Effect of expanded polystyrene waste in the creation of waterproofing paint

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Abstract. The production, use, and poor management of polymers, and especially of expanded polystyrene, have resulted in various environmental challenges, such as large-scale waste generation, accumulation of toxic substances, and the pollution of natural resources, chiefly of water and soil. Consequently, nations around the world are investing considerable research effort into developing waste treatment and reduction solutions. Some areas have even enacted bans against the use of the material, however, in the Colombian case, it continues to be highly represented in the industry, and given the low cost of this packaging, little effort has been made to find a replacement. Expanded polystyrene is a thermoplastic polymer with low weight, low thermal conductivity, low cost, and low water absorption; factors which have made it a less attractive target for recycling. It has, however, excellent resistance to mechanical compression, which makes it viable for study in other applications such as those considered in the present study, offering advantages in terms of environmental protection without the need to completely eliminate the use of the material. The present study analyses the effects of integrating waste expanded polystyrene into the process of creating waterproofing paint. The research is divided into three major phases: the first focusing on the determination of the paint’s technical requirements using previous research and by means of initial testing; the second, on elimination tests to validate the properties of various samples before preparing the final paint mixture; and finally, a third phase of final tests required for a waterproof paint. The final formula is applied to common materials in the construction sector, such as wood, metal, glass, and concrete, to validate each of the required properties. Among the main results, technical viability was identified in the second sample, which demonstrated the best results at a ratio of 1: 2.5: 2.5 of waste expanded polystyrene, D-limonene and methyl acetate, respectively.

1. Introduction

Due to its low cost and ease of production, expanded polystyrene (EPS) is attractive for manufacturing short-lifespan products such as disposable utensils, packaging for numerous products such as household appliances, and furniture filling. It is also used in a variety of construction materials [1-2]. Due to the nature of its applications, EPS must be a highly-resistant material that does not degrade quickly [3]. The pollution caused by the indiscriminate use of EPS includes municipal landfills full of the light but high-
volume material, which does not biodegrade, as it is highly resistant to the passage of time. According to a study carried out by the Universidad de Manizales, 13% of annual solid waste in Colombia is composed of plastics and their derivatives, among which is EPS, typically called “icopor” [4-6]. The environmental impacts resulting from the wide variety of waste, both degradable and non-degradable, has led to landfill sites being unable to accommodate its immense volume. In many Colombian cities – and in Bucaramanga in particular – concrete actions are not undertaken to minimize the resulting environmental damage [5-6]. Expanded polystyrene is known to be a significant part of this problem, since its non-biodegradable character leads to greater pollution, being reusable in many forms but difficult to destroy [8-9]. For these reasons, the current study proposes the creation of an alternative use for EPS to convert it into the base of an enamel-type paint useful for construction firms and for low-income builders constructing their own dwellings.

In this context, many research centers have studied possible solutions which aim to reuse and recycle EPS, helping to diminish its indiscriminate disposal in landfills or improvised garbage dumps in favour of a second lifecycle [10–12]. To this end, the present project studies the effect of integrating expanded polystyrene waste into a waterproof paint, through the use of environmentally-friendly solvents. This research has as an objective to reduce environmental impacts caused by the material by providing a better alternative.

2. Experimental procedure
The methodology of the current study was designed to achieve the project’s goals while taking into account the particular characteristics of the material under consideration. The work is of a descriptive and quantitative nature, with the results analyzed according to established theories, norms, and procedures, and the formulation of a precise composition of a suitable resin mixture, mineral oil, other solvents, pigments, and fillers, to obtain the paint. The research was divided into three major phases.

The first phase used previous test results to establish the technical conditions for the preparation of the paint. In this phase, EPS waste was collected from electrical appliance and construction packaging. This collection was undertaken without regard to population analysis or statistical sampling, since the generation of EPS waste is continual and not geographically fixed. Material already located in landfills was excluded from the study due to its degree of pre-existing contamination. Figure 1 illustrates the sample used, consisting of MS two from the construction sector. Figure 2 shows the fragmentation of this material for use in the following trials. Once the fragmented material was homogenized, it was washed, allowed to dry, and characterized in order to establish comparative parameters between the material that was recycled and the product of that process.

![Figure 1. Expanded polystyrene.](image1)

![Figure 2. Fragmentation.](image2)

Within this first phase, previous research was reviewed which verified that D-limonene meets the chemical requirements for the creation of the product [7]. This solvent, extracted from orange peels, is
both environmentally friendly and economically efficient. Figure 3 shows the orange peels before being processed, while Figure 4 shows the distillation process, with the final result pictured in Figure 5, being an essential oil of 90% limonene.

The second phase began once the raw EPS and essential oil had been prepared. This stage consisted of a process of elimination. A broad array of samples was prepared, varying the amount of essential oil as a natural solvent with artificial solvents such as ethanol and acetone, while maintaining the proportion of EPS in each case. This step was undertaken to analyze the dissolution of the EPS in a variety of solvents before proceeding to the preparation of the waterproofing paint; thus, seeking to pro-actively discard samples with ineffective results.

Finally, using the data obtained in the preceding tests, the third phase was carried out, in which the waterproofing paint was prepared. In this phase, the stoichiometric relationship of the samples was identified, and the paint was created and applied to materials commonly used in the construction sector, such as glass, wood, mortar, and metal, in order to validate the properties of each sample. The working temperature was controlled at 24 °C, and the properties of each application were checked at 60, 120, and 150 minutes. For the wood and glass tests, the paint was applied by placing a drop onto the material with a pipette and spreading it with a spatula. For the mortar and metal tests, the paint was applied with a brush.

3. Results and discussion

3.1. Previous tests
The characterization of the collected EPS waste showed it to be a good candidate for recycling in paints. The material dissolves readily into limonene essential oil and other common solvents. Previous experimental studies have indicated that the use of limonene with EPS as a resin can be used to develop new waterproofing paints with reduced environmental impact. Expanded polystyrene waste can be dissolved in a solvent such as methyl acetate to produce a more ecologically-sustainable product compared to other synthetic coatings, and the use of limonene represents an even greater sustainability advantage. For the tests carried out in the present study, five samples were prepared with equal quantities of EPS, while varying the proportions of limonene essential oil as a natural solvent, with ethanol and acetone. The results of each sample are presented in Table 1.

Of the preliminary tests, only sample 2 (EPS: d-limonene: acetone) yielded feasible results for the production of a solvent, given its excellent solubility. Film formation by drying occurred at 24 hours, since the solution was kept uncovered, at room temperature, and without additional additives.

During the second phase, various additional percentages or compositions were reformulated, with further testing performed to validate the results. In all cases, no additives, pigments, or fillers were used, and temperatures in the laboratory were maintained between 23.4 °C and 26.2 °C. The preliminary results are presented in the following Table 2.
Table 1. Sample results.

| Sample | EPS (gr) | D-limonene (ml) | Ethanol (ml) | Acetone (ml) | Observations |
|--------|----------|-----------------|--------------|--------------|--------------|
| M1     | 1        | 1               | 1            | 1            | The sample exhibited a gelatinous state before progressing to a solid state. |
| M2     | 1        | 1               | 1            | 1            | The EPS dissolved entirely, maintaining a homogeneous texture for several minutes. |
| M3     | 1        | 2               |              |              | The sample exhibited a soapy texture before becoming a solid film. |
| M4     | 1        | 1               | 2            |              | Minimum dissolution of the EPS, leaving it almost completely solid. |
| M5     | 1        | 1               | 1            |              | Only 4% of the EPS dissolved. |

Table 2. Results of preliminary tests and discarding.

| Sample | EPS (gr) | Limonene (ml) | Methyl acetate (ml) | Ethanol (ml) | Acetone (ml) | Observations and ratios |
|--------|----------|---------------|---------------------|--------------|--------------|------------------------|
| M1     | 0.25     | 0.25          | 0.50                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 2 |
| M2     | 0.25     | 0.25          | 0.75                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 3 |
| M3     | 0.25     | 0.25          | 1.00                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 4 |
| M4     | 0.25     | 0.25          | 1.25                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 5 |
| M5     | 0.25     | 0.25          | 1.50                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 6 |
| M6     | 0.25     | 0.25          | 0.10                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 0.4 |
| M7     | 0.25     | 0.25          | 0.25                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 1 |
| M8     | 0.25     | 0.25          | 0.40                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 1.6 |
| M9     | 0.25     | 0.50          | 0.50                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 2 |
| M10    | 0.25     | 0.25          | 0.75                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 3 |
| M11    | 0.25     | 0.25          | 0.10                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 0.4 |
| M12    | 0.25     | 0.25          | 0.25                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 1 |
| M13    | 0.25     | 0.25          | 0.40                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 1.6 |
| M14    | 0.25     | 0.25          | 0.50                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 2 |
| M15    | 0.25     | 0.25          | 0.75                |              |              | Soluble, viscous, formation of film in 24 hours. 1: 1: 3 |

As is evident from Table 2, the variation in quantity of additional solvent (that is, acetone, ethanol, and methyl acetate), do not follow a mathematical pattern, but are selected to achieve specific proportions. Once mixed, the behavior of the resulting compositions was observed to determine their ability to dissolve the EPS in the solvent combination, as well as to visually verify their viscosity and the film formed by molecular bonds, which maintained its odour and was impermeable once solidified. Out of all the formulas prepared, only the samples from M11 to M15 were retained, that is, those containing EPS: d-limonene: methyl acetate. The remaining samples were discarded.

In these elimination tests, it was found that acetone forms an agglomeration of EPS particles, but this does not form a homogeneous solution, but rather a malleable paste that solidifies into a dry, hard solid. This behavior is useful, in that it allows for the determination of tendencies arising from other combinations of the components. Ethanol demonstrates unfavorable behavior in the proportions used, since the mixture very quickly passes from a gelatinous state into a solid.
With the final mixtures were selected, laboratory tests were carried out after adding the remaining components necessary to produce a waterproof coating: resin, solvent, pigments, and other additives. With the final products thus prepared, they were applied to wood, metal, glass, and concrete surfaces commonly used in construction. The properties of the paints were validated under controlled laboratory conditions at a temperature of 26 °C. In view of the previous test results, additional methyl acetate was used to dissolve the EPS, with manganese dioxide added as pigment and talc as filler. Additional tests replaced the manganese dioxide with natural dyes. Figure 6 illustrates the results on wood using manganese dioxide, compared to Figure 7, which shows the sample using natural dyes on wood. Figure 8 illustrates the trial on concrete using manganese dioxide, compared to Figure 9, which shows the same material using natural pigments. Lastly, Figure 10 shows the results on glass using manganese dioxide, compared to Figure 11, using natural pigments.

![Figure 6. Trials on wood using manganese dioxide.](image)

![Figure 7. Trials on wood using natural pigments.](image)

![Figure 8. Trials on concrete using manganese dioxide.](image)

![Figure 9. Trials on concrete using natural pigments.](image)

![Figure 10. Trials on glass using manganese dioxide.](image)

![Figure 11. Trials on glass using natural pigments.](image)

The use of natural pigments could make the paint more ecologically-friendly, but were discarded for the final mixture in this study, as their opacity and impermeability were noted to be deficient. It was observed that formulations using additional methyl acetate as a solvent demonstrated superior results. For the subsequent stage, the final mixture selected was EPS: d-limonene: methyl acetate in proportions of 1: 2.5: 2.5, maintaining an equal amount of pigment and adding filler (talc).

### 3.2. Final trials and concentration

In the third phase, tests were carried out using a final concentration of 1:2.5:2.5 of expanded polystyrene, d-limonene and methyl acetate respectively; with 0.10 grams of manganese dioxide and with 0.01 grams of talc. The final tests were conducted to validate the solubility, drying time, viscosity, and opacity of the applied paint, as well as its impermeability and adhesion. An ambient temperature of 26°C was
maintained in the laboratory, as it closely mimics real-world outdoor application conditions. The results are presented in Table 3, where similar results are evident across all the simples, with the exception of those applied to glass, which show inferior adhesion compared to those applied to wood, concrete, and metal.

**Table 3.** Final concentration results on wood, metal, glass, and concrete.

| Material  | Sample | Resin (ml) | D-limonene (ml) | Methyl acetate (ml) | Manganese dioxide (gr) | Talc (gr) | Properties | S | Dry | V | O | W | A |
|-----------|--------|------------|-----------------|--------------------|------------------------|-----------|------------|---|-----|---|---|---|---|
| Wood      | MC01   | 0.10       | 0.25            | 0.25               | 0.10                   | 0.01      | 3          |   | Dry | 3 | 4 | 4 | 4 |
| Metal     | MC02   | 0.10       | 0.25            | 0.25               | 0.10                   | 0.01      | 3          |   | Dry | 3 | 4 | 4 | 4 |
| Glass     | MC03   | 0.10       | 0.25            | 0.25               | 0.10                   | 0.01      | 3          |   | Dry | 3 | 4 | 4 | 3 |
| Concrete  | MC04   | 0.10       | 0.25            | 0.25               | 0.10                   | 0.01      | 3          |   | Dry | 3 | 4 | 4 | 4 |

S: Solubility; V: Viscosity; O: Opacity; W: Waterproofing; A: Adhesion

A final ratio of 1:2.5:2.5 of expanded polystyrene, D-limonene, and methyl acetate, with additives of manganese dioxide and talc, was used for these samples. In all of the final samples (MC01, MC02, MC03, and MC04), solubility and drying time were maintained, and the viscosity, opacity, impermeability, and adhesion properties of the paint were in general very good for each of the substrate materials tested; being substantially improved by the use of the talc filler. Adhesion was noticeably weaker for the glass test, however; possibly due to the fact that it is a very smooth material with zero porosity.

**4. Conclusions**

In view of the results observed, both the elimination and the final concentration tests indicate that D-limonene represents an ecological and sustainable solvent with the ability to dissolve waste expanded polystyrene. The quantities produced by the current laboratory experiment were small, requiring the use of a similar concentration of methyl acetate to improve the solubility, viscosity, and drying properties of the paint produced.

This research suggests that coatings developed from expanded polystyrene, d-limonene, and methyl acetate represent a viable alternative for the industrial production of a waterproof, ecological, and sustainable paint. The best results were obtained from a ratio of 1:2.5:2.5 of EPS, d-limonene, and methyl acetate. Together with pigment and talc, this formula resulted in a paint with very good opacity, adherence, impermeability, and a citrus smell. Due to their density, the natural pigments tested did not yield viable results in terms of the opacity and impermeability required.

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