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Termomechanical Treatment of Recycled Polyethylene Terephthalate (PET) Refuse: A Way to Avoid its Waste

Tratamento termomecânico de Refugo Polietileno Tereftalato (PET): Uma Maneira de Evitar o seu Descarte

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Abstract

During the recycling process of polyethylene terephthalate (PET), particles with low granulometry (refuse) may stick to the screw of the extruder and be discarded. In order to avoid its disposal, this research carries out a hot pressing of this refuse to allow its use. First, the ideal duration of hot pressing for this case was determined. Next, the resulting material was evaluated by drilling and manual sawing processes, and its mechanical properties were obtained by compression tests. The medium elastic modulus obtained by experimental tests was 1.13 GPa and, its medium strength, 68.5 MPa. Yet, the resulting material presented satisfactory performance by drilling and manual sawing processes.

Keywords

Polyethylene terephthalate (PET) refuse • Hot press • Drilling and manual sawing processes • Mechanical properties • Compression test

Resumo

Durante o processo de reciclagem do polietileno terefitalato (PET), partículas com granulometria pequena (refugo) podem aderir ao parafuso das extrusoras e serem descartadas. Com o intuito de evitar este descarte, essa pesquisa realiza uma prensagem a quente deste refugo de modo a permitir o seu aproveitamento. Primeiro, determinou-se a duração ideal da prensagem a quente para este caso. Na sequência, o material resultante foi avaliado pelos processos de furação e serramento, e teve suas propriedades mecânicas obtidas por ensaios de compressão. O valor médio do modulo de elasticidade encontrado nos testes experimentais foi 1,13 GPa e, do limite de resistência, 68,5 MPa. Ainda, o material resultante apresentou performance satisfatória nos testes de furação e serramento.

Palavras-chave

Refugo de polietileno tereftalato (PET) • Prensagem a quente • Furação e serramento • Propriedades mecânicas • Ensaio de compressão

1 Introduction

The recycling of polyethylene terephthalate (PET), mainly by extrusion, and its application has been the subject of many researches. Composites were also considered. All of them showed that the higher the PET concentration the higher the elastic modulus obtained, as follows: Ávila and Duarte [1] performed compression tests of PET/HDPE (high density polyethylene) composites and showed that HPDE contribute to milling operations but decreases the stiffness of the blend. Giraldi et al. [2] evaluated the addition of fiberglass in recycled PET matrix by varying the screw speed and torque of the extrusion process, and an increase in the elastic modulus and impact strength was observed. Also, higher screw speed (200 rpm) increased the elastic modulus.

Still considering extrusion, different screw rotation and torque of the extrusion process were evaluated, and again an increase in the elastic modulus was obtained. Giraldi et al. [3] studied the addition of fiberglass in recycled PET matrix showed that the elastic modulus and tensile strength were increased at a screw speed of 200 rpm.

Different composites were also studied. The addition of montmorillonite clay (MMT) in recycled PET matrix by extrusion also increases the yield strength, the ultimate strength and the elastic modulus [4]. Zhang et al. [5] showed that the addition of compatibilizer on recycled PET (rPET) decreased the tensile and flexural strength of rPET and slightly improve its impact strength, but the introduction of r-PET to polypropylene (PP) matrix increased the tensile and flexural strength of PP. Tomisawa et al. [6] used laser spinning after extrusion to obtain PET with elastic modulus and tensile strength of 2.5 GPa and 322 MPa, respectively.

A different way of extruding the PET, called eccentric rotor extruder (ERE), dominated by an elongational flow field, was proposed and compared to the conventional twin-screw extruder (TSE), based on a shear flow field, in order to avoid molecular weight degradation, and the rPET achieved considerably higher tensile strength [7].

Beyond extrusion, some researches concerned other types of processes. Blends of waste PET, polypropylene (PP) and polystyrene (PS) were processed into filaments for 3D printing [8]. Chemical foaming of injection molded recycled PET was also studied [9]. Yet, Li et al. [10] studied PET recycling via steam gasification.

Almost all the researches cited previously evaluated the mechanical properties by tensile test., except Ávila and Duarte [1]. Among other researches that performed polymer compression tests, it can be cited: Schneider et al. [11] investigated the tensile and compression properties of self-reinforced poly(ethylene terephthalate) (SrPET) composites. Zhao et al. [12] evaluated the compressive behavior of square hybrid columns made of polyethylene terephthalate (PET) fibre-reinforced polymer (FRP) composites. Mazzuca et al. [13] performed experimental and analytical investigations concerning the influence of elevated temperature on the shear and compressive properties of PET foam. Bian et al. [14] performed plate impact experiments to investigate shock compression and spallation properties of polyethylene terephthalate. Hao et al. [15] present a uniaxial compression test set-up to cover the strain rate dependence of thermoplastics and thermosets up to 100 s^{-1}. Dandekar et al. [16] investigated the compressive property of a composite material made of polyethylene terephthalate (PET) waste and steel wool.

It can be seen from the previous explanation that improving the mechanical properties of recycled PET was studied so far mainly by extrusion. Yet, some studies tried other types of processing, but none of them considered hot press. So, the goal of this study is to define the optimum time to hot press the recycled PET refuse and evaluate its mechanical properties and drilling and manual sawing processes.

2 Materials and Methods

2.1 Hot press

The recycled PET refuse (see Fig. 1a) was hot pressed in a metallographic press machine (see Fig. 1b) which can produce circular specimens with fixed diameter of 40 mm. Specimen height equal to 17.8 mm + 0,1 mm was obtained with 30 g of recycled PET refuse (see Fig. 1c). Previous tests carried out by Ferreira [17] showed that the optimum pressure and temperature to this specific hot press process were 40 kgf/cm² and 155 °C, respectively. Besides, this research is a proof of concept to verify the possibility of hot press recycled PET refuse with low granulometry.

The hot press heating curve was as follows: a) heating up from room temperature to 155 °C in 6 minutes; b) hot press at 155 °C - 40 kgf/cm²; and c) cooling in 6 minutes. In order to define the optimum hot press time, five specimens were made with hot press time equal to 60 minutes, and another five specimens with hot press time equal to 90 minutes. No release agent was used.

(a) (b) (c)

Figure 1: (a) recycled PET refuse with low granulometry; (b) metallographic press machine; (c) hot pressed specimen.

2.2 Mechanical properties

The mechanical properties of the hot pressed recycled PET refuse were evaluated by compression test. A Time Group WDW-200E testing machine was used to perform the compression tests at room temperature and with a constant speed of 0.084 mm/s. Ten specimens were hot pressed to perform the compression tests. The following variables were evaluated: elastic modulus (E), yield stress (σ_y), ultimate stress (σ_u) and strain (ε) at room temperature.

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2.3 Drilling and manual sawing processes

In order to evaluate the possibilities of mounting and fixing this hot pressed recycled PET refuse material, two tests were carried out: drilling (with a bench drill) and manual sawing (with a carbon steel saw frame of 24 teeth by 25 mm). For the drilling, a M6 drill bit was used with three different rotation speeds: 130 rpm, 450 rpm and 1500 rpm.

3 Results and discussion

3.1 Mechanical properties

The hot pressed specimens presented good appearance and did not crumble (see Fig. 1c). As the metallographic press machine heats only on the bottom, the surface finish of the specimens was a little bit better on this side.

Figure 2a presents the performance of specimens 1 to 5 (hot press time: 60 minutes) during the compression tests, while the strength results are listed on Tab. 1. In the same way, the results for the specimens 6 to 10 (hot press time: 90 minutes) are presented on Fig. 2b and Tab. 1.

According to Tab. 1, the average value of the elastic modulus obtained for the 60-minute hot press time specimens is E = 1.13 GPa. Ávila and Duarte [1] also performed compression tests and obtained 1.46 GPa for the PET/HDPE composite with 80/20 ratio. As virgin PET presents E = 2 GPa [18], this relative low value of E may be due to PET molecular-weight degradation in the presence of moisture [1]. Yet, the strain at break is much higher than at yield, and can be due to the dimensions of the cylindrical specimens (L = 17.9 mm and D = 40 mm | L/D ratio: 0.45) but, unfortunately, concerning the metallographic press machine used (see Fig. 1b), the diameter is fixed and the height cannot be much bigger than this. Fig. 3 shows all the 10 specimens after the compression test. Also, the stress-strain curves obtained do not present an abrupt fall after the yield point (except for specimen 9), probably due to the specimen L/D ratio. In addition, Wu et al. [7] performed tension tests and obtained E = 1.14 GPa for the reprocessed by eccentric rotor extruder (ERE) PET and 1.18 GPa for the reprocessed by twin-screw extruder (TSE) PET. Although Wu et al. [7] performed tension tests and the present research performed compression tests, the values obtained for the elastic modulus are very close.

Giraldi et al. [3] obtained E = 2.8 GPa with the addition of fiberglass in recycled PET matrix. Yet, Tomisawa et al. [6] obtained E = 2.5 GPa using laser spinning after extrusion. These values are higher than the obtained in the present work (E = 1.13 GPa for the 60-minute hot press time specimens), which shows that the addition of fiberglass in recycled PET matrix or the use of laser spinning after extrusion improve the elastic modulus.

The average value of the elastic modulus for the 90-minute hot press time specimens is 1.06 GPa (see Tab. 1), 6.19% lower than the same result for the 60-minute hot press time specimens. This shows that increasing the hot press time can be harmful to the mechanical properties of the hot pressed recycled PET

Table 1: Mechanical properties of the hot pressed recycled PET obtained by compression tests.

	Hot press time: 60 minutes					Hot press time: 90 minutes				
	E [MPa]	Yield		Ultimate		E [MPa]	Yield		Ultimate	
		σ_y [MPa]	ε [--]	σ_u [MPa]	ε [--]		σ_y [MPa]	ε [--]	σ_u [MPa]	ε [--]
Maximum	1168.7	72.50	0.0898	93.5	0.3052	1119.5	68.48	0.1030	79.9	0.2649
Minimum	1066.2	61.79	0.0822	74.4	0.2207	994.2	59.93	0.0836	74.5	0.1262
Mean	1127.9	68.52	0.0862	84.1	0.2550	1056.4	65.13	0.0900	77.7	0.2310
Std. deviation	43.4	4.03	0.0033	6.8	0.0317	47.3	3.37	0.0077	2.6	0.0588

Despite the relative low value of elastic modulus, the average yield stress obtained for both 60-minute and 90-minute hot press time specimens (68.53 MPa and 65.13 MPa, respectively) were higher than the ultimate stress obtained for the PET/HDPE composite with 80/20 (22.78 MPa) by Ávila and Duarte [1], where both researches performed compression tests. The same can be said for the strain. This shows that the hot pressed recycled PET is not so brittle as the composite PET/HDPE. Thus, it may be suitable for applications such as furniture and dry walls. For these applications, if flammability is a potential safety hazard, a flame retardant may be used [19].

Virgin PET presents 80 MPa yield stress [12]. So, the values obtained in this present research are 14.34% and 18.6% less, respectively. Yet, the average yield stress obtained in the present work, by compression test, were higher than other researches that performed tensile tests, as follows: Giraldi et al. [3] obtained 60 MPa; Wu et al. [7], 65.04 MPa; Zander et al. [8], 35.1 MPa. On the contrary, Tomisawa et al. [6] obtained the tensile strength equal to 322 MPa by tensile test, using laser spinning after extrusion.

A summary of the results obtained in the present work and other researches can be seen on Tab. 2.

Table 2: Mechanical properties - present research and others.

Reference	Description	σ [MPa]	E [GPa]	ε
[3]	rPET	60	2.8	> 120%
	recycled and processed PET	58	2.6	> 122%
[1]	PET/HDPE (80/20)	22.78	1.46	0.032
[6]	As-spun fibers PET	322	2.5	213%
[7]	Reprocessed (ERE) PET	65.04	1.14	------
	Reprocessed (TSE) PET	28.28	1.18	------
[8]	rPET 3D printed	35.1	------	0.02
This work	60-minute hot press time rPET	68.53 (at yield)	1.13	0.086 (at yield)
	90-minute hot press time rPET	65.13 (at yield)	1.06	0.090 (at yield)

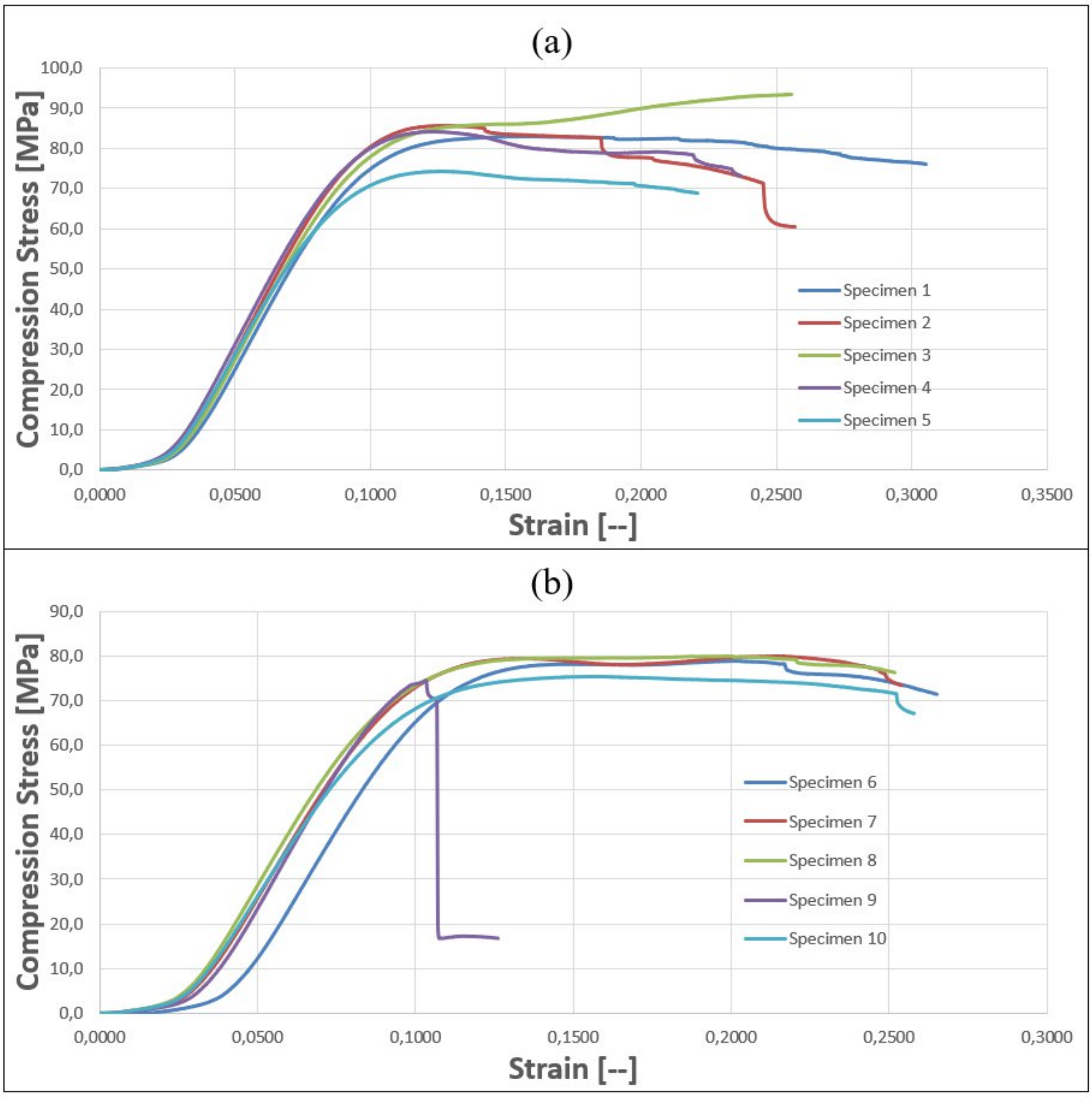

Figure 2: Stress-strain curve for specimens: (a) 1 to 5 - hot press time: 60 minutes; (b) 6 to 10 - hot press time: 90 minutes.

Figure 3: All the ten Specimens after the compression test.

3.2 Drilling and manual sawing processes

Figure 4 presents a 60-minute hot press time specimen after drilling (Fig. 4a and Fig. 4b). As the metallographic press machine heats only on the bottom, this surface with the better finish was drilled. The numbers 1, 2 and 3 on Fig. 4(a) represents the rotation speeds 130 rpm, 450 rpm and 1500 rpm, respectively. For 130 rpm drilling rotation speed, the specimen hole started to crumble, and this effect was worse for the 90-minute hot press time specimen (see Fig. 4c and Fig. 4d). Thus, the higher the drilling rotation speed the better the final surface quality. The sawing process presented satisfactory results for both specimens. The specimens did not crumble (see Fig. 4e and Fig. 4f).

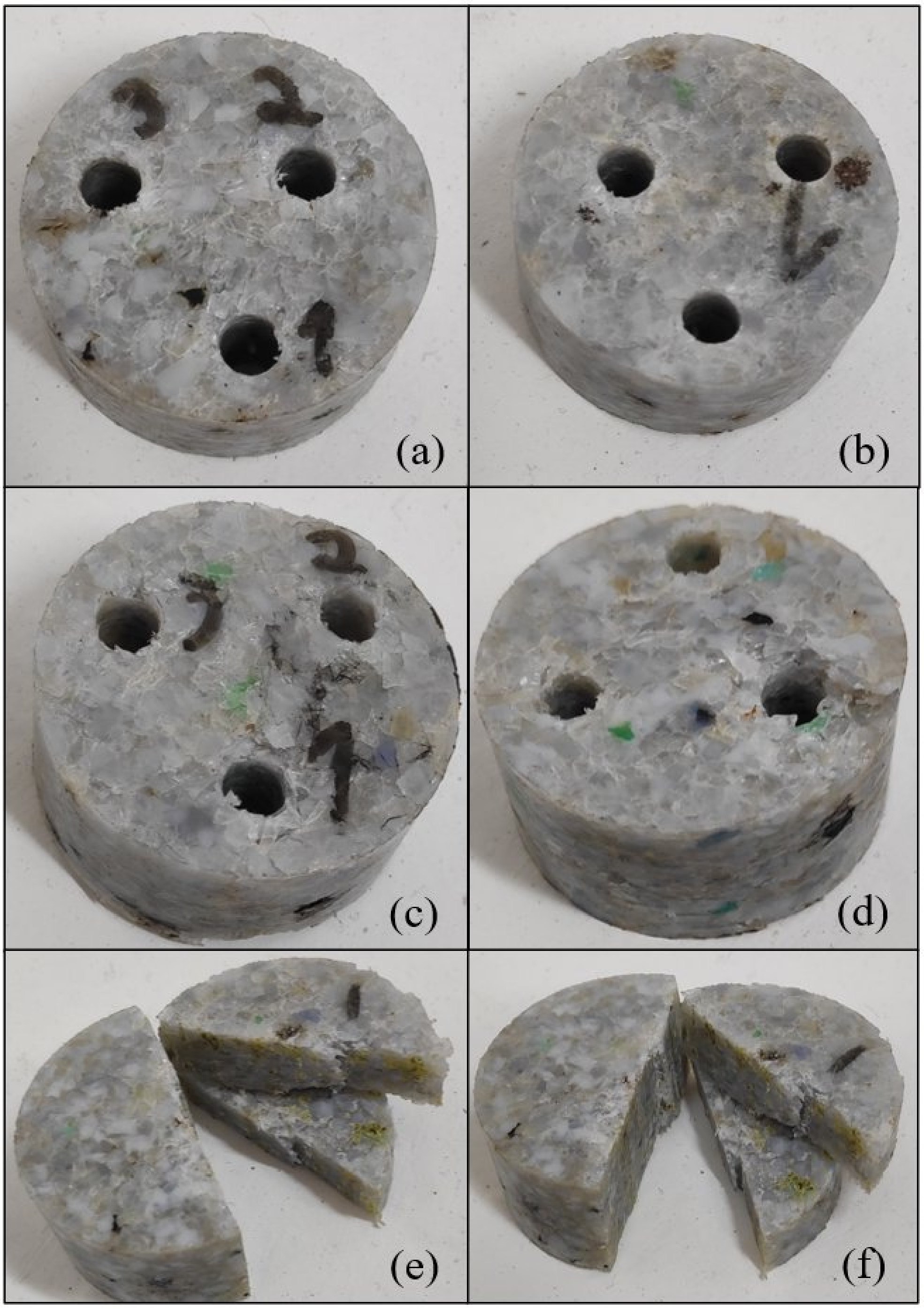

Figure 4: 60-minute hot press time specimen after drilling: (a) input drill face, (b) output drill face; 90-minute hot press time specimen after drilling: (c) input drill face, (d) output drill face; Specimens after manual sawing: (e) 60-minute hot press time specimen, (f) 90-minute hot press time specimen.

4 Conclusions

Hot pressing the recycled PET refuse showed to be viable. Its average 1.13 GPa elastic modulus may not be as high as the virgin PET value (2 GPa) but the average yield stress 68.53 MPa indicates a significant strength for this material.

The parameter hot press time is important. It was observed that high hot press times worsens the mechanical properties. Therefore, the optimal time is 60 minutes.

Also, the drilling rotational speed has a great influence on the final hole finishing. The specimens hole crumbled with 130 rpm rotational speed while best drilling results were obtained with 1500 rpm rotational speed.

Possible applications for the hot pressed recycled PET are furniture and dry walls.

Acknowledgments

The authors would like to thank the Instituto Federal do Sudeste de Minas Gerais – Campus Juiz De Fora, where the compression tests were performed, and Federal University of Juiz de Fora – UFJF, where this study was carried out.

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