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Stress-Strain Curve Analysis for the Mixture of Expanded Polystyrene and Polypropylene Plastic Waste

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The environmental problem related to urban solid waste generation and management requires alternatives that enable communities to have appropriate collection, transport and disposal methods for urban solid waste. Likewise, it is necessary to develop alternative uses as many of the materials generated can be reused or recycled. Plastic waste is among the types of waste most generated by communities, making up approximately 11 % of waste in middle income countries, some of which possess high commercial value and is easy to recover and recycle, while others are more complicated due to their volume-to-weight ratio. This is the case of expanded polystyrene, which has a low commercial value and few reuse alternatives, making it an unattractive type of waste for the recycling chain, and as a result, while being 100 % recyclable, it still ends up in municipal landfills. In order to facilitate the use of this waste, this paper presents a stress-strain curve analysis for the mixture of expanded polystyrene (EPS) and polypropylene (PP), both recovered wastes, for the purpose of contributing to the physical-mechanical characterization of this mixture to develop future research projects to reincorporate this material in the recycling chain.

1. Introduction

The generation of plastic waste at the municipal level is a growing problem that requires immediate solutions for the proper management of this type of waste, which by definition, in its majority can be reused or utilized in different ways to produce domestic and industrial products or items.

Plastics have become an essential part of the modern lifestyle, and global plastic production has increased significantly over the last fifty years (Gu and Ozbakkaloglu, 2016). However, using some types of this waste is complicated given the characteristics of the material itself, such as a quality decrease of its mechanical properties following its initial use, the technological possibilities required for its proper use as well as the technical, economic and social approaches and possibilities within the system to recover this specific waste in municipalities, as the recycling industry does not process recyclable material when it is financially unattractive (Maldonado, 2012). Likewise, not all plastics are recyclable, for example, elastomers and thermoset have restrictions, even thermoplastics cannot be recycled if they are highly contaminated, as it is more expensive to refurbish them than to send them to final disposal (Maldonado, 2012).

There are different techniques to use this type of waste (see Figure 1), as primary recycling materials are the most used. Different techniques have been developed worldwide to recycle plastic waste, thus reducing its negative impacts and the demand for virgin raw materials. However, it must be taken into account that recycling plastics has restrictions, therefore it should not be the only solution to the environmental problem generated by the increasing consumption and generation of these types of materials (Maldonado, 2012). It is worth noting that mechanical recycling is the most widely used method to recover used plastics, yet the mixture of different types of waste impacts the quality of the product, and thus its monetary value (Ragaert et al. 2017). In the case of EPS, even though there are different ways to reuse it in practice, it is not a waste of significant interest for the recycling chain, which takes into account factors such as the weight and volume of the material, technologies for its use, amount generated, responsibility of stakeholders in the solid waste management process to recover the material, and its low commercial value. The theory suggests that with greater quantities of waste, it is possible to achieve economies of scale, but the existence of other social costs

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that keep more material recovered from meaning more profit must also be taken into account (Maldonado, 2012). However, using a material such as EPS and different mixtures of plastic materials will reduce the utilization of virgin materials, and its reuse will contribute to environmental sustainability and mitigating global warming (Singh et al. 2017).

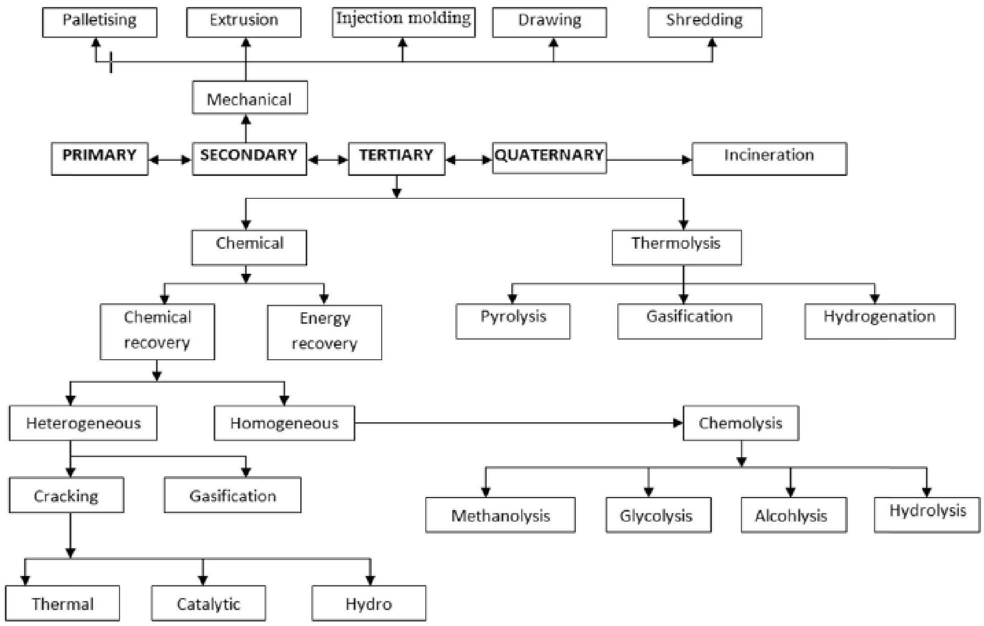

Figure 1. Plastic waste recycling methods (Singh et al. 2017).

When carrying out a bibliographic review it is evident that the EPS has been introduced as virgin material or recovered in the form of pearls, mainly to replace the fine and coarse material in the manufacture of concrete, to obtain the mixture, different types of procedures have been used. ranging from the mechanical disintegration of the materials to the mixture thereof; Within the main physical-mechanical tests developed to this type of mixtures were: compression resistance, modulus of elasticity, tensile strength and density tests; establishing favorable behaviors for this type of mixtures, among the mixtures that have been developed with the EPS, we find the following mixtures:Expanded polystyrene and paper sludge ash (Ferrándiz-Mas et al. 2014); Cement mortar made with recycled high impact polystyrene (Wang et al. 2012); Self-compacted lightweight concrete containing expanded polystyrene (Madandoust, et al. 2011); Structural-graded polystyrene aggregate concrete (Tang et al. 2008); Polystyrene, cement and Concrete (Babu et al.2006); Expanded polystyrene beads and polyamide-66 (Haghi et al. 2006); Foam polystyrene granules on cement (Laukaitis et al. 2005); Residual strength of hybrid fiber reinforced high strength concrete (Chen et al. 2004); Polystyrene aggregate (Ravindrarajah R. S. 1999); Crushed expanded polystyrene waste (Sabaa et al. 1997).

Among other mixtures we have that the EPS has been incorporated as a material recovered and mixed with wood flour through injection processes, the main physical and mechanical tests developed are: flexion and impact resistance, finding favorable behaviors for this type of mixtures (Poletto et al. 2011), (Poletto et al. 2012).

Moreover, polyolefins (particularly polyethylene and polypropylene) are the most important group of plastics, which are characterized by their odorless, non-toxic, and strong chemical resistance nature (Marek et al. 2015). This makes them attractive to use in plastic waste mixtures as a basis for formulating mixtures. Studies have found as overall results that recycled solid waste mixtures have acceptable strength and rigidity for light-duty construction applications (Bajracharya et al. 2016).

As a result, PP was selected to be mixed with EPS, given that the presence of this material (EPS) in plastic waste mixtures has demonstrated that although compounds made with secondary material have poor resistance, the presence of PP could reinforce the mixture and its overall resistance properties (Turku et al. 2017); which can be derived from the specific mechanical properties of this material.

EPS has also been used as a substitute material for fiberglass in auto part manufacturing. When mixed with original PP, the mixture with recovered EPS is viable to replace fiberglass, according to stress-strain, hardness and thermal resistance tests (Betancourt and Solano, 2016).

Moreover, EPS and PP mixture, both of which are recovered materials, has yielded positive results in terms of the mixture obtained and in the characterization of its physical-mechanical properties, such as: flex, impact, flammability and strain, with the 90 % PP – 10 % EPS mixture demonstrating its viability (Solano et al. 2017).
These results demonstrate the viability of obtaining an EPS and PP mixture. However, prior studies are not conclusive regarding the possible applications of this material and establish the need to continue characterizing this mixture in order to determine possible applications that will enable the return of these materials to the production cycle.

2. Materials and Methods

Plastic material recovered from urban solid waste was used to make the mixtures, both for EPS and PP, which was not contaminated with other substances.
Mixture preparation began once the materials were obtained, which for this experiment were established in proportions of: 90 % PP – 10 % EPS, 70 % PP – 30 % EPS, 50 % PP – 50 % EPS, 30 % PP – 70 % EPS, and 10 % PP – 90 % EPS. According to these proportions, the materials were mixed in an internal mixer at a temperature of 190º C in order to obtain a homogeneous mixture of the two materials, which in their initial conditions had different densities. This mixture was then ground in a knife mill to obtain a granulated material that was later used to develop the rod specimens by compression molding.
To conduct the strain-stress test, the ASTM D638 Technical Standard was used as a reference, taking into account the following parameters at the time the tests were performed: relative humidity, ambient temperature, conditioning period, load cell or voltage transducers (kN), test speed (mm/min), effective length (mm), nominal width of rod specimens (mm), and nominal thickness of rod specimens (mm). A total of 7 rod specimens were tested, in accordance to the test requirements.

3. Results and Discussion

The detailed results of the following parameters analyzed are presented below: maximum stress, elongation at break, modulus of elasticity; according to the experimentation percentages detailed in the Materials and Methods section.

Table 1: Results obtained in the stress test

Mixture	Function	Maximum Load [KN]	Maximum Strength [MPa]	Elongation at Maximum Load [%]	Stress at Break [MPa]	Elongation at Break [%]	Yield Strength [Mpa]	Yield Point Elongation [%]	Modulus of Elasticity [Mpa]
50 % EPS 50 % PP	Standard Deviation	0.060	1.608	0.075	1.608	0.075	0.992	0.039	128.014
	Uncertainty (95 % Confidence) ±	0.117	3.747	0.148	4.212	0.148	2.985	0.077	250.902
10 % EPS 90 % PP	Standard Deviation	0.124	2.875	0.492	2.756	0.581	3.053	0.561	307.071
	Uncertainty (95 % Confidence) ±	0.242	7.686	0.965	4.866	1.138	9.067	1.266	601.847
30 % EPS 70 % PP	Standard Deviation	0.082	2.332	0.087	2.332	0.087	1.886	0.069	244.985
	Uncertainty (95 % Confidence) ±	0.160	5.177	0.171	3.780	0.171	3.666	0.136	480.162
90 % EPS 10 % PP	Standard Deviation	0.082	2.075	0.039	2.075	0.039	1.239	0.020	83.298
	Uncertainty (95 % Confidence) ±	0.161	4.718	0.077	4.277	0.077	4.111	0.040	163.262
70 % EPS 30 % PP	Standard Deviation	0.055	1.682	0.066	1.682	0.066	0.305	0.001	184.213
	Uncertainty (95 % Confidence) ±	0.108	3.368	0.137	4.904	0.137	2.254	0.001	361.050

According to the results obtained in Table 1, the 50 % EPS – 50 % PP, 30 % EPS – 70 % PP, 90 % EPS – 10 % PP, and 70 % EPS – 30 % PP compositions; at a speed of 3.75 mm/min, the 7 rod specimens failed, demonstrating that these mixtures are fragile. Under the same conditions with respect to speed and the number of rod specimens used, the 10 % EPS – 90 % PP mixture demonstrated its ductile nature, indicating that the greater the amount of EPS in the mixture, the more fragile the material tends to be.
The maximum values behavior curve corresponding to the percentage of tensile strain vs. stress is presented below in Figure 2, while the graph in Figure 3 displays the standard deviation of the maximum force of each mixture, to analyze the data variability for this result. The 10 % EPS – 90 % PP composition sample obtained the maximum value during the tests carried out (Figure 2), which implies that the higher quality characteristics of the sample are due to the larger quantity of PP, given the characteristics of this material.
However, the curve also shows that the 90 % EPS – 10 % PP composition, even though it had the least amount of PP, was not the lowest quality according to its material behavior performance in the tests. It could therefore be presumed that it is possible to have a suitable composition with intermediate mixing percentages of these materials (EPS – PP), which would enable the use of these two types of plastic waste in considerable quantities, thus making attractive the continued experimentation and exploration of possible use applications for the material obtained.

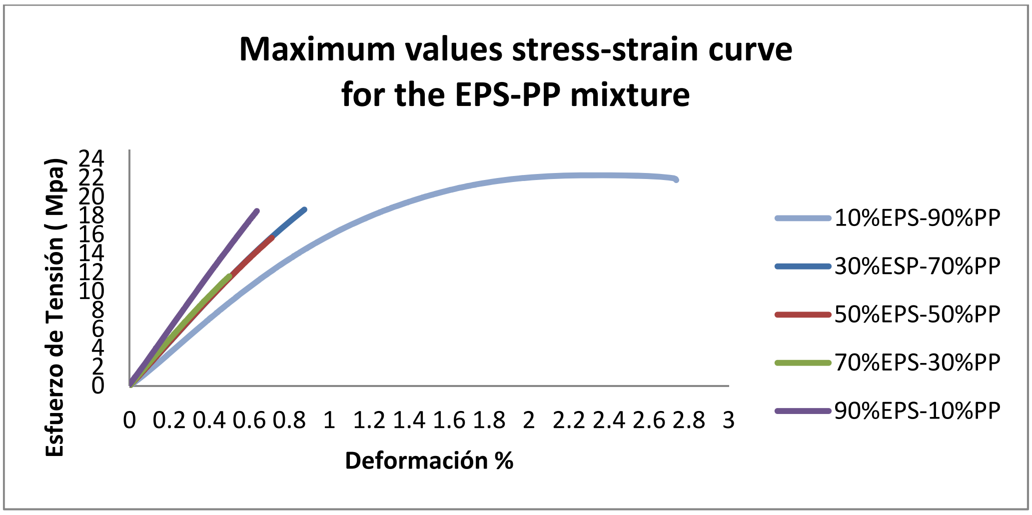

Figure 2. Maximum values obtained from the stress-strain tests.

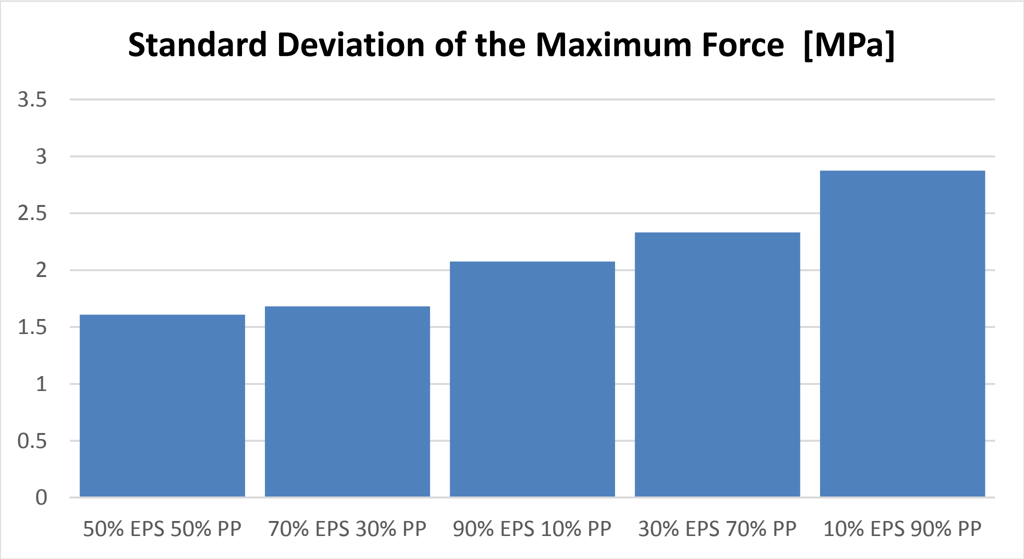

Figure 3. Standard Deviation of the Maximum Force

Figure 3 shows that four of the mixtures have the lowest standard deviation values, with 50 % EPS – 50 % PP and 70 % EPS – 30 % PP with the lowest data variability. The mixture with the highest data variability for its maximum force is 10 % EPS – 90 % PP, which indicates that higher PP content does not necessarily increase the quality of the mixture. Therefore, mixtures with 30 % - 90 % EPS content should be evaluated, which would enable greater use of this problem waste.

4. Conclusions

The maximum values obtained that represent the best material behavior in the stress-strain test correspond to the mixture with the highest content of PP (10 % EPS – 90 % PP). However, the curve analysis and the histogram of the standard deviation of the maximum force show that mixtures with an average EPS content of 30 % - 90 % are of interest to further develop the physical, mechanical and chemical characterization of the mixtures.

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References

Babu, D. S., Babu, K. G., & Tiong-Huan, W. (2006). Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete. Cement and Concrete Composites, 28(6), 520-527.

Bajracharya, R. M., Manalo, A. C., Karunasena, W., & Lau, K. tak. 2016. Characterisation of recycled mixed plastic solid wastes: Coupon and full-scale investigation. Waste Management, 48, 72–80. Waste Management, 51, 19–42. https://doi.org/10.1016/j.wasman.2016.03.005

Betancourt, S., Julieth, D., Solano, M., & Karina, J. 2016. Síntesis y caracterización de la mezcla polipropileno-poliestireno expandido (icopor) reciclado como alternativa para el proceso de producción de autopartes. Luna Azul, (43), 286-310. DOI: http://dx.doi.org/10.17151/luaz.2016.43.13.

Chen, B., & Liu, J. (2004). Residual strength of hybrid-fiber-reinforced high-strength concrete after exposure to high temperatures. Cement and Concrete Research, 34(6), 1065-1069.

Ferrándiz-Mas, V., Bond, T., García-Alcocel, E., & Cheeseman, C. R. (2014). Lightweight mortars containing expanded polystyrene and paper sludge ash. Construction and Building Materials, 61, 285-292.

Gu, L., & Ozbakkaloglu, T. 2016. Use of recycled plastics in concrete : A critical review. Waste Management, 51, 19–42. DOI: https://doi.org/10.1016/j.wasman.2016.03.005

Haghi, A. K., Arabani, M., & Ahmadi, H. (2006). Applications of expanded polystyrene (EPS) beads and polyamide-66 in civil engineering, Part One: Lightweight polymeric concrete. Composite Interfaces, 13(4-6), 441-450.

Laukaitis, A., Žurauskas, R., & Kerien, J. (2005). The effect of foam polystyrene granules on cement composite properties. Cement and Concrete Composites, 27(1), 41-47.

Maldonado, A. T. 2012. La complejidad de la problemática ambiental de los residuos plásticos : Una aproximación al análisis narrativo de política pública en Bogotá. Magister en Medio Ambiente y Desarrollo. Universidad Nacional de Colombia, Facultad de Ciencias Económicas, Instituto de Estudios Ambientales-IDEA . Bogotá, Colombia

Madandoust, R., Ranjbar, M. M., & Mousavi, S. Y. (2011). An investigation on the fresh properties of self-compacted lightweight concrete containing expanded polystyrene. Construction and Building Materials, 25(9), 3721-3731.

Marek, A. A., Zawadiak, J., Piotrowski, T., &Hefczyc, B. 2015. A new efficient method for the processing of post-consumer polypropylene and other polyolefin wastes into polar waxes. Waste Management, 46, 62–67. DOI: https://doi.org/10.1016/j.wasman.2015.08.042

Poletto, M., Dettenborn, J., Zeni, M., & Zattera, A. J. (2011). Characterization of composites based on expanded polystyrene wastes and wood flour. Waste Management, 31(4), 779-784.

Poletto, M., Zeni, M., & Zattera, A. J. (2012). Effects of wood flour addition and coupling agent content on mechanical properties of recycled polystyrene/wood flour composites. Journal of Thermoplastic Composite Materials, 25(7), 821-833.

Ragaert, K., Delva, L., &Geem, K. Van. 2017. Mechanical and chemical recycling of solid plastic waste. Waste Management. DOI: https://doi.org/10.1016/j.wasman.2017.07.044

Ravindrarajah, R. S. (1999). Bearing strength of concrete containing polystyrene aggregate. In Proc. the RILEM 8th Int Conf Durability of Building Materials and Components, Vancouver, Canada (Vol. 1, pp. 505-514).

Sabaa, B., & Ravindrarajah, R. S. (1997, December). Engineering properties of lightweight concrete containing crushed expanded polystyrene waste. In Proceedings of the Symposium MM: Advances in Materials for Cementitious Composites, Boston, MA, USA (pp. 1-3).

Singh, N., Hui, D., Singh, R., Ahuja, I. P. S., Feo, L., & Fraternali, F. 2017. Recycling of plastic solid waste : A state of art review and future applications. CompositesPart B, 115, 409–422. DOI: https://doi.org/10.1016/j.compositesb.2016.09.013

Solano J.K.M., Orjuela D.Y., Betancourt D.J.S. 2017. Determination and evaluation of flexural strength and impact, flammability and creep test through dma, (dynamic mechanical analysis) for mixing expanded polystyrene and polypropylene from municipal solid waste, Chemical Engineering Transactions, 57, 1339-1344 DOI: 10.3303/CET1757224

Tang, W. C., Lo, Y., & Nadeem, A. B. I. D. (2008). Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete. Cement and Concrete Composites, 30(5), 403-409.

Turku, I., Keskisaari, A., Kärki, T., Puurtinen, A., &Marttila, P. 2017. Characterization of wood plastic composites manufactured from recycled plastic blends. Composite Structures, 161, 469–476. DOI: https://doi.org/10.1016/j.compstruct.2016.11.073

Wang, R., & Meyer, C. (2012). Performance of cement mortar made with recycled high impact polystyrene. Cement and Concrete Composites, 34(9), 975-981.