23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

UHMWPE/PET BLEND: DEVELOPMENT, MECHANICAL AND MICROGRAPHYC CARACTERIZATION

Ivis Fernanda Teles Alves Melgaço
Alexandre Rangel de Sousa
Centro Federal de Ensino Tecnológico de Minas Gerais; Av Amazonas 5253, Nova Suissa, Belo Horizonte, Minas Gerais
ivisfernanda@gmail.com
rangelrs@yahoo.com
Helias Raphael Teles Alves
Centro Federal de Ensino Tecnológico de Minas Gerais; Av Amazonas 5253, Nova Suissa, Belo Horizonte, Minas Gerais
helias.raphael@gmail.com

Abstract. *The This study aimed to develop blends by mixing polyethylene of ultra-high molecular weight (UHMWPE) with poly (ethylene terephthalate) (PET), processed by thermal compression to obtain the mechanical properties of tensile strength , impact and wear. With molar ratio of 8.0 x106 g/mol mass and the other with 3.0 x106 g/mol, molar mass of the influence on the mechanical properties of the blends using two types of UHMWPE was also evaluated. Samples of the blends were produced with the following proportions of the two polymers: 90% PEUAPM/10% PET, 80% UHMWPE/PET 20% and 70% PEUAPM/30% PET. The addition of PET in the blend leads to a decrease in the properties of tensile strength, elongation at break, toughness and resilience compared to the pure UHMWPE. The higher molar mass of UHMWPE (A) had a percent reduction in the tensile at break values lower than the lower molar mass blend (B) by the addition of 20% PET. The elongation at break showed a marked reduction for the two molar masses, with no significant difference between them. In impact tests performed, there was no disruption of the specimens, samples subjected to mechanical wear test showed no significant mechanical wear.*
Keywords: *UHMWPE, PET, Blend*

1. INTRODUCTION

The polymer blends are the fastest way in polymer science to generate high-performance commercial materials from other commercially available. Most polymers do not form fully miscible blends, but even heterogeneous or immiscible blends combine important features of the constituents. Combining properties of the different components results in materials which can have high mechanical strength, low permeability to water and oxygen, opacity and other characteristics which make them extremely interesting for many applications. Other advantages as a single process operation, recyclability and low capital investment for manufacturing, compared to the synthesis of new polymers, are also found. They are increasingly used in packaging industries, particularly replacing packages which use multiple layers (DEMARQUETTE, 1997; AGRAWAL et al, 2008).

The ultra-high molecular weight polyethylene (UHMWPE), is considered a polyolefin engineering plastic with high performance applications, has a molar mass about 10 times compared to high density polyethylene (HDPE). Its long molecular chain without branching, with high degree of crystallinity, and gives the UHMWPE wear resistance properties and impact resistance superior to other polymers. Its use in large mechanical stress is vast, ranging from the area of biomaterials for implants, the area of mining equipment and filter coatings (COUTINHO et al, 2003). Polyesters such as polyethylene terephthalate (PET) are among the most consumed thermoplastics and available in large quantities from domestic disposal, making this polymer a technological and environmental challenge for their correct recycling and mechanical characterization. The ultimate goal is to enable a new cycle of life in the form of new products. A viable option for recycling the recycled PET is mixing it with other polymers to produce blends (MARCONCINI, 2006). To date, there were no references in the literature on the blend of UHMWPE and PET with a higher proportion of UHMWPE. The known immiscibility of these polymers is possibly because of lack of data for this specific ratio. Marconcini and Ruvolo (2006) indicate this immiscibility between polyester (PET) and polyolefins (UHMWPE), pointing out that it verified a low adhesion and high interfacial tension with gross separation of phases which reduces the mechanical properties of the blend.

The objective of this study is to evaluate the mechanical properties of the material or polymer blend of ultra-high molecular weight polyethylene -PEUAPM - with the addition of poly (ethylene terephthalate) -PET this to a lesser extent. It will also be assessed whether there is any influence of the value of the molar mass of the polymer, to a greater extent, in the mechanical properties of this material.

2. MATERIALS AND METHODS

It was used to carry out this work the following polymeric materials:

- Ultra-high molecular weight polyethylene (UHMWPE) with two average molar mass values:
  - 8.0 x106 g / mol
  - 3.0 x 106 g / mol
- Poly (ethylene terephthalate) (PET) derived from soft drink bottles discarded.

The UHMWPE was purchased in powdered form, such as commercially available for processing by thermal compression (compression then heating).

It was found on the market, until the time of this research, PET in powder form. Its most common processing involves injection using pellets (grain from the extrusion) or chips of material cut by knife mills (commonly used for recycling). Therefore, the PET from green and colorless bottles was processed in a grinder to obtain a powder and then sifted on a standard stainless steel sieve ASTM 40 / MESH / 35 TYLER (Opening 0,425mm). This sieve aims only to disposal of large pieces, which prevent their dispersion into the UHMWPE matrix, in accordance with the desired proportions in this work. It was not used compatibilizer this research, since only products in the form of pellets on the market were found, which would make their dispersion in the UHMWPE matrix unfeasible in the necessary proportions. A possible injection processing and further grinding were also eliminated, since the thermal reprocessing of the compatibilizer would be considered a new variable in the process.

Using PET adding in the percentages of 10%, 20% and 30%, the two materials (UHMWPE and PET) were blended by mechanical stirring and then thermally processed. Below are explained the conditions of thermal processing compression:

- Temperature: 270°C
- Load: 5 tons
- Degassing (load removal for steam output): 9 - 15 minutes
- Total processing time: 30 minutes
- Cooling: removed from the press and cooling in water at room temperature.

The following tests were performed in this study:

• Tensile test: Five samples were tested (specimens) of each blend. Tensile tests parameters: samples into rectangular strips of size 10X50X2 [mm], 24°C temperature, test speed 10mm / min. The equipment used was the Shimadzu AG-X 10N-10kN. Data obtained: both stress and strain at break, resilience and toughness.

• Scanning Electron Microscopy (SEM): The analysis via SEM, the polymer samples proposed in this study is the fracture surface after tensile test. The fracture surfaces of a specimen of each blend has been subjected to tensile test were analyzed. The metal surface coating of the sample used was gold deposition for 10 minutes and 3mA current. SSX 550 Shimatdzu equipment.

• Izod impact: Were subjected to the test five samples (specimens) of each blend as well as the pure samples of UHMWPE. Parameter tensile tests: samples in size rectangular strips 10X50X2 [mm], 24°C temperature, notch with 2mm depth, speed 3.5m / s, 9J pendulum. Izod type test. XJ-equipment 25Z / 50Z Series Impact, Time Group Inc.

• Wear test: The main feature of PEAUPM is its resistance to abrasion. For this work, it was designed and developed by the author, a prototype equipment wear test on laboratory scale (Figure1). This equipment is an alternative way to the common high-cost implementing methods. This principle is similar to the Los Angeles abrasion method. That is, rotating drum for accommodating abrasive environment and test samples. They were tested as a sample of each blend. Test conditions: 18 hours long, drum rotation 75rpm, abrasive sand slurry environment (300g sand and water 600ml) and room temperature (approximately 25°C). The evaluation procedure used was gravimetric (mass change): Drying of the samples for 2 hours at 65°C and subsequent weighing prior to testing; after the test has been performed the second stage of drying (also at 65°C for 2 hours) and weighed.

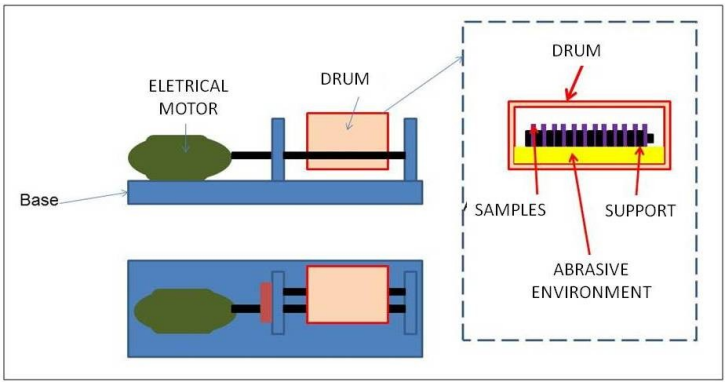

Figure 1: Wear test sketch

2.1 Results

2.1.1 Tensile Test

Figure 1 shows the tensile curves of the two pure UHMWPE used in the current study, which have molecular weights: A equal to 8.0 x 106 g / mol and B equal to 3.0 x 106 g / mol. It is observed that the tension versus deflection curves for the pure samples presented higher values of stress at break and strain at break than those established by the manufacturer (30MPa / 300% for A and B). This shows that the sample processing by thermal compression does not compromise the properties of the polymer.

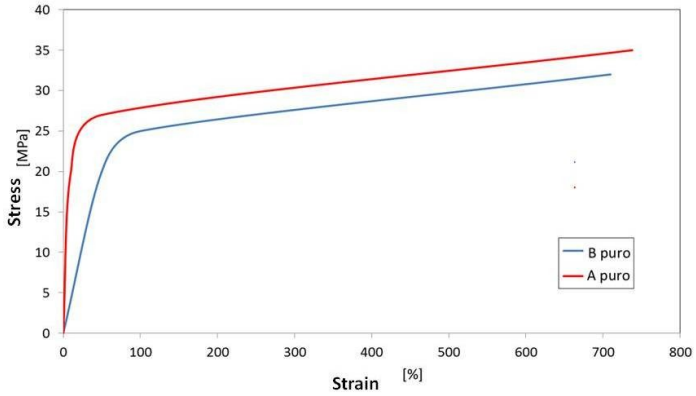

Figure 1: Tensile test results of the UHMWPE pure A (higher molecular mass) and B (lower molar mass)

Figure 2 shows the results of tensile tests of the blends UHMWPE and PET. It was observed that the higher the percentage of PET added, the greater the reduction of stress and strain at break. Regarding the influence of the molecular mass, the higher molar mass UHMWPE (A) provides a percentual reduction in the stress values at rupture less (23%) than the lowest molecular weight (B) (25%) until the percentage of 20% PET in the blend. For strain values at break, the reduction was sharp (98%) for the two molecular masses, with no significant difference between them.

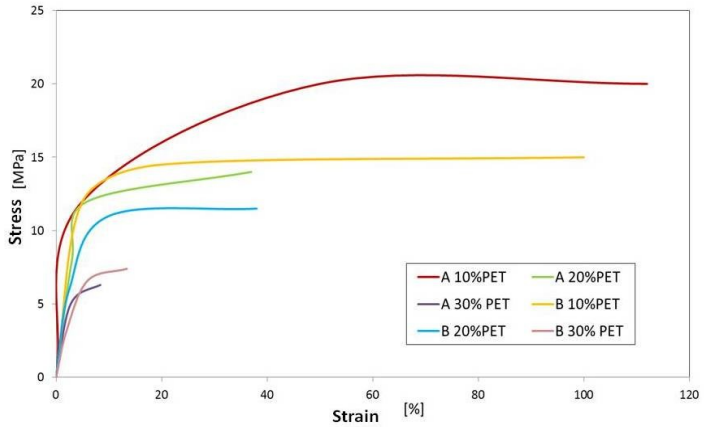

Figure 2: Results of tensile tests of the blends UHMWPE / PET

Figure 3 shows the percent changes of the data regarding stress at break and strain at break of the UHMWPE A (higher molecular mass) compared to pure UHMWPE.

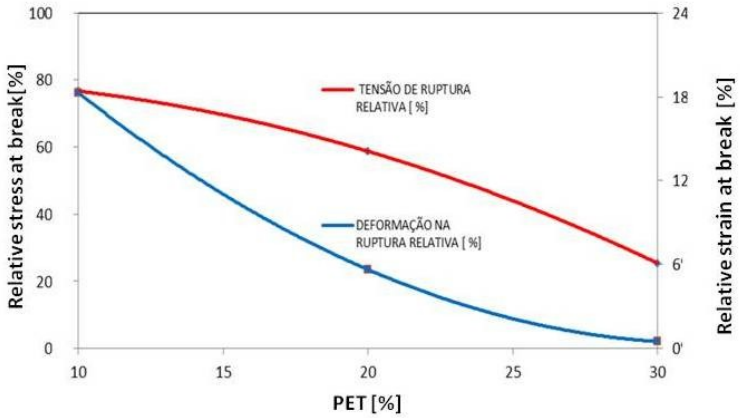

Figure 3: Graph of the results regarding relative stress at break and relative strain at break for the blends with UHMWPE A.

The blends made by UHMWPE - A (higher molecular mass), has a consequent reduction in properties of stress at break and strain at break compared to pure UHMWPE. Figure 4 shows these same properties for the blends formed with the UHMWPE - B (lower molecular mass). It is also observed a reduction in the value of these properties with the addition of PET in the blend.

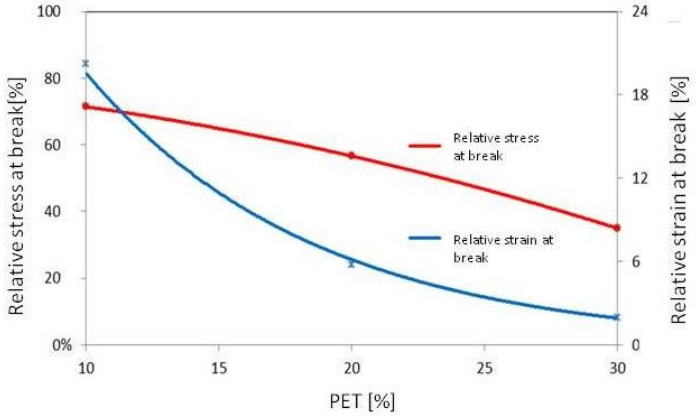

Figure 4: Relative stress at break and strain at break for the blends with UHMWPE B

Table 4: Values of standard deviation for stress and strain, both at break

	Stress at break [N/mm^2]		Strain at break [%]	
	Blends with UHMWPE B	Blends with UHMWPE A	Blends with UHMWPE B	Blends with UHMWPE A
10%PET	9,02	1,12	19,8	18,35
20%PET	0,53	2,30	12,82	0,53
30%PET	2,19	1,35	2,47	1,75

Turchette and Felisberti (2000) report that the higher the molecular mass, the lower the miscibility of the blends. In this study the blend UHMWPE / PET comparing the two types of molar mass of UHMWPE used, the reduction in mechanical properties, is lower for polymer blends composed of the molar mass of UHMWPE most up to 20% added of PET. Between 20% and 30% addition of PET, the smallest reduction in stress and strain properties, both at break, are found to blends formed with the UHMWPE - B (lower molecular mass). Table 4 shows the calculated resilience values (area under the average stress-strain curve in the elastic regime) and toughness (total area under the stress-strain curve of the average value) of the blends as well as the A and B pure UHMWPE.

Table 5: resilience and toughness values to pure UHMWPE A and B and blends UHMWPE / PET in their ratios of study.

	B				A			
	PURE B	10% PET	20% PET	30% PET	PURE A	10% PET	20% PET	30% PET
RESILIENCE [MPa]	0,75	0,7	0,55	0,2	8,8	0,4	0,59	0,042
TOUGHNESS [MPa]	140,22	14,2	3,63	0,69	208	18,8	4,6	0,28

The resilience and toughness values were also cut with the addition of PET. The resilience and toughness are dependent on the morphology of the blends. The immiscibility between UHMWPE PET and generates a low interaction between phases and consequently increases the brittleness of the formed blend (PASSADOR, 2006). The lower values of strain at break and stress at break, compared to those shown for pure UHMWPE B and A, bring result in low toughness and resiliency of the blend. To resilience was presented a reduction of up to 71% (70% B UHMWPE / PET 30%) and 99.5% (70% UHMWPE / 30% PET). The toughness was reduced to 99.5% (70% B UHMWPE / PET 30%) and 99.8% (70% UHMWPE / 30% PET).

2.1.2 SEM analysis of the blends microstructure

The UHMWPE / PET blends submitted to the tensile test, as well as pure samples of UHMWPE A and B, had their morphology analyzed via scanning electron microscopy. Figure 5 shows the images obtained by SEM of the pure UHMWPE samples A and B.

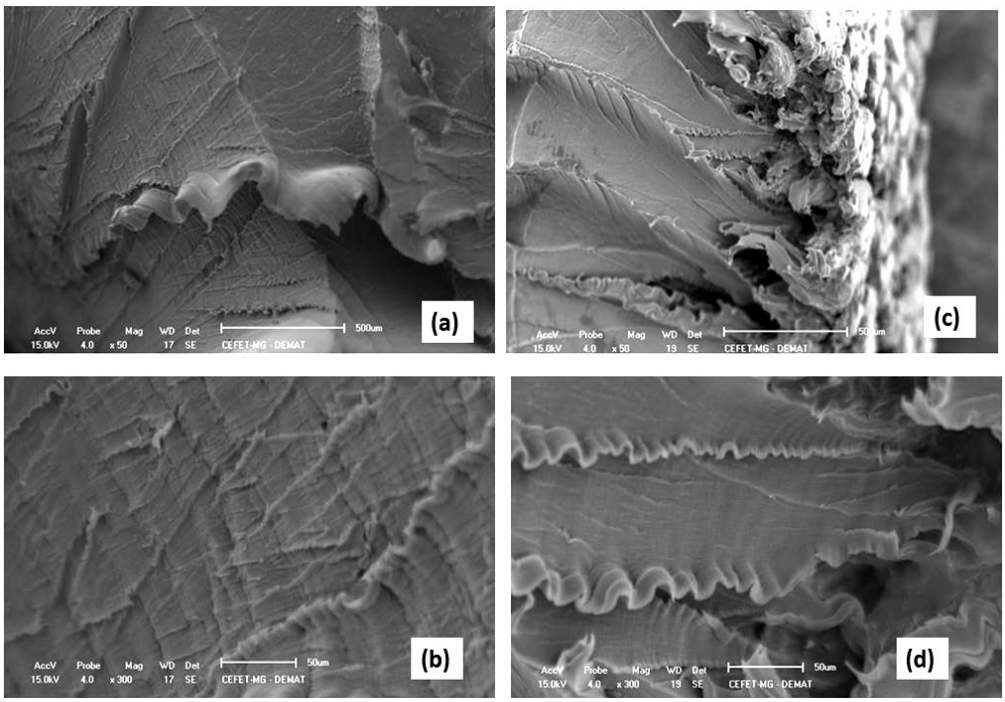

Figure 5: Images obtained by SEM of the pure UHMWPE samples (a) and (b) with lower molecular mass - B, (c) and (d) with a higher molar mass - A.

Figure 5 is a structure observed in the form of triangular blades with ridges on the edge. Probably this format due to the sliding and drawing of layers of UHMWPE (triangular blades) to its breaking (crests). The images also showed a layer (0.5 mm) of a porous structure on the external surface of the blend, Figure 5 (c). This is a higher concentration of UHMWPE in the metallic mold manufacturing background. This concentration is also observed macroscopically in the plates produced, characterized by a white color located in its lower surface, ie the surface that was in contact with the

lower metallic mold. This can feature an irregular heating process of the press, which preferably occurs in the upper block , and with greater effect on polymer A, for all samples, possibly due to its higher molecular mass. Figure 6 shows the SEM images for the blend composed of (a) UHMWPE B / 10% PET; (B) The UHMWPE / 10% PET.

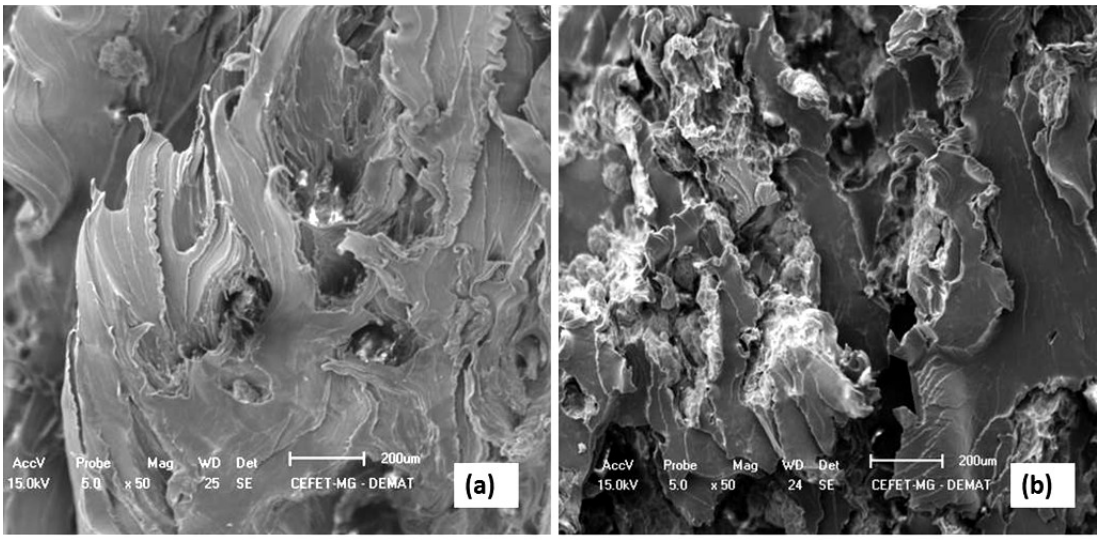

Figure 6: Images obtained by SEM of samples of the blends: (a) UHMWPE B / 10% PET; (B) UHMWPE A / 10% PET.

Are observed in these images, the structures of triangular shaped blades with edge ridges similar to those shown in the pure polymers (UHMWPE Figure 5 A and B). Additionally, they are shown embedded grains, possibly dispersed PET in the UHMWPE matrix. Specifically, Fig. 6 (b) contains a structure with fewer crests that of Figure 6 (a) and more porous regions are likely generated by tearing of the PET pellets during the tensile test. Figure 7 shows the images for the blends in other PET ratios for UHMWPE A and B.

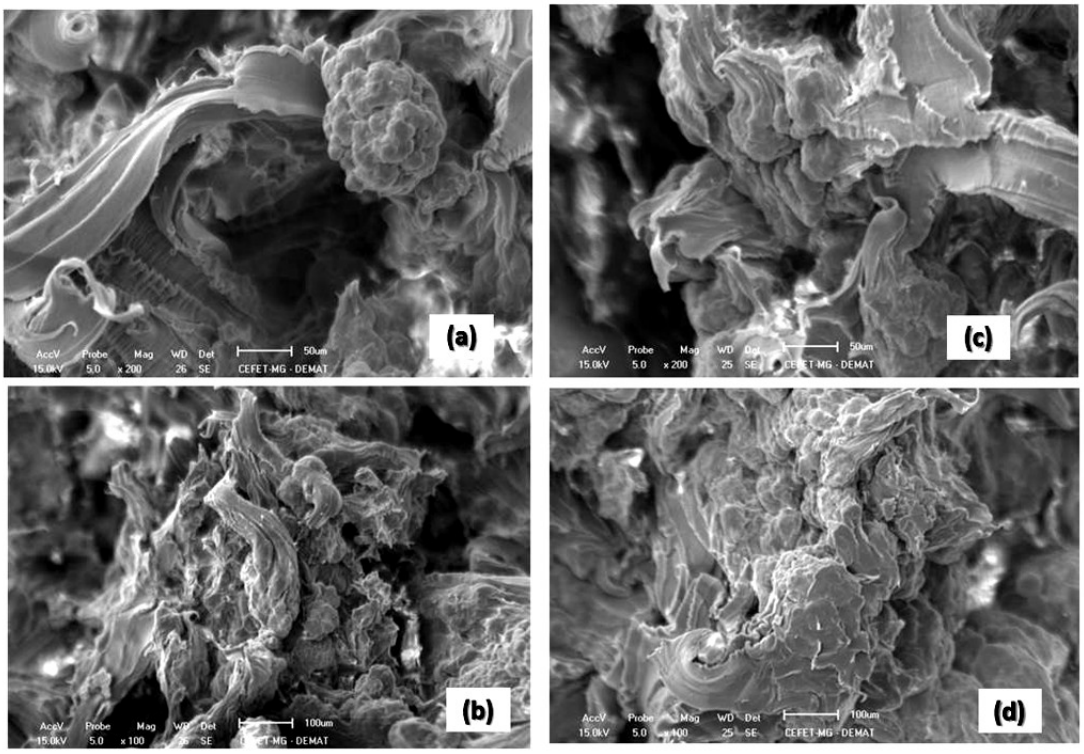

Figure 7: Images obtained by SEM of the blends samples: (a) UHMWPE B / 20% PET; (B) UHMWPE B / 30% PET; (C) UHMWPE A / 20% PET; (D) UHMWPE A / 30% PET.

Among them there are no significant differences. All feature a UHMWPE cluster and its exposed deformation as grain stretch in the form of triangular blades with ridges on the edge. The type of structure observed in pure samples differs from the blends presented in the presence of UHMWPE grain agglomerates. That is, the presence of PET hinders the fusion of UHMWPE, generating in the blend these grain agglomerates and thus decreasing the cohesion of the material. This may explain the reductions in both stress and strain at break. Munaro (2007) mentions that the structure segregated phases, immiscible blends in this uneases the reconfiguration of the polymeric chains in the UHMWPE matrix, which may explain the early rupture and little strain of blends with the PET addition compared to the pure UHMWPE.

2.1.3 Impact test

The impact tests for samples of pure UHMWPE A and B, as well as the blends UHMWPE / PET were made. None of the samples showed disruption during testing. The UHMWPE's main characteristic is high impact resistance. Coutinho (2003) comments that the long molecular chain, high density and absence of branching in their structure to provide UHMWPE, among other properties, high resistance to impact fracture. This fact was verified in the impact test performed on pure samples of UHMWPE. The addition of PET to UHMWPE matrix leads to the creation of an immiscible blend, with low interfacial adhesion. That is, it was expected to occur reducing the mechanical property values (RUVOLO, 2006). But even with the reduction in toughness values, obtained by tensile test, during the impact test no disruption of specimens was obtained. It can be concluded that the addition of PET, until the percentage of 30% did not generate rupture in the samples of the blends in the impact test for the test conditions of this study.

2.1.4 Wear Test

Pure samples of UHMWPE A and B were subjected to the wear test with the created equipment and showed no wear for the study period. The samples were weighed at the beginning and end of the process and there were no differences of the masses after the test. Also on visual inspection, were found regions or points which would configure some wear. This fact corresponds to the information found in the literature, as quoted by Callister (2002) of the mechanical properties of UHMWPE is its resistance to abrasion. For the samples of the blends, Figure 8, the wear found varied between 0.007% and 0.080%. As a comparison, pure PET samples reached a wear of 0.171%. That is, it is observed that the addition of PET until the percentage of 30% by weight in the blend UHMWPE / PET does not compromise the wear resistance compared to pure PET. For blends, it was also not checked, on visual inspection, points or wear characteristics regions.

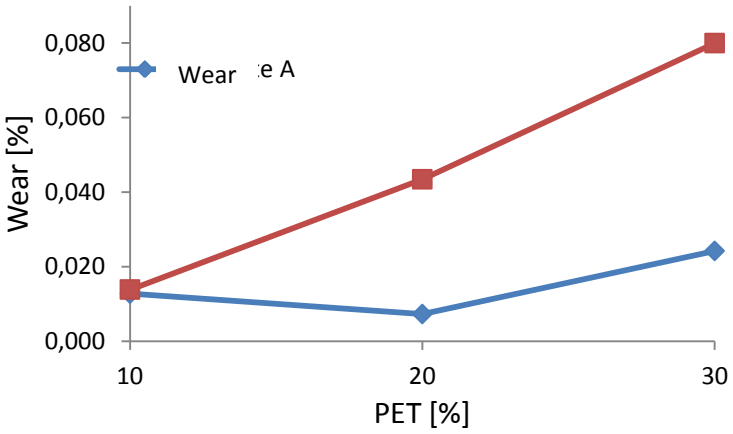

Figure 8: wear test results of the blends UHMWPE / PET, A: UHMWPE with higher molar mass and B: UHMWPE with lower molecular weight.

2.2 Conclusion

From the tensile test performed with the blends UHMWPE / PET, it is observed that the addition of PET leads to a decrease in properties of stress at break, elongation at break, toughness and resilience in comparison with the pure UHMWPE. In relation to the molecular weight, the higher molecular weight UHMWPE (A) gave a percent reduction in the stress values at rupture less (23%) than the lowest molecular weight (B) (25%) until the percentage of 20% PET in

the blend. The strain at break showed a sharp reduction (98% decreases) for both molar masses with no significant difference between them.

In impact tests performed, there was no disruption of specimens. Despite the addition of PET in the UHMWPE matrix lead to the creation of an immiscible blend with low interfacial adhesion and consequent reduction in the mechanical property values, it is observed that the addition of PET, until the percentage of 30% did not generate rupture in samples of the blends, in the impact test for the test conditions of this work.

The pure UHMWPE samples A and B, referred to the wear test showed no significant wear the study period. Weight variation analysis and analyzes were conducted by visual inspection. For the samples of the blends, wear found varied between 0.007% and 0.080%. As a comparison, samples of PET; from bottles; a wear reached 0.171%. That is, it is observed that the addition of PET until the percentage of 30% by weight in the blend UHMWPE / PET causes less wear than the one presented by pure PET. For blends, was also not observed in the visual inspection points or wear characteristics regions.

In the analysis of absorption of water by the blend found values calculated by gravimetric method (percentage change in weight) is between 0.15% and 2.78% mass, higher than those found in the literature for PET of 0.6% mass. This fact can be explained by the porosity of the samples checked in the analysis via SEM images.

3. REFERENCES

AGRAWAL, P. *et al.* Reometria de torque, propriedades mecânicas e morfologia de blendas compatibilizadas de PA6/PEAD. **Polímeros: Ciência e Tecnologia**, v.18, nº2, p.152-157, 2008.

CALLISTER J., W. D. **Ciência e engenharia de materiais:** uma introdução. 5.ed. Rio de Janeiro: Livros Técnicos e Científicos, 2002. 589p.

COUTINHO, F. M. B.; MELLO, I. L.; MARIA, L. C. de Santa. Polietileno: Principais tipos, propriedades e aplicações. **Polímeros: Ciência e Tecnologia**, v.13, nº 1, p.1-13, 2003.

DEMARQUETTE, N. R.; KAMEL, M. R. Comparação entre o Método da Gota Pendente e o Método da Gota Girante para Medida da Tensão Interfacial entre Polímeros. **Polímeros Ciência e Tecnologia**, v.7, n.3, p.63-70, jul 1997.

MARCONCINI, J. M.; RUVOLO, A. F. Análise termodinâmica do comportamento mecânico na região elástica de blendas de poli(tereftalato de etileno) reciclado e poliolefinas recicladas. **Polímeros Ciência e Tecnologia**, v.16, n.4, p.323-331, out. 2009.

PASSADOR, F. R.; PESSAN, L. A; RODOLFO JÚNIOR, A. Estado de mistura e dispersão da fase borrachosa em blendas PVC/NBR. **Polímeros: Ciência e Tecnologia**, v.16, nº 13, p. 174-181, 2006.

4. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.