PLEA 2020 A CORUÑA

35th PLEA Conference on Passive and Low Energy Architecture

Planning Post Carbon Cities

Editors:
Jorge Rodríguez Álvarez
&
Joana Carla Soares Gonçalves

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Exploration of an Architectural Component with Environmental Functions from The Mechanical Recycling of PET

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ABSTRACT: This interdisciplinary research uses a process of mechanical extrusion and pressing to incorporate titanium dioxide nanoparticles (TiO2) into a recycled PET plastic film in order to explore the potential for a new building envelope material with the capacity to degrade atmospheric contaminant gases. The behaviour of a new architectural material with 8% of photocatalytic nanoparticles incorporated in this mixture, microscopy observations confirm the presence of TiO2 nanoparticles at the surface of the new material, reaffirming the photocatalytic potential. Assessment of the fragility properties showed tendency to break, with a loss of viscosity and elasticity, this combination and coordination of materials to achieve a new polymer with enhanced properties and characteristics constitutes an important opportunity in architectural design that could lead to the incorporation of new, environmentally beneficial functional properties and trigger a new phase of prototype development.
KEYWORDS: Recycled plastics, Architectural materials, Nanotechnology, Secondary raw material, Building envelope

1. INTRODUCTION

The present research concerns the creation of a new material and is oriented and motivated by the key materials design notions of origin, technological sense, and objectives. As such, it addresses the problems of plastic waste accumulation and urban atmospheric contamination by exploring the possibility of converting this waste into a new material with added photocatalytic properties which could contribute to atmospheric decontamination in cities. The proposal involves the manufacture of a new building envelope material from mechanically recycled polyethylene terephthalate (PET) imbued with photocatalytic potential by the incorporation of a semiconductor catalyst in the form of titanium dioxide nanoparticles.

1.1 Photocatalytic envelopes

In the context of the environmental challenges facing architects today, the issue of the envelope as a building component has opened up new, very specific fields within the development of new technologies and building systems. One of these fields concerns the problem of urban atmospheric contamination and addresses the possibilities of mitigating the impact of this environmental phenomenon by means of the building envelope itself.

The construction industry has embraced the notion of incorporating photocatalyst nanoparticles into architectural materials based on their capacity, through a process of oxidation, to degrade contaminants such as carbon monoxide (CO), nitrogen oxide (NO_X), volatile organic compounds (VOCs), formaldehyde (CH_2O), and other industrial emissions.

According to data from the Iberian Association of Photocatalysis (AIF), in 2019, the principal applications for photocatalytic materials were paved surfaces (51%), façades (40%), interior surfaces (7%), and roofing (2%) [2]. The most commonly used photocatalytic façade surfaces include ceramic coatings and panels, cement mortars, waterproofing barriers, and photocatalytic vitrified steel panels. Our focus on the building envelope as the subject of exploratory research into plastic reuse is to expand this emerging field of application with the design of a new photocatalytic PET material.

1.2 Atmospheric contamination and its implications in Chile

Atmospheric contamination in urban areas remains one of the most severe environmental problems facing the fields of architecture and urban sustainability. On the global level, OECD estimates for 2050 suggest that, unless addressed immediately, poor air quality in cities may become the principal environmental cause of illness and death [6]. In this context, PM10 and PM2.5 particulate matter are

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among the main atmospheric contaminants, with the latter having the most serious effect on short- and long-term personal health.

The 2018 World Air Quality Report [1], which assesses the world's most polluted countries and cities, identified Chile as the country with the highest levels of PM2.5 contamination in the Latin American and Caribbean region. Of the ten most contaminated cities in the region, seven are in Chile, and the capital, Santiago, is the seventh most contaminated in the region. Of the remainder, the cities of Padre de las Casas and Osorno are categorised as "unhealthy for sensitive groups".

Although the problem of pollution has led to implementation of plans and programmes by the Chilean government, the focus has been on management of critical episodes in certain cities by means of palliative measures such as vehicle restrictions, transport management measures, clampdowns on fixed sources, agricultural burning bans, and bans on the use of solid fuel heating [7].

In light of this, one of the objectives of architectural and materials design should be to develop solutions to mitigate atmospheric contamination in urban centres. As such, the present research seeks to explore the possibility of creating a material which responds to its surroundings through its photocatalytic capacity to degrade atmospheric contaminants.

1.3 Plastic waste as a raw material

Initiatives aimed at the reintroduction of materials into production cycles have identified waste as a potential secondary raw material. The European Parliament Directive on waste (2008/98/EC) is one such initiative, and establishes that, by 2020, at least 70% of non-hazardous construction and demolition waste should be prepared for re-use, recycling and other material recovery [4].

Within this new cyclical notion of raw materials, particular attention has been paid to plastic waste. Plastic waste has been identified and documented as both a political and an environmental issue [3,5] and, given its potential toxicity and slow rate of degradation, has been identified as a risk to human health and ecosystem welfare. The present research therefore seeks to address the cycle of this material.

2. MICROARCHITECTURE OF A NEW PHOTOCATALYTIC ENVELOPE MATERIAL

Given the possibilities for reintroduction of plastic waste into the production cycle and the urgent need for atmospheric decontamination in cities, the present study focuses on the design of a new photocatalytic building envelope material. The first step in this process is the mechanical recycling of PET waste and its material stabilisation through incorporation of photocatalytic titanium dioxide (TiO_2) nanoparticles. This was achieved by means of an interdisciplinary process that we have termed *microarchitecture*, and which involved various exploratory phases.

2.1 Stabilisation of the new material

An iterative, exploratory process of trial and error was used to achieve a stabilised mixture. The procedure involved qualitative analysis of certain mechanical properties of the new material, namely fragility, presence of bubbles, and calcination. This permitted us to determine the behavioural viability of the material in accordance with construction industry standards, as well as to establish the optimum procedure and raw material proportions.

Furthermore, in terms of its potential to degrade atmospheric contaminants, we needed to demonstrate the presence of nanoparticles on the surface of the material, thus ensuring a photocatalytic reaction upon exposure to ultraviolet rays. This was achieved by means of an electron microscopy of the semi-finished product, which revealed the presence of nanoparticles both within and on the surface of the material.

2.2 Exploratory questions

Exploration of the stability of the new material was conducted in response to two critical questions:

How does the new material behave in terms of fragility (tendency to break) and calcination (as a result of overheating)?

Does the process result in a presence of TiO_2 nanoparticles at the surface of the new material?

3. EXPLORATORY METHOD

Exploration of this new building envelope material was conducted at the Environmental Architectural Materials Exploration Laboratory (LEMAA, School of Architecture), the Polymers Laboratory (POLILAB, Faculty of Chemistry and Biology), and the Centre for Nanoscience and Nanotechnology (CEDENNA), all of which are part of the University of Santiago, Chile.

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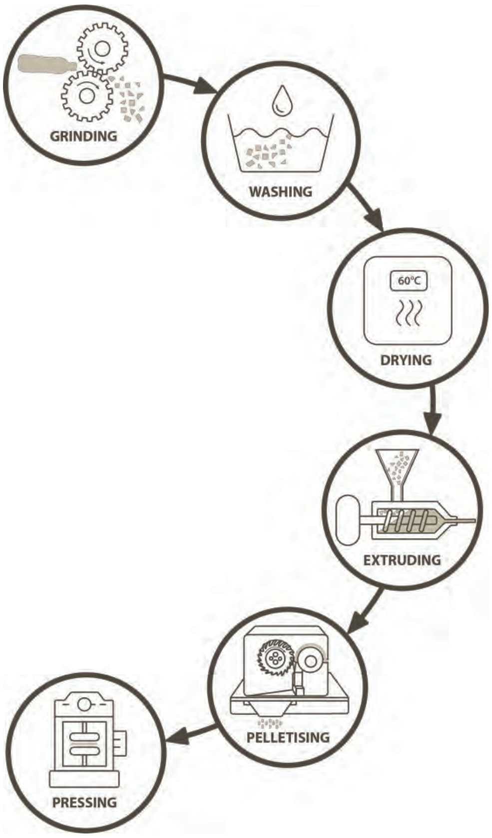

Figure 1: Mechanical exploration process.

As can be seen in Fig.1, PET waste is prepared by means of a mechanical process of grinding and washing in readiness to be mixed with the catalyst nanoparticles in an extruder, where temperature, pressure, and rotation speed variables are iteratively adjusted to achieve an optimal mixture. The newly extruded material, known as Masterbatch, is then pelletised.

Finally, the pellets are pressed according to different configurations of temperature, pre-contact time, contact time, and cooling time.

4. MICROARCHITECTURE RESULTS

Component proportions and a number of variables relating to the mixing process itself were found to be crucial to ensuring the stability of the new material.

We succeeded in establishing the optimum temperature and mixing duration for thermofusion and extrusion of the components.

Plastic materials are subject to two main transition temperatures: glass transition temperature (Tg) and melting temperature (Tm). As a material reaches each of these transition temperatures, changes occur to its properties and it transitions from rigid to rubbery, and eventually to liquid.

A differential scanning calorimetry (DSC) suggested that the material would become flexible at between 73°C and 80°C (Tg) and combine at between 240°C and 260°C (Tm).

A larger proportion of nanoparticles resulted in a more fragile Masterbatch with reduced elasticity and increased viscosity, while the incorporation of too few nanoparticles would diminish the photocatalytic properties of the material's surface.

Figure 2: Exploratory microarchitecture: Masterbatch experimentation.

As can be seen in the right hand image of Fig.2, combination of PET waste and nanoparticles according to the temperature ranges established above resulted in a stable Masterbatch. The extruded mixture was irregular in thickness, cloudy white in colour, homogeneous in terms of component distribution, and had greater fluidity.

5. MECHANICAL QUALITATIVE ASSESSMENT

Having mechanically combined the two components, the resulting Masterbatch is then pressed according to certain temperature, pressure, cooling time and pressing time variables to produce films of 150 mm x 150 mm x 3 mm in accordance with Chilean testing standard NCh 873.

Changes to the pressing variables resulted in different film behaviours. Thermal treatment of the Masterbatch prior to pressing resulted in improved visual, mechanical and chemical behaviour.

Furthermore, addition of Teflon sheets over the stainless-steel plates to protect the material as it is pressed improved homogeneity and expansion within the pressing frame and reduced fragility caused by sharp changes in temperature.

5.1 Fragility

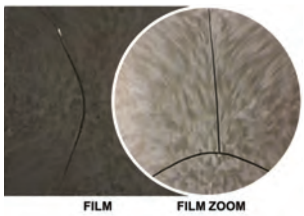

Figure 3: Qualitative assessment of brittle film.

As shown in Fig.3, analysis of pressed samples reveals clear differences between the films. The amount of moisture absorbed by the Masterbatch must be less than 4%, as greater humidity results in increased fragility and makes mechanical testing impossible. This was a novel finding that confirmed the value of the experimental procedure adopted by the present microarchitecture study.

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5.2 Bubbles

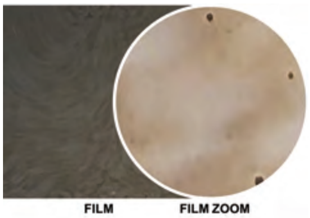

Figure 4: Qualitative assessment of film with bubbles.

The distribution of the pelletised Masterbatch on the pressing plates, i.e., whether all of the material is placed in the centre of the plate or spaced out evenly to the edges, is another variable that affects the behaviour of the film.

A study of the microarchitecture of the pressed film revealed the presence of surface bubbles as a result of uneven distribution of pellets on the pressing plates (Fig.4).

5.3 Calcination

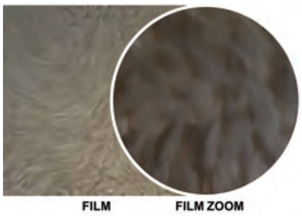

Figure 5: Qualitative assessment of calcinated film.

As shown in Fig.5, differences in film colouration are observed according to thermal treatment of the material during pressing. Temperatures higher than 260°C resulted in calcination at the edges of the film and directly affected the mechanical properties of the material.

6. CHEMICAL BEHAVIOUR

Following incorporation of the TiO_2 nanoparticles, the chemical behaviour of the mixture was analysed, and the films were studied to determine the presence of nanoparticles at the surface and thus establish the photocatalytic potential of the material.

Two electron microscopy analyses were conducted in order to test the behaviour of the nanoparticles within the film.

6.1 Transmission Electron Microscopy

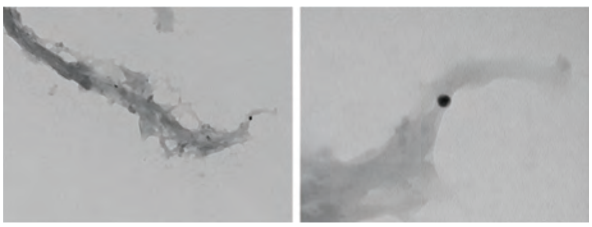

Figure 6: Presence of nanoparticles on film surface.

As can be seen in Fig.6, transmission Electron Microscopy (TEM) analysis of the samples revealed a distribution of the nanoparticles throughout the film, thus validating the proposed combination of recycled PET with TiO_2 to achieve a photocatalytic building envelope material.

6.2 Scanning Electron Microscopy

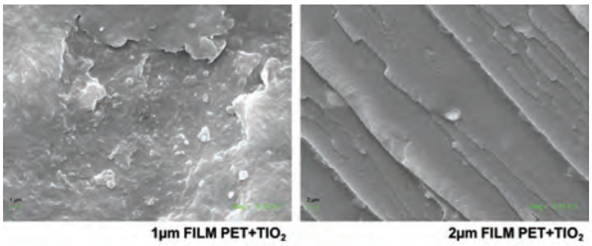

Figure 7: Surface analysis of new material.

Greater surface roughness would increase the area of contact between the film and the air, thus increasing its capacity for gas exchange. Scanning Electron Microscopy (SEM) analysis of the composition and surface of the material revealed an irregular but uniform microarchitecture that would not only improve its photocatalytic performance but would also make it tactile and easy to clean, making it more attractive as a potential building envelope material (Fig.7).

7. CONCLUSION

Analysis of the test samples suggests that effective combination of the two components is indeed possible.

Incorporation of 8% titanium dioxide (TiO_2) nanoparticles resulted in a loss of the original viscosity and elasticity of the recycled PET and the production of more aqueous and viscous extruded samples that showed greater crystallinity following pressing – in other words, greater fragility of the film. These observations constitute a basis for future studies into nanoparticle weights and proportions in order to improve compatibility of the two elements.

Using electron microscopy, we were able to identify varying distributions of TiO_2 nanoparticles throughout the recycled PET film according to different configurations of the production process, thus confirming the potential for the creation of a recycled polymer for photocatalytic applications.

According to data from the Iberian Association of Photocatalysis (AIF), the most commonly used photocatalytic façade surfaces include ceramic coatings and panels. Our focus on the building envelope as the subject of exploratory research into plastic reuse is to expand this emerging field of application with a new photocatalytic PET material, like an architectural component.

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In the current state of this research, this film development is understood as a semi finished product, according to ISO 15270 [8]. Therefore, to validate a proof of concept it's necessary the elaboration of exploratory films in accordance with Chilean testing standard NCh 873 [9], could be scaled as a highlight to the possibility of design a prototype tile for exterior walls of buildings.

As demonstrated by the present study, the combination and coordination of materials to achieve a new architectural component with enhanced properties and characteristics constitutes an important opportunity in architectural design that could lead to the incorporation of new, environmentally beneficial functional properties and trigger a new phase of prototype development.

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Polymers Laboratory (POLILAB), Faculty of Chemistry and Biology, University of Santiago, Chile.

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