Post-consumption foamed polystyrene coatings for surface tension modification

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Abstract. Foamed polystyrene, commercially known as Icopor, occupies a very important place in the transport systems, and conservation of freight and food, but it is also one of the main polymeric pollutants, due to its low biodegradability, and low reuse. Polystyrene has in its structure aromatic and aliphatic functional groups, which have a high hydrophobicity, which makes them candidates as modifiers of permeability and surface properties, although for this purpose the implementation of solvents is also required. In the following work, polystyrene residues for domestic and food use were used to obtain coatings, which allow surface tension to be modified, on surfaces with high water permeability. For this purpose, the polymeric residue was dissolved in organic type solvents, generating a varnish, which was used to coat the study surface, from which the surface tension with respect to water was previously known by analysing the contact angle; to be compared with those obtained after coating, resulting in an increase in the contact angle, which indicates an increase in surface tension, conferred on the new surface hydrophobicity.

1. Introduction
Foamed polystyrene (PS) is one of the most used materials, in our daily life we can identify it in the transport of food and merchandise, its good mechanical properties and asepsis, have made it the first option when choosing a material for packing food, but its low biodegradability has made it a post-consumer waste, quite uncomfortable, to the point of prohibiting its entry or use in educational institutions or factories [1-3].

One of the biggest problems in the construction sector, is the degradation of its materials, due to the effect of moisture, which enters the ceramic materials, usually of high-water permeability, leading to aesthetic and structural damage of the material [4].

The following investigation wants to solve the problem of water degradation in ceramic construction materials, by developing a coating based, on post-consumer foamed polystyrene residues. As an initial step, foamed polystyrene residues from fast food packaging were collected, the material was washed and dried, continued with characterization by infrared (IR) spectroscopy, consecutively solubility tests were carried out on different organic solvents, with the objective to select, the compound that best dissolved the polymer, and allowed to obtain a varnish that, when used as a paint in ceramic materials, that post evaporation of the solvent, generates a polymer film that protects the material against moisture, this protection was evaluated by measuring the angle of contact between ceramic materials and water, the increase in this parameter, corroborates that the surface tension increased and therefore also the hydrophobicity of the material [5,6].
2. Materials and methods

The methodology to develop the coatings, consisted of a characterization and identification of the residue by IR spectroscopy, subsequently, solubility tests in which solvents, were selected for the development of the coatings. The next stage was the implementation of the coatings in the ceramic materials, to finally evaluate the modification of the surface tension, by determining the angle of contact between the ceramic surface and the water.

2.1. Waste characterization

The polymeric material was collected from residues of food products, was subjected to a water wash and ambient drying and cut into small pieces, later it was characterized by IR spectroscopy in a range from 400 cm\(^{-1}\) to 4000 cm\(^{-1}\) with a Bruker Tensor 27 with attenuated total reflection (ATR) cell. The characteristic signals for this type of material were determined.

2.2. Solubility test

Solubility tests were carried out in: toluene, heptane, chloroform and acetone, using 10 grams of polymer in 150 ml of each of the solvents for 24 hours, from these solubility tests, the solvents that showed the greatest solubility of polystyrene were chosen, for later with these apply the coating to the ceramic materials. The polymers have two solubility phases, the initial is only a solvation stage, but the second is a single-phase polymer with the solvent, the solvents chosen, will be those who reach the second stage of solubilization.

2.3. Coating evaluation

The coatings were prepared, by means of the solubilization, of the polystyrene residue in the solvents, previously chosen in the solubility tests, For the evaluation of surface tension 3 types of materials were used, plaster, concrete and foamed concrete, the latter consists of a concrete that at the time of setting gas was injected, generating a structure of greater porosity, therefore, increasing its water permeability. The contact angle was determined using the Dataphysics OCA 15 EC device with a volume of drops was 4 mm\(^3\). Additionally, pieces of the foamed concrete of approximately 12 grams were immersed for 24 hours, in the selected polymer solutions, allowed to dry at room temperature for 6 hours, then submerged in water for 30 minutes and weighed, the results were compared against to a sample without contact with the coating, with the objective of evaluating the effect of the coatings on the water sorption of the material.

3. Results and discussion

3.1. Waste characterization

By infrared spectroscopy Figure 1, it was corroborated that the residue corresponded to foamed polystyrene, the characteristic signals for C-H were observed at 2800 cm\(^{-1}\) - 3200 cm\(^{-1}\), the signals corresponding to the C-C bond of the aromatic ring 1400 cm\(^{-1}\) - 1600 cm\(^{-1}\). Also corresponding to the aromatic fraction, signs are observed in 1943 cm\(^{-1}\) and 700 cm\(^{-1}\) - 800 cm\(^{-1}\).

![Figure 1. IR spectrum of foamed polystyrene waste.](image-url)
3.2. Solubility test

The solubility tests were carried out in 4 solvents toluene, heptane, chloroform and acetone (Figure 2(a)), in all the same amount of residue was added, total solubility was observed in chloroform and toluene (Figure 2(b)), in the case of the latter the high Solubility is due to the presence of aromatic rings in residue as well as the solvent, on the other hand, chloroform being a polar solvent favors the solubility of the residue of a polar nature. While in solvents such as heptane and acetone, solubility was presented, but the process was very slow to the point that \[2,3\], after 24 hours of testing, part of the residue still remained un solubilized. (Figure 2(c)) for this reason, polystyrene solutions in toluene and chloroform were used as coatings.

![Figure 2. (a) Solvents solubility test, (b) solubility test 1 hour, and (b) solubility test 24 hours (c).](image)

3.3. Coating evaluation

Three surfaces were used to evaluate the effectiveness of the coatings: plaster, concrete and foamed concrete, an attempt was made to measure the contact angle, between the water and the three surfaces, but the absorption is so high, that the drop quickly disappeared from the surface of the material, forming angles below 10° for the case of the three materials. The plaster was coated with the PS-Toluene coating (Figure 3(a)) and PS-Chloroform (Figure 3(b)) in both cases an increase in hydrophobicity was observed, obtaining contact angles of 100° and 120°.

![Figure 3. Contact angle plaster coated with (a) PS-toluene and water and (b) PS-chloroform vs water.](image)
In the same way the concrete was covered (Figure 4(a) and Figure 4(b)) in this case there was also an increase in hydrophobicity, manifested by the contact angle obtained of 90°. In the case of foamed concrete (Figure 5(a) and Figure 5(b)), contact angles of 120° were obtained for both coatings.

![Figure 4](image1.png)  ![Figure 5](image2.png)

**Figure 4.** Contact angle concrete coated with (a) PS-toluene and water and (b) PS-chloroform vs. water.

**Figure 5.** Contact angle foamed concrete coated with (a) PS-toluene and water and (b) PS-chloroform vs. water.

In the three materials an increase in the hydrophobicity of the material was seen, this result of the hydrophobic nature of the PS, which when the solvents evaporate generates a thin film, which retains its hydrophobic properties and therefore increasing the surface tension between the water and the materials[8-12].

The results of the sorption test (Figure 6) show how the foamed concrete, that was treated with the PS-Toluene and PS-Chloroform coatings after 30 minutes, of being in contact with water absorb less water against, the untreated sample which absorbed about 5 times more water (Table 1).

![Figure 6](image3.png)

**Figure 6.** Treatment of foamed concrete with PS-Toluene and PS-Chloroform.
Table 1. Sorption water in foamed concrete test.

| Treatment    | Material weight (g) | Material weight (g) post treatment | Material weight (g) post treatment + water | Absorbed water (g) |
|--------------|---------------------|------------------------------------|------------------------------------------|-------------------|
| PS-Toluene   | 12.4230             | 12.6893                            | 14.2712                                  | 1.5818            |
| PS-Chloroform| 12.6549             | 12.8909                            | 14.8104                                  | 1.9195            |
| No treatment | 12.0441             | 12.0441                            | 17.0966                                  | 5.0525            |

4. Conclusions
The coatings obtained, from the dissolution of foamed polystyrene residues, in organic solvents such as toluene and chloroform, increase the surface tension between water and ceramic materials from the construction industry, such as plaster, concrete and foamed concrete, the increase in surface tension is due to the increase in the hydrophobicity of the material. According to the results obtained, the type of coatings obtained are the starting point for the development of protective agents for water and moisture ceramic surfaces.

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