE) using a magnetic fluid. To improve the polyolefin waste using it is necessary to obtain composites materials with different types of composition. Polyolefin's composite materials domain is very large due to the multiple combination possibilities that have developed over the years.

Because these composite materials can be used in applications requiring mechanical friction, this paper presents determination of static coefficient of friction on flat surfaces. The selection of polymeric composites from waste as materials for sliding components of machines and devices is a very important aim for tribologists as well as tribological behavior of non-polymer-on-polymer tribosystems. The best tribological combination practically confirmed is steel on polymer; therefore the tests were done with this system. Based on research of [2], [3] and [4], Z. Rymuza presents for non-polymer-on-polymer contacts in [5] that mechanical and adhesive interactions are located in the very thin surface layer of polymer being in frictional contact. The ratio between mechanical and adhesive component depends in particular on roughness of the counter-body. The coefficient of friction is usually very high at small roughness because of high adhesion, and it decreases down to minimum value at increase of roughness and then increases at further increase of roughness when mechanical component of friction force becomes very high. The similar tendency was confirmed also experimentally in the case of wear rate. But the minimum value of friction coefficient, wear rate, and also the shape of the characteristic curves are fairly similar. In conclusion, the polymeric tribosystems can operate without lubrication. Very wide possibilities to modify polymeric materials by fillers, lubricants and many other additives give very good perspectives to find polymeric composites that show excellent tribological properties both as matched with non-polymer or with another polymeric component.

As Georgescu comments, generally the additions of reinforcement and/or lubricating materials improve the tribological behavior [6]. The additives with lubricant role cause the decrease of surface energy and also the decrease of material resistance due to the weak joining. The reinforcement materials increase the polymeric tensile strength but can drastically modify the surface roughness. So, the friction coefficient could increase, also the surface roughness, but the protective and uniform transfer film will no longer form. Not all additives in the polymers composition enhance the matrix characteristics. For example, in certain conditions, the presence of fibers causes the wear deterioration. Evans and Lancaster note that the fibers additions in polymers generally have benefic effects on the wear but seldom produce the decrease of this property [7]. An increase of other characteristics was observed: decrease the deformation under the load without affecting the conformability, sometimes the friction coefficient is smaller and constant; some additives facilitate the quick heat removal [8]. The huge interest and the polymeric composites consumption in recent years highlight the limits in properties optimization [6], [9], [10].

N. K. Myshkin and A. V. Kovalev evidenced that in the range of moderate loads of 0.02 to 1 N the friction coefficient decreases with load increase [11]. Such behavior may be explained by the elastic deformation of surface asperities. Also, theoretically, the friction force should not depend on the sliding velocity. For polymers, however, this statement is true only if the temperature within the contact area has negligible increase. Usually there is a complex dependence of the friction coefficient on the velocity explained by variations in the relaxation properties and physicochemical activity of macromolecules.

A.S. Pouzada et al. consider that in injection molds an important factor arising from the model is that the static coefficient of friction between the plastic and metal surfaces in contact is greatly influenced by the surface roughness, contact temperature and some processing variables, such as cooling time, melt temperature and holding pressure [12]. The comparison between experimental data and simulation suggested that substantial errors could derive from not using a coefficient of friction adjusted to the actual processing conditions.

As V. Quaglini and P. Dubini remark in [13], it is generally accepted that at low and medium pressure levels plugging of a polymer on smooth metal surfaces can be neglected [14], [15], and friction is explained in terms of the adhesion mechanism only.

H. Jiang, R. Browning et al. studied the effect of Ra and contact load on µs of a set of model TPO systems. Their conclusions were that the findings show that µs increases when contact load increases or Ra decreases. However, the effect of Ra becomes less significant under higher contact loads [16].

The progress in engineering will provide many new opportunities in applications of plastics, and new research in their mechanical and tribological behavior will be a challenge to science and technology.

Because these composite materials can be used in applications requiring mechanical friction, this paper presents the obtained values of static coefficient of friction on flat surfaces, between polyolefins matrix based composites and steel..

The aim of this paper is to check the possibility of replacing in specific applications the virgin PP based composites by composite materials obtained by using second raw materials coming from polymeric wastes.

2. Sample preparation

2.1. Materials

The materials used in this research are composites materials. Pure polyolefins and POs resulting from waste recycling, additives and filler materials (fig.1.) have been used in order to obtain them. The characteristics of virgin polyolefins are presented in table 1.

Mixed polyolefins waste with different polyolefin content, resulted from municipal solid waste polymers (MSWP) collected by Urban Company in September 2010 from Brasov County, Romania. Five charges, each of one kilo weight have been collected.

Taking into account that the municipal solid waste represents a mixed plastics type, it is necessary to perform selective separation to increase its value.

The separation method was flotation in different densities solutions. The separation solutions were: water (ρ=0.997 g/cm^3), ethyl alcohol: water (ρ=0.788 g/cm^3; 0.880 g/cm^3; 0.908 g/cm^3; 0.923 g/cm^3; 0.935 g/cm^3; 0.964 g/cm^3), aqueous solution of: NaCl, Na_2CO_3 (ρ=1.0053 g/cm^3; 1.1029 g/cm^3; 1.1469 g/cm^3; 1.197 g/cm^3; 1.27 g/cm^3).

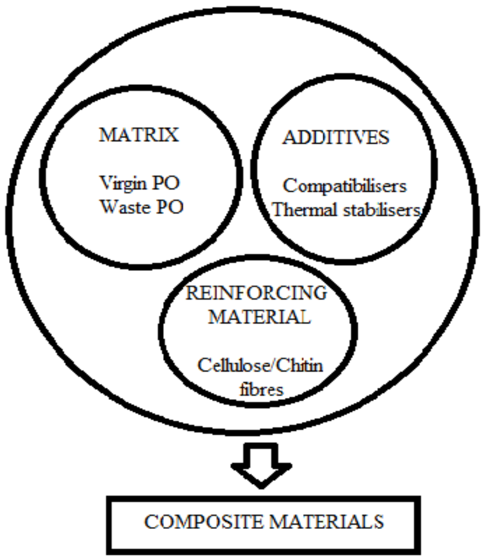

Fig.1. Samples composition

Table 1. Virgin polyolefin characteristics.

Mat. type	Commercial denomination	Producer company	Material characteristics
PP - homo poly mer	Lupolen 3010 D	Lyondell Basel Ind.	Softness index (190°C; 2.16kg)=0.25g/ 10 min; ρ=927 kg/m^3

Before the separation MSWP was washed, frozen and shredder.

For the research, it was considered the polyolefins materials with the density between 0.8848 and 0.964 g/cm^3 from the MSWP.

The smaller or greater density fraction than considered interval mentioned before were classified as contaminants of polyolefinic waste.

Table 2. Thermal stabilizers and coupling agents used for composites materials

Additive type	Commercial denom.	Producer company	Function in composite
Octodecil 3 (3,5-ditertbutil-4-hidroxifenil) propionate	Irganox 1076	Ciba	Thermal stabilizer
Polymer graft with maleic anhydre	PP-MA	Sigma Aldrich	Coupling agent
Vinil trietoxi-silan	VTS	Fluka	Coupling agent

After separation there were obtained 13 density fractions, but the research was focused to the following density fractions: W3: ρ3 = 0.884 – 0.908 g/cm^3, W4: ρ4 = 0.908 – 0.923g/cm^3, W5: ρ5 = 0.923 – 0.935g/cm^3 and W6: ρ6 = 0.935 – 0.964 g/cm^3, taking into account that only these fractions include polyolefins. Identification and quantification of the components were performed by combining gravimetric method with spectral analysis (FTIR ATR), image processing with Adobe Photoshop CS5 package, and Essential FTIR data base use. As filler material, cellulosic fibers modified with chitin, acquired from Shandong Helon Textile Sci. & Tech. Co., Ltd. China (Mainland), on commercial denomination Chitcel has been used. As additives, thermal stabilizers and coupling agents have been used (Table 2).

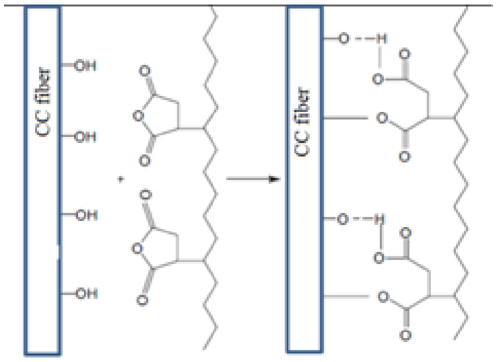

Fig. 2. Coupled mode of compatibilizing agents modified with maleic anhydre, on cellulosic fiber [17-19].

The coupling agents have a double role, on one hand to ensure a proper interface between the components of the polyolefins density fractions and on the other hand to provide the best interface between matrix and fibers (figure 2).

2.2. Getting composite materials

The samples are composite materials with virgin polypropylene (PP) matrix (table 3, first four samples), polyolefins from MSWP no separated waste, density fractions 0.884-0.964g/cm^3 (table 3, last four samples), CC fibers as filler material, according to table 3.

The composite materials were obtained at “Petru Poni” Institute of Macromolecular Chemistry Iasi, Chemistry Department from Transilvania University of Brasov and Department of Polymer Engineering from Budapest University of Technology and Economics. All details are presented in [20].

Table 3. Samples composition.

Code	PP %	PE %	PS %	PA %	CC fibers %	Irganox 1076 %
PP	100	-	-	-	-	-
PP2C	97.000	-	-	-	2	0.5
PP10C	89.000	-	-	-	10	0.5
PP30C	69.000	-	-	-	30	0.5
W_{3-6}	23.577	74.356	1.356	0.211	-	0.5
W_{3-6}2C	23.103	72.862	1.329	0.207	2	0.5
W_{3-6}10C	21.207	66.883	1.220	0.190	10	0.5
W_{3-6}30C	16.468	51.937	0.947	0.147	30	0.5

For each sample, the difference up to 100% is the addition of thermal stabilizers and compatible agents.

One stage of the obtaining process is desiccating at 60-80°C, 2 hours drying chamber maintaining, followed by cryogenic frozen and shredder in ZM 200 centrifugal mill, in the polyolefins waste case. For a better intermixing, the particles dimensions are 0.5-1mm. The mixing process and the obtaining of the samples are presented in [20]. After cooling and shredder operations, followed the pressing process in a mold using a Collin hydraulic press. The dimensions of the laminas were L x l x h: 150 x 150 x 1 mm.

2.3. Friction coefficient determination

Taking into account that elaborated composite materials presented above will be able to be used-up in practical applications, it was considered needful to define de friction coefficient. 1N load was the pressure force on a sample with the dimensions 20x20mm (figure 3).

Fig. 3. Samples dimensions for friction coefficient

Fig. 4. Calibration of the roughness checker

3. Operating method

To determinate the friction coefficient it was used a testing machine-a high precision tribometer with prisms, including two plane semi couples, one fix and the other one mobile. The tribometer worked on the principle of the inclined plane and measure the angle hereupon the sliding phenomena go on. All details concerning the method and the equipment are presented in [21]. This principle consist of correlation between slope angle α and friction coefficient μ ($tg\alpha = \mu$). It is possible to define the static friction coefficients (which appear on the borderland between removal and repose). The friction sheet, part of the ensemble polymer-metal, is steel, because this is the best tribological combination confirmed practically. Each friction coefficient value represents the average of 20 tests on each sample.

Fig. 5. The parameters calculated with Surtronic 25

Fig. 6. Friction coefficient determination in progress

The surface roughness was measured using a Surtroni 25 surface roughness tester (Taylor Hobson) [22]. Ra is the arithmetic mean of the absolute departures of the roughness profile from the mean line. The unit contains a drive motor which traverses the pickup across the surface to be measured. The measuring stroke always starts from the extreme outward position. At the end of the measurement, the pickup return to this position ready for the next measurement.

Firstly, the calibration of the instrument checker (figure 4) has been done. The Surtroni 25 stylus can traverse up to 25mm (or as little as 0.25mm) depending on the component. The Gauss filtered measurements were done for an evaluation length of 4 mm (figures 5 and 6). Four measurements on each surface have been done and the average values of Ra were recorded.

4. Results and discussion

The roughness of the steel sheet is 0.34 μm in the sliding direction of the sample. In table 5, the obtained values of the friction coefficients of materials are very close.

The addition of the microfibers up to 30% decreases the samples roughness thereafter is identified an increasing of the value. This indicates active participation of polymer matrix fibers in the mixing process. The full effect is exerted in the waste matrix with complex composition. At high concentrations of fibers, their possible agglomeration leads to increase the material roughness.

Table 5. Values of μ and Ra for PP and W_{3-6} serie. s

Code	Average μ	Standard deviation μ	Ra [μm]
PP	0.369	0.022	1.175
PP2C	0.344	0.022	1.155
PP10C	0.340	0.026	0.980
PP30C	0.366	0.035	1.280
W_{3-6}	0.369	0.023	1.350
W_{3-6}2C	0.313	0.053	1.070
W_{3-6}10C	0.352	0.040	0.980
W_{3-6}30C	0.332	0.034	1.195

Although variations in roughness shall attract variation of the friction coefficient, the obtained last values are negligible.

This is possible to be explained by a compensatory effect that could be exertion by the variations of other materials characteristics that influence the friction process and consequently the friction coefficient. These include: changing the surface energy of the samples due to compositional differences between samples, material rigidity changes due to crystallinity changes of adding fibers as well as cross linking reactions or fibers transfer that occur both, during the life cycle of materials from waste as well as a result of their thermal processing. Some of these data are presented in other papers [23]. Practical applications of materials obtained from waste must involve a careful assessment of all their properties and their correlation, in order to optimize their composition for specific applications.

4. Conclusions

This study reveals that the use of polyolefinic waste fractions separated from municipal solid waste polymers, as such, as a matrix for fiber composites can successfully replace polypropylene and its fiber composites in applications involving friction processes.

The study will continue by testing materials with higher fiber content in order to controlled modify the friction coefficient of materials for specific applications.

Also, the correlation of friction coefficients with other composites properties obtained from waste and establish the role of contaminants, remains a goal of future research.

Acknowledgement

This research was funded by FP7 Grant 212782, „Magnetic Sorting and Ultrasound Sensor Technologies for Production of High Purity Secondary Polyolefin's from Waste", acronym W2P Plastics.

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