Thermal and Mechanical properties of recycled PET and its blends

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Abstract

This paper discusses the thermal and mechanical properties of virgin PET ,recycled PET and their blends. Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) were used to study the thermal properties. The tensile tests at ambient and elevated temperature were used to study the mechanical properties. There were significant differences in the recrystallization behaviour as far as the thermal properties were concerned. In the case of mechanical properties, the tensile test at elevated temperature showed that the strength of the blends of recycled PET/virgin PET were lower than those ones of virgin PET.

Introduction

Polyethylene terephthalate(PET) is a condensation polyester produced by the reaction of di-acid and di-alcohol. The major raw materials for the production of PET are dimethyl terephthalate (DMT), terephthalicacid (TPA) and ethylene glycol (EG). PET is a major polymer with diverse applications. The semicrystalline nature of this polyester allows one to generate a wide variety of both physical and mechanical properties well suited for the fabrication of fibers, films, bottles and different molded parts. These parts are converted into finished products such as garments, carpets, packages and industrial goods. Most of the physical and mechanical properties of PET improve as the molecular weight increases. The molecular weight required is dictated by the end use of the polyester. So the PET resins (especially food grade) undergo solid state polycondensation in order to lift up its molecular weight. PET is known to be a hygroscopic thermplastic material absorbing moisture easily. Thus optimum drying condition is very crucial prior to processing. Moisture content in polymer promotes degradation while processing leading to a breakdown of molecular weight which in turn affects final product properties.

Experimental

Materials:

Granules of three different grades of PET were supplied by Leading Synthetics Pty:

i) 100% virgin PET (BK3180).
ii) 100% recycled food grade PET.
iii) 100% recycled fibre grade PET.

Procedures:

Blends of virgin PET and recycled food grade PET were prepared in the following weight ratios.

i) 90% virgin PET 10% recycled PET
ii) 80% virgin PET 20% recycled PET
iii) 70% virgin PET 30% recycled PET
iv) 50% virgin PET 50% recycled PET.

All the different grades of PET were dried in a vacuum oven at a temperature of 170°C for four hours. The dried materials were sealed in an aluminium foil bag in order to prevent its exposure to the atmosphere. Samples for mechanical tests were produced using "Battenfeld BA 350/75 Plus"injection moulding machine with the following settings:

Barrel temperature:

Reverse zone:	25°C
Mid zone:	290°C
Front zone:	285°C
Nozzle:	285°C.

Cooling time: 13 sec
Mould temperature: 10-15°C

The Differential scanning calorimeter (DSC) tests were run in a nitrogen atmosphere with a 10°C/min heating/cooling ramp from room temperature to 290°C using a sample mass between 6-12mg. The TGA tests were run at a temperature ramp of 10°C/min from room temperature to 500°C. TGA was done to note the differences in the degradation behaviour of the materials. In the case of the DSC, 2-cycle tests were run. The first cycle erases the thermal history of the sample, heating it above the melting temperature, so that the data from the second cycle is not influenced by undefined process related cooling. Tensile tests were carried out initially at ambient conditions and then at elevated temperature for all materials. At ambient conditions, the test was run in a Zwick Z010 universal testing machine as per the Australian Standard AS 1145.1-2001. The tensile test at elevated temperature was performed on an INSTRON tensile tester using a thermal chamber surrounding the clamp set-up and the tensile sample and the temperature employed was 110°C. These conditions were chosen to compare the stretching behaviour of various materials. The maximum possible test speed the clamps could hold without the samples being slipped was about 200 mm/min. The tensile bars were given 5 minutes in the thermal chamber to achieve equilibrium temperature before the test was started. Here again five samples were tested to obtain one set of result for each material.

Results and Discussion

Table 1 shows the variations of melting temperature and the crystallinity with the recycled PET content. The results indicate that the degree of crystallinity is hardly affected by the content of recycled PET. However, significant differences were seen in the recrystallisation temperatures of different materials. Fig 1 shows that the recrystallisation temperature is entirely dependent on the recycled content. The higher the recycled content in the PET material the higher the temperature at which the material starts to recrystallize. The recrystallisation temperature for the virgin PET is the lowest while both the recycled food grade and the recycled fibre grade showing values way ahead of the virgin one. The recycled food grade PET shows much higher recrystallisation temperature than the virgin PET though the degree of crystallinity for both of them differ merely by 0.5% (Table1). The recycled fibre grade PET has the highest melting temperature as well as the highest level of crystallinity when compared to other grades. The TGA tests didn't reveal any sort of differences in the degradation behaviour of the materials. Virgin PET starts to degrade slowly around 380°C before the weight starts to decrease significantly at 400°C. For all the materials tested the plot of TGA looks the same. There is no difference between the virgin and the recycled materials. None of the materials showed a significant weight loss until 380°C.

In the case of mechanical properties, the tensile test at ambient conditions showed that the virgin PET had tensile strength almost similar to those of the 90-10, 80-20, 70-30 and 50-50 blends. They had a value approximately equal to 57MPa while the rest of the two 100% recycled PET showed a tensile strength of 66MPa. This was due to higher crystallinity of the recycled PETs as compared to the other materials. Fig 2 indicates that the modulus of elasticity for the virgin

PET and recycled PET (food and fibre grade) are fairly similar when compared to their blends. In the tensile test done at elevated temperature, as the test temperature was above the glass transition temperature of PET, the tensile bars went into a rubbery state which explains why the tensile strength of the materials is much lower than at ambient temperature. Fig 3 shows that at elevated temperatures the tensile strength and modulus of elasticity of recycled grade PETs are lower than that of the virgin PET while at ambient temperature the trend is quite opposite.

Conclusions

The recrystallisation temperature is directly influenced by the recycled PET content. Addition of more recycled content in virgin PET increases the recrystallisation temperature significantly with 100% recycled PET showing the maximum value. At elevated temperature,the tensile strength and modulus of elasticity of virgin PET are higher than the recycled PET and their blends. This showed that the mechanical properties of the blends of virgin/recycled PET are worse than those of the virgin ones.

Keywords

Virgin PET, recycled PET, mechanical properties, thermal properties.

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Recycled content of PET in %	Crystallinity in %	Melting temperature, °C
100% virgin PET (BK3180)	33.01	250.0
90% virgin PET/10% RPET	30.84	250.0
80% virgin PET/20% RPET	27.21	249.8
70% virgin PET/30% RPET	32.03	249.9
50% virgin PET/50% RPET	32.04	249.7
100% RPET (food grade)	34.03	251.2
100% RPET (fibre grade)	36.39	251.6

Table 1: Degree of crystallinity of PET blends

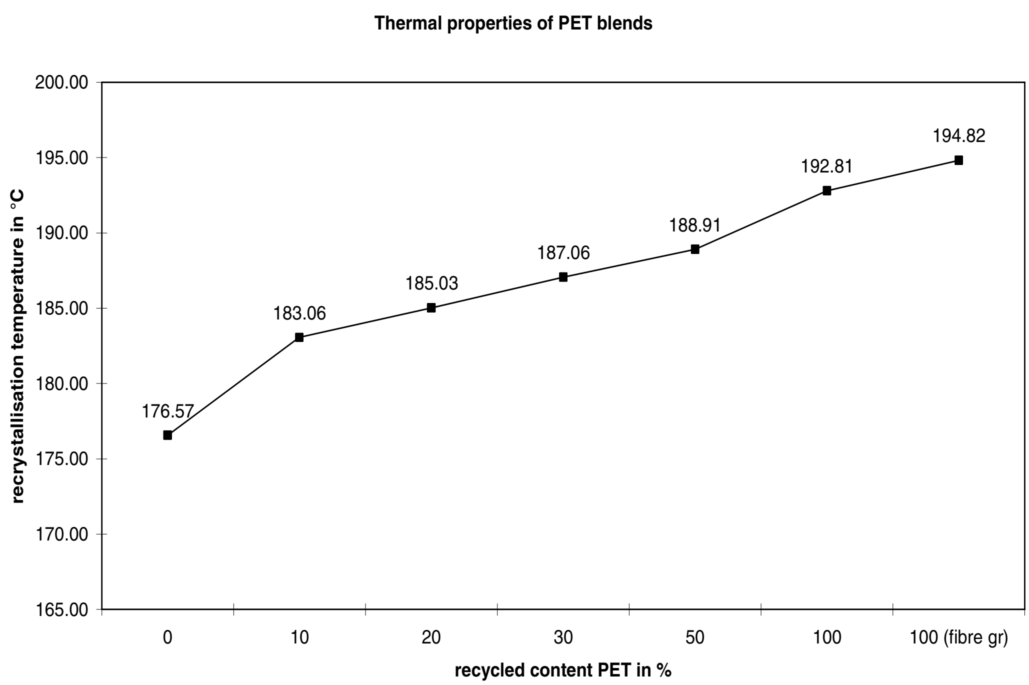

Figure 1: Recrystallisation temperature of PET blends.

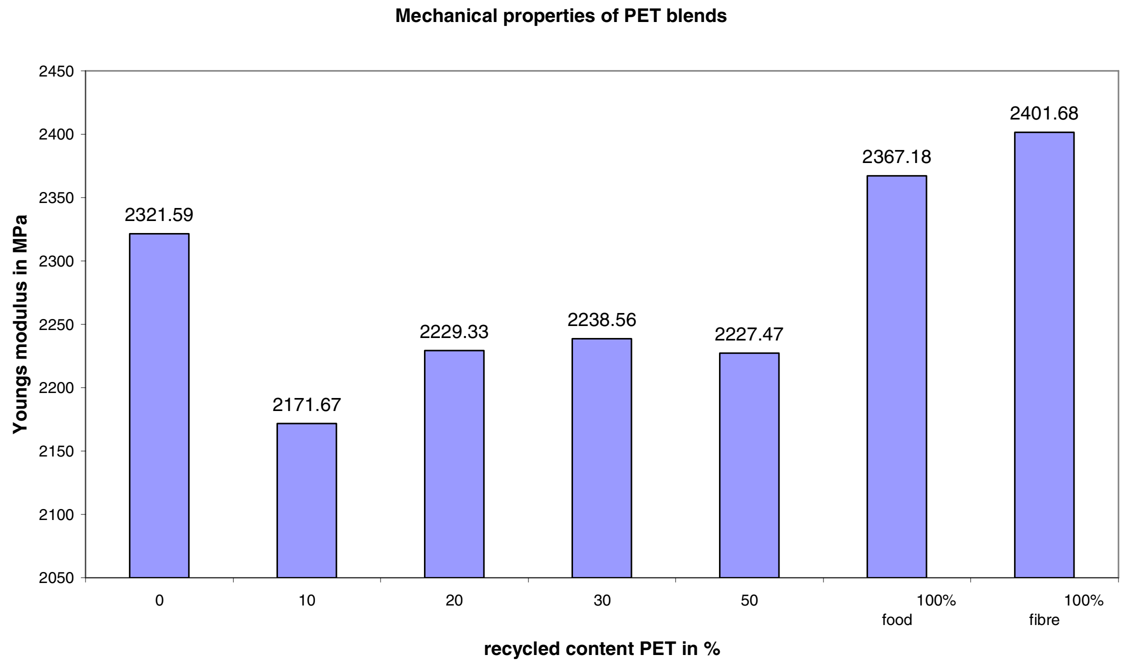

Figure 2: Young modulus of PET blends at ambient temperature

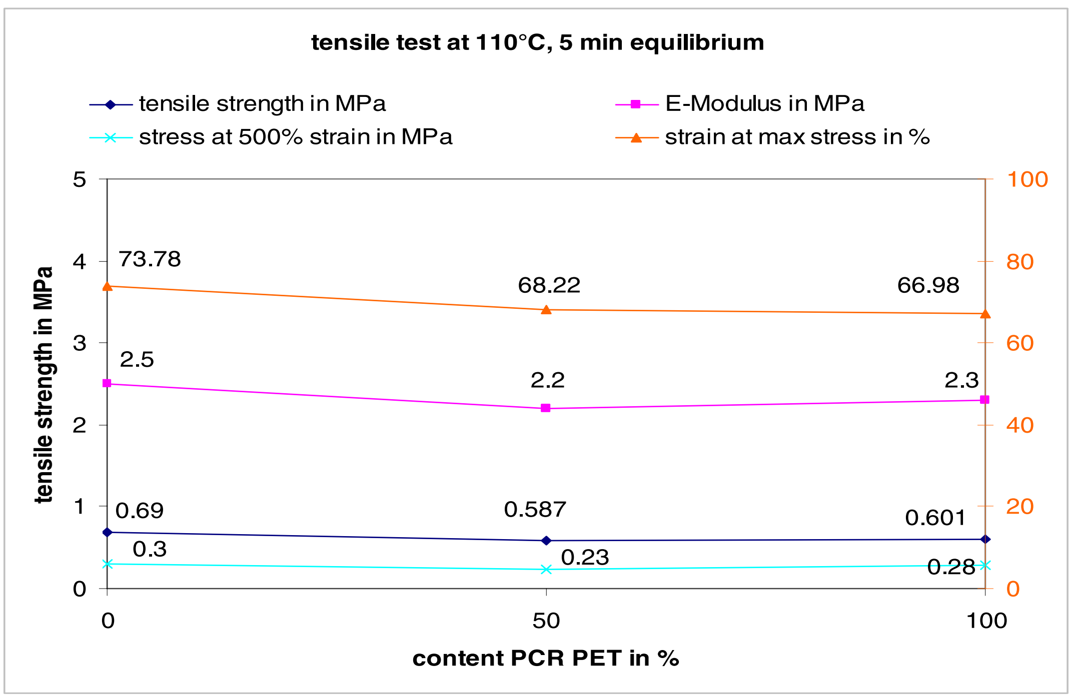

Figure 3: Mechanical properties of PET blends at 110 °C