Research on Recycling Mixed Wastes Based on Fiberglass and Organic Resins

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Abstract. In recycling, according to principles of Directive 2008/98/EC of the European Parliament and of the Council on waste, research is upheld for achieving innovative technologies for reuse and keep as long it is possible, in economic chain, a waste. The aim of this research is to study and test a new composite material based on fiberglass waste mixed with organic resins with large application in the industry but not limited to this. Fiberglass is a material widely used for reinforcement of composite materials. As waste, fiberglass was less studied for ways to be reused. Filling fiberglass mixed with organic resins as PMMA and epoxy resins possess proper physical features for thermoforming. Three mixes are studied: fiberglass with PMMA, fiberglass with PMMA and rubber granules or sawdust. Samples will be tested for to define the mechanical and chemical behavior to have a complete description of the material. Analyzing the results can be concluded that mixes are suitable for board production, with improved features, compared with equivalent products on the market.

1. Introduction
Recycling worldwide, in the last decades, became a significant issue in industrial production. On the strength of legislation, which sets new goals to be reached, but also is a demand for sustainable management implemented in a rapidly increasing number of companies. Reasons are increasing efficiency through reducing costs. Reuse of outputs, and reintroduce them in the production process, is a way these aims can be achieved. EU legislation through European Strategy for plastic in a circular economy proposes to change the way in which plastic products are generally treated, and improve the design of plastic products, growing recycling rates and enhance the quality of recycled products.

The concept of physically blending of two or more polymers to provide a new material is attracting large interest and commercial utilization [1]. The main material used is fiberglass mixed with PMMA. Other components are studied as being utilized in addition. PMMA is widely used in the glazing sector and rubber-reinforced materials were developed to improve its properties [2]. Three mixes will be studied. The purpose of the research is to conceive, design, fabrication and test the composites materials based on three mixes.

PMMA parts can be created by a wide range of techniques including hot embossing, injection molding, laser ablation, reactive ion etching or deep UV lithography and have mechanical properties superior to those of poly(dimethylsiloxane), (PDMS, another material of choice for microfluidic applications), guaranteeing a better fidelity to the initial shape under mechanical stress conditions [3].
The use of recyclable wastes as precursors for new composite materials is an intensely exploited research field, that has been approached by many research groups [4, 5] in order to obtain new materials with improved physical and mechanical behavior.

In our research group, obtaining new composite materials [6, 7, 8], especially those in which they are used diverse types of waste, constitutes a continuous preoccupation. Several results relating to the design and characterization of the composite materials using as materials diverse types of waste have already been published [9, 10].

In this paper we present a new obtaining method of composite materials, based on production wastes containing glass fibers and poly(methyl methacrylate) (PMMA), without the addition of other components.

2. Materials and methods

Poly(methyl methacrylate) (PMMA) is a polymer widely used in various industries. As boards, it is used in the industrial process, where is thermoformed, for obtaining bathtubs. After cooling from the mold, it is reinforced, on the outside, with sprayed fiberglass in order to become more resistant. Later the product is polished to remove the roughness and to fit for commercial use. Along with this process, a variable quantity of PMMA and fiberglass flakes is results (see Figure 1).

![Figure 1. Fiberglass mixed with PMMA.](image)

In our studies, three types of mixture were used, as shown in Table 1.

| Sample | Components                   |
|--------|------------------------------|
| 1      | Fiberglass, PMMA             |
| 2      | Fiberglass, PMMA, rubber     |
| 3      | Fiberglass, PMMA, sawdust    |

For samples manufacture was used a forged steel mold. Working pressures vary between 0.7÷0.15 MPa and temperature between 110÷170 ºC. With a cylindrical shape and two plates mounted on both sides of the mold, is designed to heat the material in both directions through ERH (electrical resistance heating) embedded (figure 2).

When the mold mix reaches optimum temperature, as consequence acquires the necessary plasticity, the hydraulic cylinder is turned on to distribute uniformly the mix in the mold forming cavity. The product is kept in the mold under pressure, for a certain period, for a gradual cooling of samples. Figure 3 show a sample obtained by this technique.
Figure 2. Mold used to obtain the samples.

Figure 3. Sample obtained from PMMA with fiberglass.

The traction testing was accomplished using an INSTRON 3366 equipment (Figure 4). ASTM-D618-87 is the procedure for determining the traction characteristics of composites having a polymeric matrix and being reinforced with discontinuous and continuous fibers.

Figure 4. INSTRON 3366 during bending testing.

Standards and norms to determine traction characteristics of composites having a matrix, consisting of plastics and reinforced with fibers, are: ASTM E83-85 for checking and calibrating extensions and ASTM E4-85 for testing the samples on test machines. Figure 5 show a sample tested for bending.

Figure 5. Sample used for bending test.
In order to determine the bending behavior testing was realized following standards: ISO 14125, DIN 53390, ASTM D 4476, conducted with INSTRON 3366 equipment.

The method of processing for the obtained samples is thermoforming, the working temperatures for thermoforming ranged 110÷180 °C and the processing time is 60 minutes.

3. Results and discussions

PMMA is used in this case as a polymeric matrix to take over and transmit the load in the obtained composite material, for this reason must have high mechanical strengths. In order to achieve materials with good physical properties, the matrix must be compatible with the reinforcement material; it must adhere and be embedded with it. In the presented case, this strong bond between the two materials was achieved, and after the grinding process the materials used were uniformly mixed. This gives us advantages such as lower processing temperature and better embedding of the fiber with the matrix.

The melting temperature Tt varies between a maximum of about 130 °C and a minimum of 70 °C, this being a measure of the degree of crystallinity.

Physical compatibility is determined by the difference between the coefficients of thermal expansion, the deformation capacity and the melting temperature of the composite components. The difference between thermal expansion coefficients is less so physical compatibility is better.

\[ \Delta \alpha = \alpha_m - \alpha_f \rightarrow 0 \]  

Where: \( \alpha_m \) is the coefficient of thermal expansion of the matrix material and \( \alpha_f \) is coefficient of thermal expansion of the reinforcement material. The melting point of the reinforcement material (1300°C) is superior to that of the matrix (105°C), thus avoiding the melt degradation of the reinforcement material. However, the deformation of the two components must be close (coefficient of thermal deformation of the matrix material PMMA is 0,065 [mm/m °C] DIN 53752 and the coefficient of thermal expansion of the reinforcement fibers is 0,5·10^{-5} [{°C}^{-1}].

The obtaining of the material is carried out in a mold at a pressure of 10 tones, the polymer being brought to the softening temperature. Due to the softening temperature, the polymer acquires the necessary plasticity and the pressure distributes it to the mold cavity.

The thermoforming process is held inside the mold (figure 2), under pressure for 1 hour, after which the mold is opened, and the plate is left in place for cooling until it reaches 60 °C and the finished piece is removed. Heat for plasticization, pressure, temperature and pressing time represented the main process parameters.

For testing the mechanical properties of the materials, bending tests were performed according to the standards ISO 14125, ASTM D 4476, DIN 53390. The samples used to determine the bending properties had the section size of 7x7 mm and the length between the milestones was \( L = 10 \) mm.

The bending tests results are shown in Figure 6.

![Figure 6. Bending tests results.](image)

The tensile test was performed, according to the standards ASTM-D618-87, by applying an increasing axial force to a specimen, usually until it is broken, recording variations corresponding to
the length of the specimen. In order to perform this test, two samples with the size of 12x7 mm and the length between the milestones was L = 65 mm was used. The shape of the samples used in the tensile test is illustrated in Figure 6. The results obtained by tensile tests are illustrated in Figure 7.

![Figure 7. Tensile tests results.](image)

The both bending and tensile testing are the most important type of analysis to evaluate the mechanical stress which can occur in the case of a product.

4. Conclusions
PMMA mixed with fiberglass and in addition to other components is a versatile material and possess characteristics for being reused in industrial production. Boards are a desirable form to be produced, with a large domain of usability.

PMMA starts to soften at a relatively low temperature of 110°C and offers the possibility of adhering to the surfaces of the constituent materials, in this case the glass fiber. In the collision, the press material was completely homogenized in the die cavity forming a flat plate without material gaps or surface defects. In order to obtain the good results, account must be taken of the properties of PMMA, which is the most sensitive component of the composite material.

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