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Thermal compression process for the recycling of composite materials

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Abstract

In this paper the recycling process of composite materials by thermal compression is presented. The types of materials that can be recycled through this process are composite materials of a percentage of polyethylene, polyester and polyethylene terephthalate, which will serve as binders. The process consists of three stages; the first stage is crushing the material for obtaining flakes, the second stage is the compression combined with heating up to 200°C for dissociation of the particles and the third phase consists of the gradual cooling to prevent heat stress. This allows the process to be flexible; it depends on these parameters, so that this recycled material presents suitable mechanical and thermal properties. The material obtained by this recycling process can be recycled back an indefinite number of times without losing any of its properties, it is also a flexible material in terms of processing the same as machining and thermoforming being able to be used in various applications.

Keywords: *Thermal Compression, Recycling, Process, Composite material.*

1. Introduction

Nowadays composite materials are used in diverse applications such as packages, containers, coatings, seals, furniture, among others due to their mechanic and thermic properties. These types of materials are composed by layers or grains of different materials, combining most of the cases; metals, plastics, fibers or celluloses. For example, we have the Tetra Pak containers better known as Tetra Brik.

For the merging and forming of the composite material including layers or particles of polyethylene, polyester or polyethylene terephthalate that is used as a binder is required [1, 2].

The problem of using composite materials is found at the end of their service life because given their composition they are not biodegradable and the recycling by traditional methods results difficult and expensive. For the recycling of composite materials by metals plastics and celluloses, the repulping process is used; it separates the material's particles into its original components. Another option is using the material as fuel for ovens, reactors or turbines since cellulose is a combustible material. Thus, metals such as aluminum can be used as catalyzers in ovens and the polyethylene works as oxidizer. Unfortunately, these two processes generate high costs and pollutant effects also few times the 100% of the material is recovered [1, 2].

Thermal compression presents a cheap and simple alternative to repulping, besides allowing the forming of a useful material for different applications such as; the creation of containers, furniture, construction panels, construction pieces and insulators, among others.

Thermal compression is a simple process that can recycle almost every composite material with a minimum of pollutants and energy consumption. This process does not require the adding of binders for particles and does not generates any remnant since the 100% of the material is used for obtaining the final agglomerate. Also, it is a flexible process since the involved variables as pressure, temperature and time can be modified in order to obtain different results according their physical properties.

Nowadays only a little percentage of composite materials are recycled by similar processes to thermal compression.

1. Thermal compression process

In this work the process of thermal compression for recycling urban solid waste was applied, specifically Tetra Brik aseptic cartons for food. These containers are composed by 6 layers of 3 different materials: aluminum, LDPE (low density polyethylene) and Kraft paper. The Layers are disposed as shown in the figure 1.

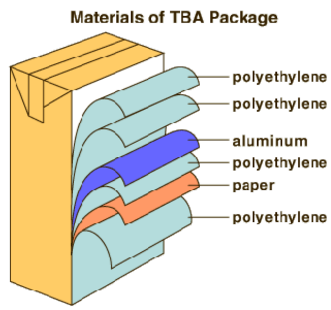

Fig. 1. Layers distribution in Tetra Brik Aseptic cartons.

Although the materials in the container are highly recycled individually at industrial and domestic environments, when the walls of the container are formed they adhere permanently and it turns the separation and recycling process expensive and complex.
The common process for recycling this material is repulping, process driven and created by Tetra Pak, which involves the crushing and separation of materials by centrifugation. [4]
Each Tetra Brik package contains in average 75% of cardboard, 20% of low-density polyethylene and 5% of aluminum. The material of which the package is made of becomes ideally for this process due to it contains 20% of binder.
The developed thermal compression process consists of three stages described in figure 2.

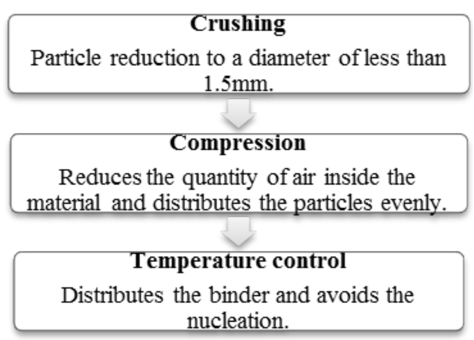

Fig. 2. Stages of thermal compression for recycling materials.

Each stage grants the material a previous preparation necessary for obtaining a homogenous result and a material with mechanic properties such as: resistance, flexibility, malleability and hardness.

Fig. 3. Metals, plastics and celluloses.

1.1. Crushing

The composite materials such as aseptic containers for liquids are made of mostly from celluloses and plastics as PET, PVC, HDPE, LDPE and PP which are soft materials.
The crushed material is composed by at least three parts; metals in low amounts, celluloses or fibers and polymers. When crushing a material, it is aimed to cut it obtaining a reduction of particles with a diameter smaller than 1.5mm composed by a percentage of all the present materials in the original material. With this, the even distribution of the polymer, which will be used as binder, is expected and will grant the final mechanic properties as resistance and hardness [6].
For crushing the material, a shear strength of 1.3Pa is needed, which can be generated by any grinder or mill used for grains such as coffee, corn or chickpea.
During the crushing stage, the separation of the material is not desired but the mixture of all materials in pellet form. Therefore, the diameter of the particle must be controlled by controlling the distance between the grinder's blades.

1.2. Thermal Compression

In the compression stage it is needed to obtain the appropriate density of the material by the even distribution of its particles. This is achieved by suppressing the air between the particles because it enhances the contact of the solids with the binder and reduces the nucleation of the material.
Pressure is the variable to interact with in this stage. Given that we talk about plastics, metals and celluloses in the same particle we need different points of cadence and resistance. Therefore, pressure must generate enough stress for the deformation of all kinds of materials, but it must not avoid the distribution of the binder element because in that case it could generate porosities that may affect the internal resistance of the material [5].
For this stage it is required to include molds that will serve as dies and will be responsible of the final form in the recycling process. The needed pressure will be between 50KPa and 150KPa, distributed along the whole material,

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being 50KPa the minimum for obtaining a solid material that will not break or have porosities.
In order to obtaining a solid state of the material, it is required that the particles agglutinate forming an agglomerate.

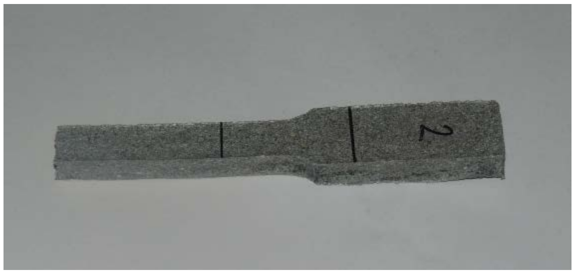

Fig. 4. Agglomerate after thermal stage

1.3. Temperature Control

In order to achieving the union of particles it is needed to take the polymer on its liquid stage where it could occupy the vacancies between the other particles and in that way generate an internal support web. For a plastic such as PET, HDPE, LDPE or PP the yield point by temperature is obtained at 170°C [6,7].
After the temperature increase, a decrease of itself must exist. If not, the material could lose cohesion. The temperature decrease must be gradual and controlled until it reaches a temperature of 5°C. It is important that the material continues confined in the mold or swage during this stage, the confined time depends of the size of the mold.

2. Results

For this process, a hand-cranked grain mill from the brand “Estrella” and a self-made hydraulic press with 20 Ton “Surtek” cylinders and temperature controls taken from a “Bosch” electric oven used for baking bread, with a range from 20°C to 500°C.
The process was applied to Tetra Brik aseptic containers, which have layers of the three suitable materials for the process.
For this process the presence of the binder is needed, in this case, it is the low density polyethylene which will create an internal support web for the remaining particles. Therefore, the variation of size of the particles and temperature for study was pursued.

Table 1. Stages and its variation throughout the process

Stage	Type of variation	Range	Objective
Crushing	Size of the particle	1.5 - 5 mm	Improve the resistance to compression, traction and shear strength.
Compression	Pressure on the particles	50 - 150 KPa	Eliminate the air particles, improve cohesion.
Thermal stage	Maximum exposition temperature	120 - 200 °C	Improve the flow of the binder
	Exposition time	5 - 25 min	

In Table 1 the corresponding rubric to each variable applied to each stage is shown. Each variable is applied for obtaining a specific objective that has repercussion in the mechanic properties of the material.
In figure 5 the results of the variation of previously showed parameters are shown and their repercussion on the resistance of the material. The traction tests were performed under the ASTM-E8 norm, made on a universal Shimadzu machine.

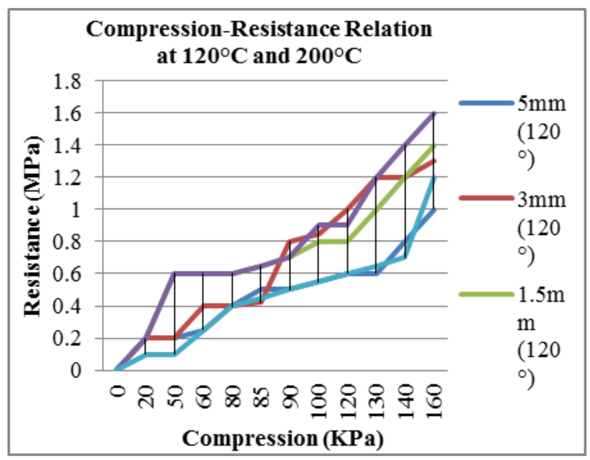

Fig. 5. Relation between compression and resistance of the material at a temperature of 120°C.

In figure 5 we can notice one of the tests of the thermal compression process applied to the recycling of Tetra Brik containers varying the size of the particles from 1.5mm to 5mm and the pressure level for compression from 10KPa to 160KPa. We can observe a comparison between the material under a temperature of 120°C and 200°C.
When increasing the pressure over 160KPa the gaps between particles are eliminated. Therefore, the polyethylene in liquid state cannot flow properly and the

material will lose cohesion and will become breakable and porous.

In figure 5 we can also notice that at a pressure of 87KPa there is no variation in the resistance of the material even when changing the temperature between the particles of 1.5mm and 3mm. This allows us to find pressure points where the size variations of particles would not affect the resistance of the material.

4. Conclusions

Statistics of the generation of urban solid waste in Mexico show that the 31% of urban solid waste consists of materials such as metals, plastics and celluloses.

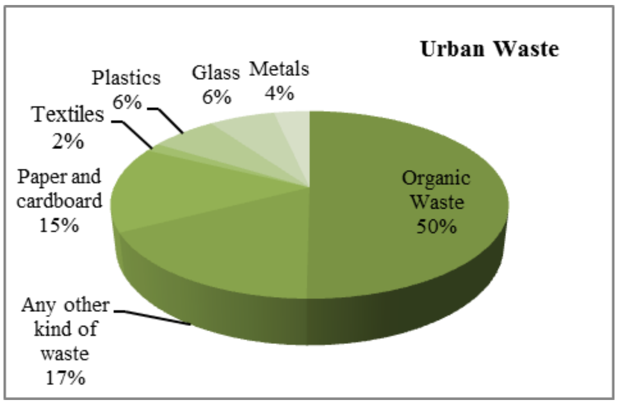

Fig. 6. Composition of Urban Waste in Mexico. [4]

Almost 9 million tons of waste can be recycled annually only in Mexico City, at least 40,000 annual tons are calculated per entity to be composite materials that could be recycled by thermal compression.

By using thermal compression process for recycling of a percentage of urban solid waste it could be saved almost an 80% of resources used in the production of materials with the same applications of the recycled materials.

The thermal compression process offers flexibility in two main aspects:

It can be applied to different types of composite materials such as food packages, wheels, cellulose panels and fibers, among others.

The parameters could vary in order to obtaining from the same raw material diverse types of materials with different applications and properties.

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