# Evaluation of a non-conventional process of recycling amber PET to obtain decorative plates

## Evaluación de un proceso no convencional de reciclaje de PET ámbar para la obtención de placas decorativas

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## Abstract

This work studies the obtaining of decorative plates from recycled PET, taking into account the effect of temperature and time in a type of alternative processing of recycled PET in the resistance to bending, optimizing these parameters for the production of plates for the possible replacement of decorative ceramics. To this end, the recycled amber PET was washed and cut into squares of approx. 1 cm2 long Subsequently, the bending test was determined in a Tinius Olsen H50KS universal machine under the ASTM D790 standard in amber, green and transparent PET plates obtained at 320 ºC, 330 ºC and 340 ºC in 20, 30 and 40 minutes. Thus, the thermal properties of the raw materials were studied by means of thermogravimetry and differential scanning calorimetry, at a heating rate of 10 °C/min, in air, and a temperature range of 30 °C to 500 °C. Additionally, mixtures of Amber PET (PA) with transparent PET (PT) and green PET (PV) were made in the following proportion: 70 % PA - 30 % PT, 70 % PA - 30 % PV, and 70 % PA - 15 % PT - 15 % PV allowing to improve the mechanical properties and achieve different tonalities in the plate. The results indicated that the optimum temperature and time to melt the plates are: 320 °C and 40 minutes respectively, which would allow reaching a flexural strength of 71 MPa. Under these same conditions of temperature and time, the mixtures that incorporate transparent PET and green PET showed a significant decrease in the resistance to flexion. It is concluded that the plates obtained from recycled amber PET are suitable for decorative use since according to the mechanical tests these reached 71 MPa for the bending test.

***Keywords:*** amber PET; recycling; plastic; waste; materials.

## Resumen

Este trabajo estudia la obtención de placas decorativas a partir de PET reciclado, teniendo en cuenta el efecto de la temperatura y el tiempo en un tipo de procesamiento alternativo de PET reciclado en la resistencia a la flexión, optimizando estos parámetros para la elaboración de placas para el posible reemplazo de cerámicas decorativas. Para ello el PET ámbar reciclado se lavó y cortó en cuadrados de aprox. 1 cm2 de largo. Posteriormente se determinó el ensayo a la flexión en una máquina universal Tinius Olsen H50KS bajo la norma ASTM D790 en placas de PET ámbar, verde y transparente obtenidas a 320 ºC, 330 ºC y 340 ºC en 20, 30 y 40 minutos. Así se estudiaron las propiedades térmicas de las materias primas mediante termo gravimetría y calorimetría diferencial de barrido, a una velocidad de calentamiento 10 °C/min, en aire, y un rango de temperatura de 30 °C a 500 °C. Adicionalmente se realizaron mezclas de PET Ámbar (PA) con PET transparente (PT) y PET verde (PV) en la siguiente proporción 70 % PA - 30 % PT, 70 % PA - 30 % PV, y 70 % PA - 15 % PT - 15 % PV permitiendo mejorar las propiedades mecánicas y lograr diferentes tonalidades en la placa. Los resultados indicaron que la temperatura y el tiempo óptimos para fundir las placas son: 320 °C y 40 minutos respectivamente, que permitiera alcanzar una resistencia a la flexión de 71 MPa. Bajo estas mismas condiciones de temperatura y tiempo, las mezclas que incorporan PET transparente y PET verde presentaron una disminución significativa en la resistencia a flexión. Se concluye que las placas obtenidas a partir de PET ámbar reciclado son adecuadas para uso decorativo, ya que según los ensayos mecánicos estas alcanzaron 71 MPa para el ensayo de flexión.

***Palabras clave:*** PET ámbar; reciclaje; plástico; residuos; materiales.

# Introduction

At present, it is difficult to do without plastics, not only for its usefulness but also for the economic importance they have. This is reflected in the growth rates of this industry that, since the beginning of the last century, exceeds almost all industrial activities. In Colombia, the plastics industry has been characterized by being, under normal conditions, the most dynamic manufacturing activity of the last three decades, with an average annual growth of 7 % (Ministry of Environment, Housing, and Territorial Development, 2004).

Plastics are used to package, conserve and distribute food and beverages that can reach the population in a safe, hygienic and practical way. At present one of the materials most used by man as raw material for the manufacture of packaging is PET (polyethylene terephthalate), which due to its characteristics make it suitable for this type of use. PET is a 100 % recyclable material, which is an advantage; But due to the large volume of waste generated on the planet, polymer waste remains in nature for a long time because it takes a long time to decompose and landfills can no longer supply, and some of this waste is contaminated due to the proliferation of waste. bacteria The recycling of PET is done mechanically (Awaja and Pavel, 2005), converting waste again into raw material for the manufacture of different products. However, due to its low density, it hinders storage and generates low price compensation, which is why it is not attractive to waste pickers (da Rosa, Michelin, and Campomanes, 2011).

PET is a polymer obtained from the combination of terephthalic acid and ethylene glycol (Awaja and Pavel, 2005), both obtained from petroleum, for which a great environmental impact is presented to obtain it and it is also the material most currently used by the industry for the manufacture of packaging; The global consumption of PET is estimated at 12 million tons per year with an annual growth of 6 % (Ortega, 2012).

On the other hand, Ramírez (2011) in his research proposes a proposal for the use of polyethylene Terefltate-PET-recycled as reinforcement material for the manufacture of building elements and thus contributes to minimizing the impact generated by industrial, domestic and waste plastics. consumption in the environment. Most of the plastic containers used in the industry are composed of non-disposable polymeric materials, which generate a high level of contamination after use. For this reason, there is a need to try to effectively recycle those polluting waste materials, and thus stop or try to limit the pollution process they generate (Ramírez, 2011).

Since PET is recyclable, the containers that are recovered are mechanically transformed, but the central problem for the recycling of PET is the collection due to the low rates of return and the low incentive that does not look very attractive for the collectors; as well as the separation of other components as it may become confused with other types of plastic, however there are some methods of separation but these generate that costs are raised (Ministry of Environment, Housing, and Territorial Development, 2004). Regarding storage, this can cause a health risk, since containers contaminated with food and drinks are presented (Careaga, 1993). To all the above is added the fact that some market sectors show resistance to the use of recycled materials in some products (Valderrama, and Chavarro, 2014).

Due to the large figures of PET consumption and the problem of recycling it, this research aims to take advantage of PET waste that is accumulating in landfills, obtaining decorative plates and thus give another use to this material. For this, different thermal characterization techniques and mechanical tests were carried out. With the above, it seeks to establish a technique that leads to the reduction of this material in landfills, and thus contribute to the conservation of the environment (ONU, 1992).

# Methodology

## *Materials*

To carry out this study, amber, green and transparent PET bottles were used after consumption, which was previously washed and cut into flakes of approximately 1 $cm^2$ (Figure 1). The material was collected from recycling collection centers. For the preparation of the plates, 60 grams of amber PET were used in order to obtain dimensions of 10 cm in width, 10 cm in length and 0.5 cm in thickness, equivalent to a volume of 50 $cm^3$.

*Figure 1.* ET in flakes
Source: the authors.

## *Methods*

In order to optimize the temperature and residence time in the furnace, the following temperatures were evaluated: 320 °C, 330 °C, 340 °C, based on the thermal characterization made to the materials by the technique TGA/DSC (Figure 2). For each temperature, three different holding times were used: 20, 30, 40 minutes, defined times after performing several runs in the furnace, and the response variable was the resistance to bending. It was determined to optimize the time and temperature factors for the AMBAR PET since this is the material object of the present study. Subsequently, having the optimal parameters, mixtures of Amber PET (PA) with transparent PET (PT) and green PET (PV) were made, making two binary mixtures and a ternary 70 % PA – 30 % PT, 70 % PA – 30 % PV, and 70 % PA – 15 % PT – 15 % PV in order to change the shade of the plates and evaluate the effect on the resistance to bending.

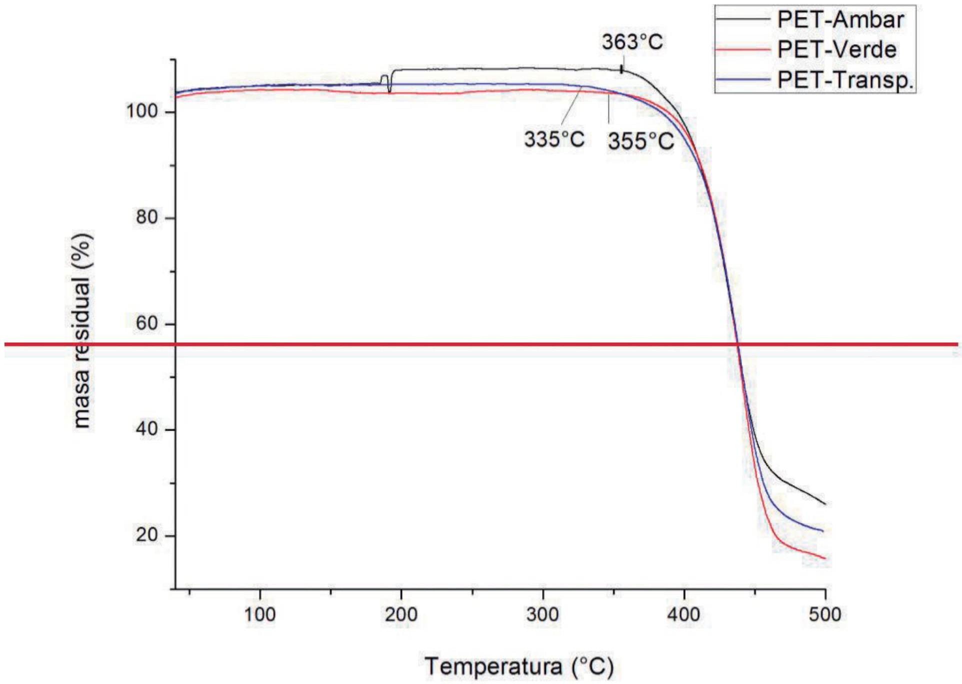


*Figure 2*. TGA curves for amber PET, green PET, and transparent PET
Source: the authors.

To shape the plate, the PET was cast in a steel mold of square geometry and dimensions 10 cm X 10 cm (Figure 3). The mold needed a pre-heating approximately 15 minutes at the working temperature to ensure that the temperature of the oven and the mold was the same at the time of introducing the material. Subsequently, the mold was removed with the material from the oven, and 30 seconds were waited to prevent the plate from being deformed during cooling in water. Water was chosen as the optimal cooling method since a rapid cooling prevents the crystallization of the material (Mano, 2003). Non-stick paper with Teflon was used to easily demold the plates.

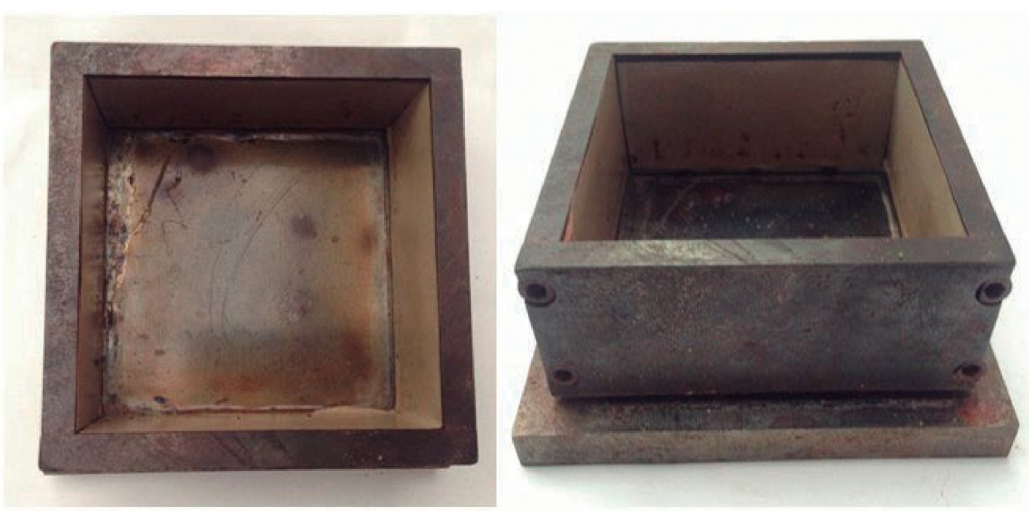

*Figure 3*. Mold
Source: the authors.

The thermal characterization of the materials before processing was carried out using the technique of thermal gravimetric analysis (TGA, for its acronym in English) and differential scanning calorimetry (DSC, for its acronym in English) in a Mettler Toledo equipment under the following conditions : heating speed 10 °C/min, in air, and in a temperature range between 30 °C and 500 °C. The flexural strength test was carried out based on the ASTM D790 standard (American Society for Testing and Materials, ASTM, 2011) by using the Tinius Olsen H50KS universal machine, which is located in the University's research laboratory. Valley. For this test, rectangular specimens were cut from the plates, with the dimensions based on the specifications of the aforementioned standard.

# Results and analysis

## • *Gravimetric Thermo Analysis (TGA)*

Figure 2 shows the residual mass percentage curves as a function of temperature for the three types of PET. It is observed that the percentage of mass loss for materials is approximately 80% coinciding with that reported by Arrazola et al., (2013).

This loss of mass begins at 335, 355 and 363 °C for transparent PET, green PET, and amber PET respectively, which is attributed to the onset of thermal degradation (Th) of these materials. The thermal degradation of the materials studied in the present investigation is lower than that of a virgin PET, which is around 380 °C (Arrazola *et al*., 2013) because these were processed previously and their content of loads and additives. According to the TGA curve (Figure 3), the processing temperature for the three types of PET used in this study should not exceed 335 °C. In the case of mixing between these and to be used individually, it must be taken into account that the degradation temperature for each of them should not be exceeded.

## • *Differential scanning calorimetry (DSC)*

Generally, PET has a glass transition temperature (Tg) around 79 °C (Mano, 2003) however in the DSC curves of Figure 4, this characteristic endothermic peak is not clearly observed because polymers with a large percentage of crystallinity do not clearly exhibit the glass transition temperature. Figure 4 shows an endothermic peak corresponding to the melting temperature (Tm) at 251 °C for the three types of PET, coinciding with the melting range (240-260 °C) of PET found by Araque (2008); Callister (1996).

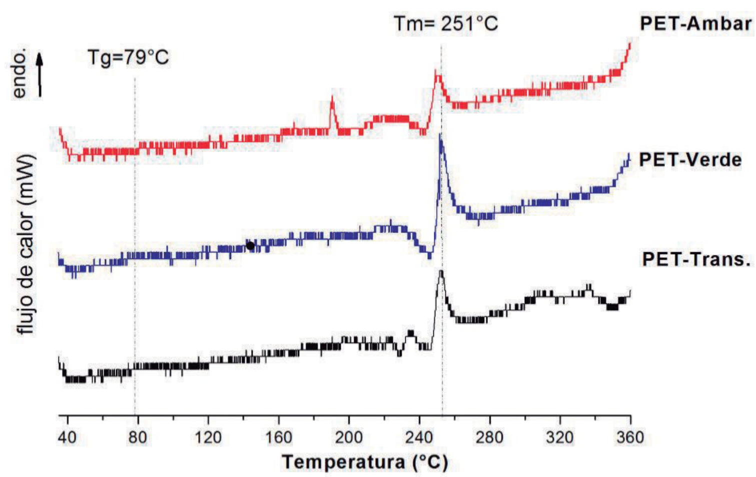


*Figure 4.* Differential scanning calorimetry for different types of PET
Source: the authors.

## • Flexural strength

The bending test was performed on the amber PET specimens obtained from the molten plate since in the first instance it is necessary to find an optimum sample to subsequently make the mixtures between the different types of PET. Figure 5 shows that the test pieces that were subjected to different temperatures for a time of 20 minutes showed resistances lower than 35 MPa, so they were discarded since they reached low resistances in comparison with the other test tubes. In addition, those specimens that were treated at 320 °C and 340 °C for 30 min showed lower resistance, which is why they were also discarded.

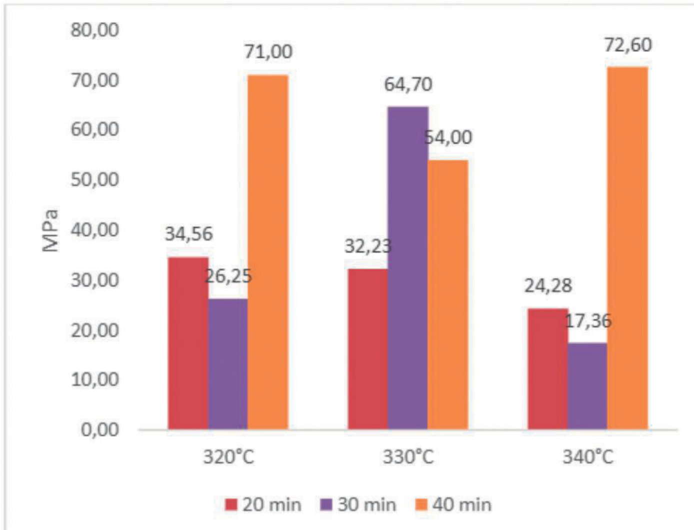


*Figure 5.* Results of bending tests for amber PET
Source: the authors.

The sample that showed the highest resistance (72.60 MPa) was treated at 340 °C for 40 min, however it was decided to take as an optimal sample, that which was treated at 320 ° C for 40 min, because it requires less energy consumption obtaining resistances (71 MPa) similar to the maximum. Although the material obtained in the present investigation has already been processed twice, the resistances of this one approach the lower limit of the range established for the virgin PET (80-110 MPa) (Núñez, Roca, and Jorba, 2013).

Figure 6 b) shows the stress vs. strain curve of the flexure test for the amber PET sample at 320 °C and 40 min, in which a hard and resistant behavior is observed according to the graph obtained (Billmeyer, 1975). In addition, in Figure 6 a) it is appreciated that the test piece does not fail catastrophically.

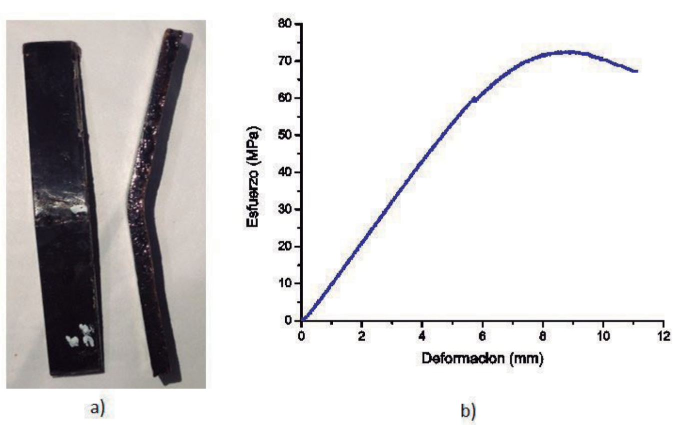


*Figure 6.* Results of bending tests for amber PET
Source: the authors.

According to the results obtained by Ramírez (2011) in his research, the matrix of polyester resin and PET addition exhibits a fragile failure behavior, which indicates that the material obtained in the present investigation can be applied as a matrix option for the elaboration of composite materials.

Ramírez (2011) also studied the flexural strength for transparent recycled PET molten in an oven at similar conditions and obtained maximum resistances of 9.9 MPa. In addition to investigating the flexural strength of a composite material where ground PET is used as filler and polyester resin as a matrix, obtaining maximum flexural strengths of 13 and 14 MPa, the foregoing indicates that the material obtained in the present investigation may be applied as a load option for the production of composite materials.

## • *PET mixtures*

Mixtures were made with the incorporation of transparent PET (PT) and green PET (PV) in order to improve the mechanical properties and achieve different tonalities in the plate, as shown in Figure 7.


*Figure 7*. Samples of PET mixtures: a) PA-PV, b) PA-PV-PT, c) PA-PT
Source: the authors.

Figure 8 shows the results obtained from the flexural strength test for the optimal sample (100 % PA) and for the different binary and ternary mixtures. It was obtained from the results of resistance to bending (Figure5) that the optimum sample shows greater resistance (71 MPa), followed by the mixture made with PA-PV which presented a resistance of 31.03 MPa, in this same order, the mixture made with PA-PT presents lower resistance ( 17,09 MPa); This behavior is attributed to the fact that the PT and the PV have degradation temperatures (335 and 355 °C) close to the processing temperature of 320 °C. On the contrary, the good performance of the PA sample occurs because the degradation temperature (363 °C) is higher with respect to the PT and PV, as mentioned in the thermogravimetric analysis (Figure 3). which helps to prevent it from degrading.

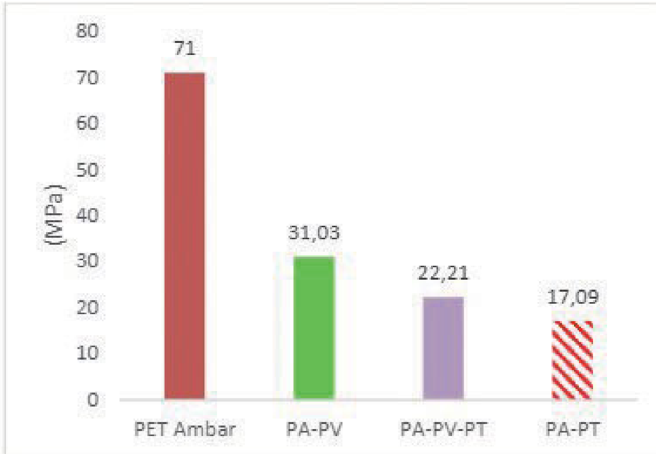


*Figure 8.* Flexural strength for PET mixtures
Source: the authors.

## Conclusions

The process carried out with recycled amber PET is an unconventional process since it does not correspond to the traditional mechanical recycling processes. Variables were optimized as temperature and, time 320 °C, and 40 minutes; using a cooling in water. These results show that this process is a good option to reduce the environmental impact since a large volume of PET is needed to make each plate.

Based on the results of the thermal analysis of the different types of PET, it was found that when PT and PV are added, there is a decrease in the resistance to bending due to the fact that the degradation temperature is close to the working temperature ( 320 °C); however, the mixtures that were developed with PET of another pigmentation, allowed to modify tonalities of the plates.

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