Reuse of post-consumer polyethylene terephthalate in the construction industry

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Abstract

There is an increasing demand for polyethylene terephthalate from the beverage sector like in water, oil, and soft drink packaging, which implicates the need to give a suitable destination to waste PET bottles. In order to attribute value to this material, more and more new means of re-use are being sought. For that purpose, we carried out a bibliographic study on new insulating materials for buildings with use of PET residue and an estimation of its potential to replace Expanded Polystyrene (EPS) used as thermal and sound insulation for slabs. We found polyurethane composites with the incorporation of 35% and 45% of PET and alumina trihydrate, which may be an option as a thermal and sound insulation because they meet the Brazilian standards, presenting adequate behavior in the horizontal burning rate test and mechanical compressive strength. It was estimated that between 14 to 18 tons of PET were recycled in Brazil in 2012. Of the total Brazilian production of PET in 2012, a production between 14 and 18 thousand tons of PET was estimated. The incorporation of PET into a new material increases the percentage of recycling and provides gains for the environment and society, thus reducing the amount of waste and contributing to cleaner production dissemination.

Keywords: Recycling, Polyethylene terephthalate, Polyurethane, construction industry.

1. Introduction

Society is constantly seeking to improve its quality of life, which makes people more aware of the products they are consuming, their origin, and the benefits they can provide, as well as the social and environmental responsibility of the producing companies (Aminudin et al., 2011). This behavior can bring great benefits to the environment, because in order to stay in the market, companies must align with the consumers' behavior and demonstrate social and environmental responsibility, which includes proper waste management and disposal (Ronkay, 2013).

The adoption of sound socio-environmental practices should be based on the concepts of Cleaner Production. Cleaner production is the continuous application of an integrated preventive environmental strategy applied to processes, products and services, incorporating the most efficient use of natural resources, and minimize the generation of waste and pollution, thus avoiding to pose a risk to human health (Molinari et al., 2013, Domingues; Paulino, 2009). The primary aim of this methodology is to prevent the generation of waste and gas emissions (Pimenta; Gouvinhas, 2012; Molinari et al., 2013). When waste cannot be prevented, recycling is the next best option. Companies should either reintegrate it into their production process or find a third-party solution. (Molinari et al., 2013).

Approximately 56 million tons of polyethylene terephthalate (PET) were produced worldwide in 2013, and its main consumers were the beverage and food industries (Yoshida et al., 2016). In that same year, a total of 195 billion beverage containers were sold in the United States, of which about 20 billion bottles were recycled, representing a little more than 10% (Kanga et al., 2017; Euromonitor International, 2013). In Europe, 25.2 million tons of plastic waste were produced in 2012, of which 62% was recovered through recycling and energy recovery processes and 38% was discarded in landfills (Europe; Plastics Recycling, 2017). According to Hendges (2014) in Brazil, a total of 562 thousand tons of PET were produced in 2012, of which 331 thousand tons (56%) were recycled, a higher index than in Europe and the USA. The main PET recycling sector is the textile industry, which accounts for 38% reuse of the waste. The industries of unsaturated and alkyd resins reuse 23.9% and the packaging industries recycle 18.3%. It is important to highlight the speed of growth of this market, which is around 6% per year. ABIPET (2016) has forecasted a growth rate of more than 30% from 2012 through 2016, given the estimated production of 840,000 tons of PET.

The use of PET in short-term consumption products, if not recycled, will result in environmental problems due to their slow degradation and high environmental impact. The advances of new technologies and the support of academic research can promote the use of industrial residues in other sectors of the market (Pivnenko et al., 2016; Magnago et al., 2016a, b; Sadrmomtazi et al., 2016; Yam; Mak, 2014; Andrade; Medeiros, 2012; Zarbin; Oliveira, 2013). The construction industry may consume a large amount of PET waste by including it in its formulations (Pivnenko et al., 2016; Yoshida et al., 2016; Pereira, 2016; Foti, 2011; Fraternali et al., 2011).

Both polystyrene (EPS) and polyurethane (PU) are materials used for construction purposes to improve thermal and acoustic comfort, minimize structural weight, and reduce power consumption (Mendonça, 2014).

In 2013, Brazil produced 100,000 tons of EPS, the most part of which was used in the construction industry (Abiquim, 2014). According to Milk (2013), real estate expansion, mainly housing, added 166 million square meters of construction to the market, with an estimate consumption of 40,000 tons of EPS for sound insulation on construction slabs of buildings.

The construction industry also welcomes the value that polyurethane panels can bring to cost reduction and quality improvement. This happens because of the thermal and acoustic comfort these panels provide in the environment, such as roofs, walls and floors, in which they are installed (GUO et al., 2015). The thermal insulation provided by polyurethane depends on the thickness of the panels, with temperatures ranging from -40 °C to +120 °C. These conditions provide a 14% to 20% reduction in power consumption when installed in walls and a 36% to 42% reduction when installed in the roof with sandwich tiles. When compared to other materials, a much smaller thickness of PU insulation is required to achieve the same level of performance (Europe, 2017).

The use of PU in buildings is possible, provided that it has flame retardant additives, in order to increase safety and evacuation efficiency (ABNT NBR 9178:2015; UL94). The use of PU and EPS as an insulator in building construction is regulated by the Brazilian Association of Technical Standards, namely by ABNT NBR 9178:2015, ABNT NBR ISO 15366-2:2006, NBR 11752:2016, ABNT NBR ISO 31000:2009 and ABNT NBR 15575:2013.

The lack of people's knowledge and often the resistance of businessmen to the added value of recycled materials may lead to improper disposal of residues. Landfill dumps pose a risk of being compromised by flooding and spill dangerous substances into rivers and beaches, in addition to a negative visual impact (National, 2017; Abiquim, 2014). That is why PET recycling is so important. This study presents a bibliographical review of new insulation material for buildings by using PET residues and an estimate of the potential to replace EPS of slabs.

2. Methods

This bibliographic review offers a contribution to the socio-environmental scope, seeking alternatives to using post-consumer waste materials in the construction sector. In terms of methods, the main guideline for the scientific design was the analysis of basic properties of materials to be used as thermal and acoustic insulation of buildings.

As a methodological strategy, we divided the bibliographic material into two topics. Firstly, we identified studies on alternative materials produced from PET and PU, and identify basic criteria for their use in the construction sector, thus facilitating the analysis of these materials. Secondly, we examined the amount of most common insulators consumed by the Brazilian construction market to figure out the potential of replacement by post-industrial waste materials.

An electronic search for articles about recycled PTE materials for the construction industry was conducted in the EBSCO, Google and Scielo databases, using the following keywords: "Insulation Thermal Acoustic", "PET" and "Recycling". For norms and regulations about the use of building materials the following keywords were used: "Technical Standards", "Residential Building", "Risk Management", "Flexible Foam" and "Thermal Acoustic Insulation".

Properties required for building material components include fire resistance and compressive strength, as well as thermal and acoustic resistance, according to the norms ABNT NBR 9178:2015, ABNT NBR ISO 15366-2:2006, NBR 11752:2016, ABNT NBR ISO 31000:2009, and ABNT NBR 15575:2013. Assessment was made of the material properties and the level of compliance with the norms and regulations.

After analysis of the horizontal burning test, fire resistance was measured using the following scale: "complies overall", when the combustion rate was not greater than 38 mm/min (1.5 inches/min); "complies partially", when the combustion proceeded at a rate not higher than 75 mm/min (3 inches/min); and "does not comply", when the combustion rate exceeded 75 mm/min. The materials met the compressive strength requirements if they withstood a minimum tensile load of 1.0 kN (Isoplast, 2017).

To estimate the amount of recycled PET materials that could be used to produce thermal and acoustic insulation boards, we took into account the housing market growth in Brazil, given that apartment buildings most commonly use these insulation boards on the slabs (Leite, 2013), as well as the amount of PET residues incorporated in the composites studied.

Another parameter adopted to calculate EPS substitution was examining whether the recycled materials complied with the norms and regulations of the construction industry as found in the literature. We then estimated the amount of these materials required to replace EPS based on the efficiency information found in the literature. This analysis indicated the potential reuse amount of the selected materials, allowing us to estimate the amount of PET to be recycled. Once the amount of PET in composite percentage was defined, it was possible to infer the quantity of tons per year that would be required to supply the needs of the construction industry in Brazil, based on the EPS consumption previously checked out.

3. Results

New opportunities arise to invest in the production of polymer systems that have properties close to conventional polymers, which meet the needs of other sectors. These products can minimize environmental problems and meet market requirements. The review of the literature pointed to four composites that have from 35% to 50% of PET residue, which was the focus component of the recycling analysis in this study. These composites were analyzed according to the standards required for use as insulators in apartment building slabs.

Using materials for thermal and acoustic insulation in buildings requires examination of the synergistic interaction of the materials due to flammability concerns. The selected authors developed PU plates by mixing PET and 40% alumina trihydrate (ATH) (Magnago et al., 2016b). ATH acts as a flame retardant and smoke suppressor (Ribeiro et al., 2013).

Table 1 displays information about samples with different percentages of PET waste from the mineral water packaging and bottling industry (Magnago, 2016b).

Sample	Percent incorporation	Horizontal burning (UL94)	Mechanical compressive strength
PU/50PET[1]	50	Complies partially	Complies
PU/ATH/50PET	50	Complies	Does not comply
PU/ATH/45PET	45	Complies	Complies
PU/ATH/35PET	35	Complies	Complies

Table 1. PU/PET and PU/ATH/PET composites with different percentages of residue and respective behavior in the horizontal burning test and mechanical compressive strength test.

In the preparation of the PU/ATH/PET composites, part of the isocyanate and polyol monomers were replaced by PET residue, thus reducing the consumption of raw material. The PU plates with different percentages (35%, 45% and 50%) of post-consumer PET bottles presented adequate compressive strength and fire resistance (UL94), as well as good thermal and acoustic insulation. The samples shown in Table 1 have the desirable properties to be used as filler in buildings because they are light materials, and sufficiently rigid and inert to water.

The samples of PU/ATH/PET with 35% and 45% of PET presented a mechanical compressive strength greater than 1.0 kN (0.001 MPa), which means they meet the norms for application in the construction industry.

Determining the burning characteristics of the materials is vital for insulation purposes in buildings, given that polyurethane foam forms toxic gases when taken to complete/incomplete combustion, (Singh; Jain, 2008; Vilar, 1999). In the horizontal burning test (UL 94) the PU/ATH/PET samples in the percentages of 35%, 45% and 50% met the required standards. In this way, polyurethane foams contribute to keep the environment safe because the test results revealed a deceleration of the flames and suppression of smoke, providing greater evacuation time in case of fire.

The samples of PU/ATH/35PET and PU/ATH/45PET, having 35% and 45% of post-consumer residue in the compositions, respectively, were considered suitable for thermal and acoustic insulation after mechanical compressive strength and flammability tests.

According to the bibliographic review, the total volume of EPS used annually for thermal and acoustic insulation of slabs in buildings was 40,000 tons (Leite, 2013). To estimate the volume of EPS to be replaced, we calculated the equivalent percentage of PU/ATH/35PET and PU/ATH/45PET composites.

The calculations for the composites approved by the normative comparisons led to the following results. The PU/ATH/45PET composite, with the highest amount of PET, indicated a possible use of 18,000 tons of PET per year, according to the findings by Leite and France (2013). The PU/ATH/35PET composite indicated the recycling of 14,000 tons of PET waste. These figures would represent 2.5% to 3.2% of the 562,000 tons of PET produced in Brazil in 2012 (Hendges, 2014). If the production projections of ABIPET (2013) were taken into account, the recycling potential could rise to 21,000—29,500 tons of PET by using the composites.

The amount of solid waste is increasing dramatically worldwide, mainly because of the development of the fast-food industry (food and beverage packaging) and population growth. It is known that it takes about 300 years for PET to decompose naturally through the action of biological agents. The

PU/ATH/PET composites contribute to the proper waste disposal and add value to the post-consumer PET waste. PET reincorporation into the production chain represents a new life cycle and avoids environmental impacts. PET bottles have high volume compared with their weight ratio, which causes occupying lots of space during transport and disposal in landfills. Therefore, one of the ways to eliminate plastic waste is to reuse it in other industrial areas. The construction sector seems to be appropriate because it can consume a significant amount of PET waste. Thermal and acoustic insulation panels have a long-life cycle, and therefore, are not disposable in a short period of time. Another advantage of using insulation panels is energy saving, giving that heating costs in the winter and cooling costs in the summer are very high. To sum up, there is a great potential for the use of PET residues as an aggregate in the manufacturing of thermal and acoustic insulation panels.

4. Conclusions

In this study, the combined effects of PET particle residues on PU materials on the mechanical properties and flammability of PU/ATH/PET composites were analyzed. The following conclusions were drawn:

1) The incorporation of 35% and 45% by weight of PET to PU resulted in the manufacturing of plates suitable for handling and possible installation as a sandwich-slab structure.

2) The PET-particle composites complied with the required tensile and compressive strength.

3) PU/PET composites showed decelerating fire propagation behavior in the horizontal burn test (UL94), although the addition of ATH was required to meet the standards.

4) The composites increase the possibilities of post-consumer PET recycling, thus contributing to increase plastic waste recycling.

5) The use of PET residue contributes to proper waste disposal and prevents further damage to the environment.

Further studies on PET recycling are recommended. A pilot-study should be carried out on PU/ATH/PET plates with 35% or 45% residue, and the economic feasibility should be analyzed.

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