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Investigation of the mechanical behavior of laminated composites gypsum-based plastic sack waste fiber

Indra Mawardi*, Samsul Bahri, Hamdani, Irwin Syahri Cebro, Luthfi, Zuhaimi, Ismi Amalia
Department of Mechanical Engineering, State Polytechnic of Lhokseumawe, Lhokseumawe, 24301, Indonesia
*Corresponding author: indratm@pnl.ac.id

Abstract

The existence of plastic waste, such as used plastic sacks in large quantities, is a crucial problem for the environment and health because of its very low biodegradability. Therefore, reusing plastic sack waste as reinforcement in gypsum composites is a major research issue. This study investigates the mechanical and physical properties of gypsum composites reinforced with fiber layers from plastic sack waste. Gypsum composites are produced using casting gypsum flour as the matrix and various fiber layers from plastic sack waste (1, 2, 3, 4) as reinforcement. Gypsum-based laminated composites were tested for density, flexural strength, and compression. The behavior of mechanical, physical, and damage properties is studied to see its suitability as a building material. The results showed that gypsum composites' density decreased with increasing sack fiber layers. The density of gypsum composites ranges from 1064-1199 kg/m^3, with a maximum value in samples with 100% gypsum. The flexural strength of gypsum composites ranges from 2.21-4.10 MPa, and the compressive strength ranges from 3.5-6.66 MPa. Increasing the number of layers of plastic sack fibers reduces density, flexural strength, and compressive strength. However, all the mechanical properties of gypsum composites met the requirements of the EN 13279-2 standard. Failure of fiber delamination with the resulting matrix is the main cause of the decrease in mechanical strength.

Keywords:
plastic sack waste, gypsum composite, flexural strength, compressive strength, laminated

1 Introduction

Plastic materials have become part of human life and are gradually replacing glass, wood, and metal. Every year the consumption of plastic products in every country continues to increase. It is inseparable from the characteristics of plastics that are lightweight, inexpensive, easily formed, moisture resistant, corrosion resistant, and have good dielectric capabilities, which are the reasons for their use [1], [2]. Furthermore, the massive use of plastic has increased the volume of plastic waste every year, which has become a threat to countries worldwide [3], [4]. Borrelle, et al. [5] estimates that there will be 20-53 million metric tons per year of plastic emissions polluting aquatic ecosystems by 2030.

As plastic waste soars into the environment, countries worldwide struggle to manage the volume of plastic waste using various multidimensional techniques [6], [7]. Management of plastic waste within the circular economy framework is very important; where it be used until its useful life rather than becoming waste that has an impact on health and the environment. It is also one of the techniques for achieving global sustainable development goals.

Plastic sack waste is one of the products of plastic that is widely used as packaging for various raw materials, such as fertilizer, rice, and other agricultural products. Plastic sacks produced in a circular woven form from used and damaged polypropylene polymer material have become one of the plastic wastes that can pollute the environment. Plastic sack waste has the potential as a reinforcement in composites.

The valorization of plastic waste in the construction sector to produce new construction materials for various sustainable building applications plays an important role in the new circular economy model. In line with gypsum and cement composite material engineering by utilizing plastic waste, multiple studies on plastic waste recycling with various review focuses have been carried out by several previous researchers.

Oliveira, et al. [8] have studied the properties of thermal conductivity, density, and flexural strength of gypsum composites reinforced with recycled cellulose fibers and polystyrene. The resulting flexural strength has met the minimum strength requirements for use as a gypsum composite but is insufficient for use in places requiring mechanical resistance.

The mechanical strength of gypsum composites reinforced with low-density polyethylene waste has been published by Gomez, et al. [9]. The resulting gypsum composite with plastic waste has a lighter density, but adding plastic waste causes a decrease in mechanical strength. However, all values of flexural strength and compressive strength exceed the standard's minimum values. Gonzalez et al. [10] have analyzed the feasibility of recycling extruded polystyrene (XPS) waste as a lightweight aggregate in composite gypsum. His research results show that XPS aggregates help reduce density by up to 25.5% and increase thermal conductivity by up to 30%. However, in the same condition, it will significantly reduce the mechanical properties of the composite. Furthermore, several previous researchers have also studied the feasibility of polymer waste as a reinforcement for gypsum composites .[8], [11]–[14].

In another study, it has been reported the use of plastic waste in cement composites. The valorization of plastic bag waste as fine aggregate in concrete on concrete's mechanical and physical properties has been analyzed [15]. The density of concrete decreased significantly after the use of plastic waste reached 40%. This result is also followed by decreased mechanical strength, bending, and compression. The utilization of polyethylene waste to produce plastic cement has also been published [16]. The results showed that plastic cement products contained in a mixture of 25%, 30%, and 35% polyethylene produced the best compressive strength.

Previous researchers have studied various plastic wastes as composite reinforcement for the construction sector. Still, these works have yet to find the use of laminated plastic waste in forming gypsum composites. Therefore, this research investigates the mechanical properties of gypsum composites reinforced with layers of plastic sack waste fibers as a new material in the civil construction sector. Buildings and also promote sustainable materials. Gypsum composite is formed laminated with varying numbers of layers of sacks. Tests for flexural strength, compressive strength, and density were carried out to obtain mechanical and physical properties.

2 Method

2.1 Materials

The material used to form gypsum composites consists of gypsum flour as a matrix and fibers from plastic sack waste as reinforcement. Gypsum flour is obtained from the local market and meets the specifications for gypsum board (ASTM C-1396). This casting gypsum flour is widely used to produce fibrous sheets, list profiles for rooms, moldings, and handicrafts from plaster and sculptures. Used plastic sacks used as reinforcement are one of the wastes collected from PT. Pupuk Iskandar Muda, Aceh. Fig. 1 shows a plastic sack.

Fig. 1. Plastic sack

2.2 Production of gypsum composites

The formation of the gypsum composite begins with placing the gypsum flour in a container and then continuing to add water to the gypsum flour. The percentage ratio of gypsum flour to water is 100: 65. Water is added little by little and then stirred using a mixer at 200 rpm for 30 seconds. The mixture of gypsum and water that has been mixed homogeneously is then poured into the mold that has been provided. The compacted gypsum dough showed a setting time of about 20 minutes, and after 2 hours, the specimens were disassembled, dried for three days in the sun, and finally stored in a room with humidity RH = 50% until the test was carried out.

The gypsum composite reinforced with plastic sack waste is formed in layers (laminate) with a variant of the number of layers of 1, 2, 3, and 4 layers, as for the control sample formed with 100% gypsum. Gypsum composites with variations in the number of reinforcing layers are shown in Fig. 2, and the composites produce in three samples of each variation.

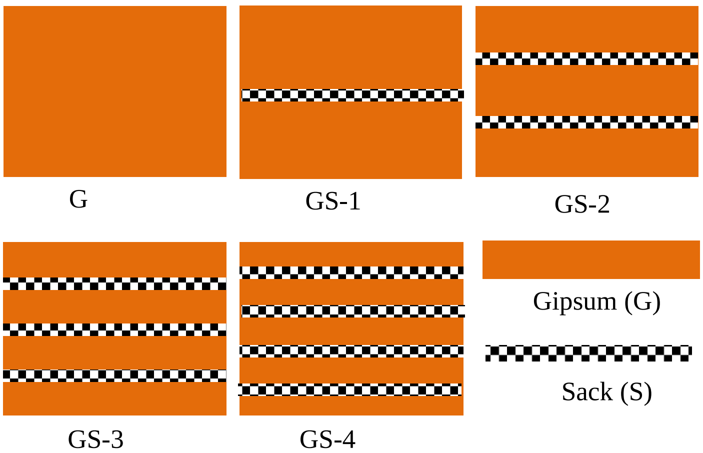

Fig. 2. Variation of gypsum composites reinforced with plastic sack waste

2.3 Testing of gypsum composite with plastic sack waste reinforcement

The gypsum composite test tests the density, flexural strength, and compressive strength. Density testing specimens are formed with dimensions of 50x50x15 mm. The specimens were dried in an oven at 50^0C until the weight was constant. After drying, the specimens were weighed. To get the specimen's density, volume, and weight then calculated by eq. (1), where m is dry mass of the specimen (kg), and *V* is specimen volume (m^3).

$$\rho = \frac{m}{V} \quad (1)$$

The gypsum composite flexural strength test was carried out to test the flexibility of the gypsum composite specimens. Flexural test specimens were made in 3 pieces with dimensions of 405x 105x15 mm, following the ASTM C473 standard [17]. This test was carried out using the three-point bending method with a pressing speed of 2 mm/minute. Fig. 3 shows the flexural testing process for gypsum composites and the flexural strength of gypsum composites calculated by eq. (2), where is maximum load (N), L is pedestal length (mm), b id specimen wide (mm), and t is specimen thickness (mm).

$$\text{Flexural Strength} = \frac{3PL}{2bt^2} \quad (2)$$

Fig. 3. Testing the flexural strength of gypsum composites

The compressive strength testing to obtain the resistance of the gypsum composite for compressive strength. Three specimens of each type of gypsum composite with dimensions of 50 mm × 50 mm × 50 mm were prepared for compression testing. Compression testing follows ASTM C472 standard [18]. This test uses the same machine as the flexural test, with a pressing speed of 3 mm/minute. Fig. 4 shows the compressive testing process for gypsum composites reinforced with plastic sack waste.

Fig. 4. Testing the compressive strength of gypsum composites

3 Results and discussion

3.1. Gypsum Composite Density

Fig. 5 shows the density of the gypsum composite with reinforcement from plastic sack waste fibers. The fig. shows that the density of all variants of the gypsum composite reinforced with sack fiber (50-150 kg/m^3) is lower than that of the sample formed from unreinforced gypsum (200 kg/m^3). The substitution of plastic sack waste for gypsum has reduced the density of all gypsum variants so that the gypsum composite becomes lighter. The density value of gypsum composites in all cases decreased with the increase in the number of layers of plastic sack waste. Compared to the control sample (G), the most prominent decrease in density occurred when the amount of 4-layer plastic sack waste added to the gypsum paste mixture decreased from 1199 to 1064 kg/m^3. This result has been verified by several previous authors, Merino et al. [19] and Gomez et al. [9], who stated that the decrease in mortar density was probably due to the substitution of heavier materials with lighter materials.

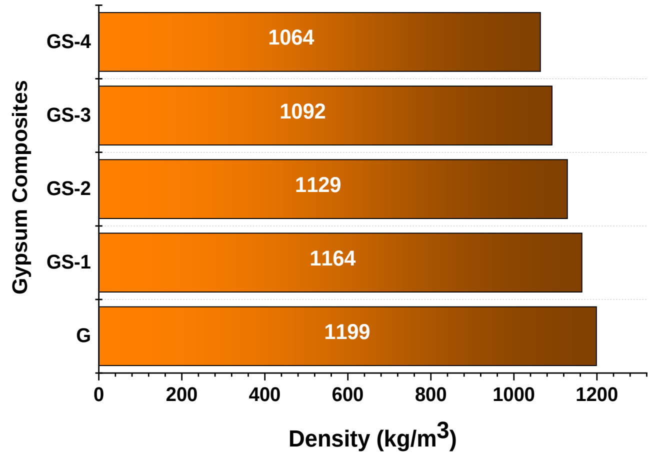

Fig. 5. Density of fiber-reinforced gypsum composites from plastic sack waste

3.2. Flexural strength of gypsum composites

Fig. 6 shows a typical test curve for the flexural strength of fiber-reinforced gypsum composites from plastic sack waste with various layers. The curve generally indicates a trend of decreasing bending stress and increasing strain values with an increasing number of sack fiber layers. This phenomenon indicates an increase in the flexibility of gypsum composites with the addition of sack fiber layers. Plastic sack waste made from polypropylene has positively increased the elasticity of gypsum composites in general.

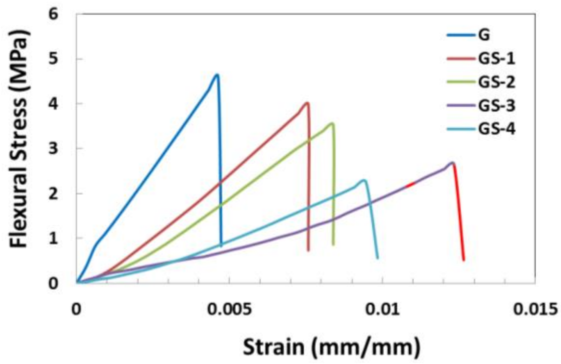

Fig. 6. Typical flexural stress curve for gypsum composites reinforced with plastic sack waste

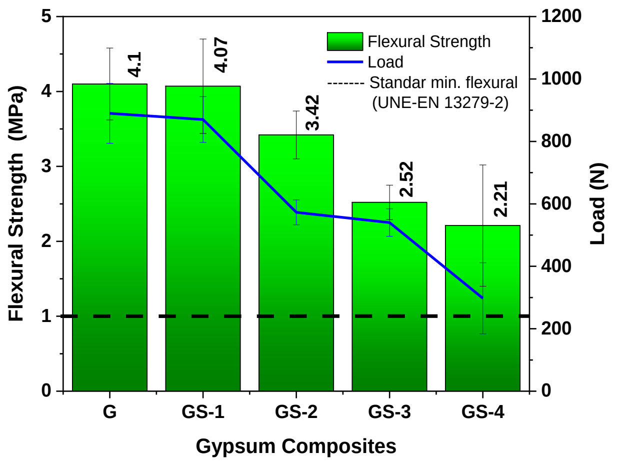

Fig. 7. Flexural strength of gypsum composite reinforced by plastic sack waste

The magnitude of the load and flexural strength of fiber-reinforced gypsum composites from plastic sack waste with various variations in the number of layers is shown in Fig. 7. From Fig. 7 can be observed that the highest flexural strength was produced by the unreinforced variant (variant G) of 4.10 MPa and the lowest at the gypsum composite variant with four reinforcing layers (GK-4) of 2.21 MPa. The flexural strength values resulting from this work are still better than extruded polystyrene-reinforced gypsum [19], low-density polyethylene-reinforced gypsum [9], and match gypsum coated with polycarboxylate [20].

In this case, there has been a decrease in the flexural strength of the gypsum composite up to 53.90% with the addition of 4 layers of sack fiber to the control sample. The decrease in flexural strength due to the reinforcing layer may be due to the poor interfacial bond between the sack and the gypsum paste, where delamination of the reinforcement, in this case, the sack fiber to the matrix in the form of gypsum, occurs. The delamination failure process is the main failure process of the fiber-reinforced gypsum composite from plastic sack waste. Damage due to delamination will increase with the increase in the number of reinforcing layers, which reduces the gypsum composite's flexural strength to the lowest value. However, the value of the flexural strength of the gypsum composite reinforced with fiber from plastic sack waste is above the minimum requirement of 1 MPa set by EN 13279-2 standard [21].

The flexural strength data obtained made it possible to analyze the relationship between density and flexural strength of the gypsum composite fiber-reinforced plastic sack waste. Fig. 8 shows the relationship between flexural strength and density, where the greater the number of sack layers in the composite, the density decreases, and consequently, the mechanical strength also decreases. The results of the relationship between these two properties have also been reported by several previous researchers [8] and [15], where the authors concluded that there is an exponential relationship between density reduction and decreased flexural strength of gypsum composites with the addition of plastic waste.

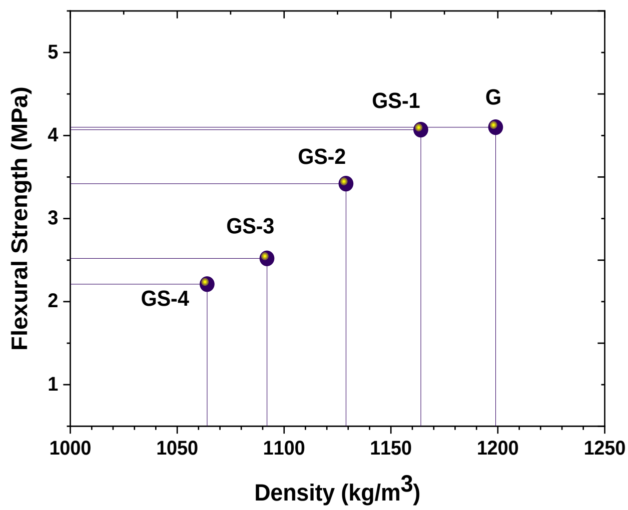

Fig. 8. The relationship between flexural strength and density

3.3. Compressive strength

The results of compression tests on fiber-reinforced gypsum composites from plastic sack waste with the various number of layers are presented in this section. Graphs of the compressive stress curve and compressive strength of the gypsum composite fiber-reinforced plastic sack waste are shown in Fig. 9 and Fig. 10. The compressive stress curve (Fig. 9) generally indicates the same trend as the flexural stress curve. The compressive stress decreased and was followed by increased strain value by adding a layer of sack fiber as a reinforcement.

Fig. 10 shows the compressive strength and maximum load values to obtain the compressive strength values of used sack fiber reinforced gypsum composites. The compressive strength of used sack fiber reinforced gypsum composites ranged from 6.56-3.50 MPa. The gypsum composite produced the highest compressive strength without reinforcement (6.66 MPa), while the lowest value was for the gypsum composite with four layers of used sack fiber reinforcement.

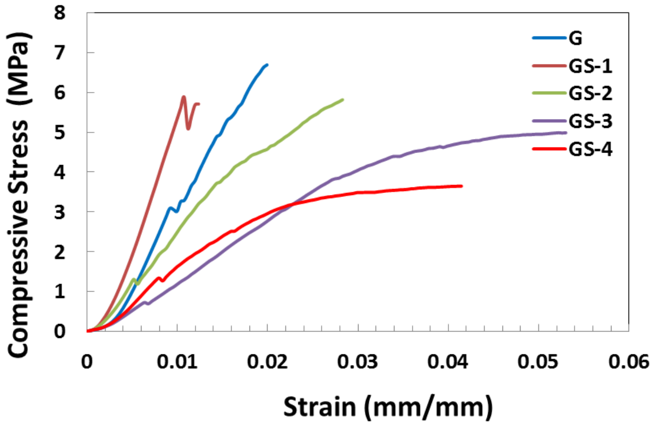

Fig. 9. Typical compressive stress curve for gypsum composites reinforced with plastic sack waste

The compressive strength value of the gypsum composite from this study was higher than the minimum requirements of the gypsum composite set by the EN 13279-2 standard [21]. The results of this work show better than composite cement-reinforced waste polyethylene [16] and lightweight recycled gypsum with residue polystyrene [8].

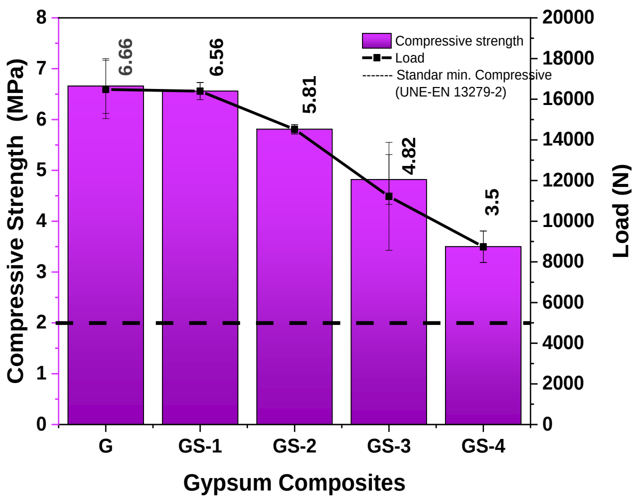

Fig. 10. Compressive strength of gypsum composite reinforced with plastic sack waste

In this case, the compressive strength shows the same trend as the tensile strength with a larger value. With the increase in the ratio of layers of plastic sack waste, the compressive strength value of the gypsum composite of plastic sack waste decreases. This decrease in the compressive strength of the gypsum composite may be due to the poor interfacial bond between the cement paste and the plastic sack waste. The compressive strength decrease increases with the number of layers in the gypsum composite.

3.3. Gypsum composite failure analysis

Damage due to separation between layers (delamination) caused by soft gypsum pastes binding plastic sack waste as reinforcement. Gypsum cannot penetrate the sack fiber layer, so the bond between the gypsum and fiber interfaces becomes weak. It is also inseparable from the differences in the characteristics of the two types of materials. Fig. 11 shows the fracture occurring in each sample layer due to compression and flexure testing. The sack layer triggers the delamination of the fibers against the gypsum composite matrix.

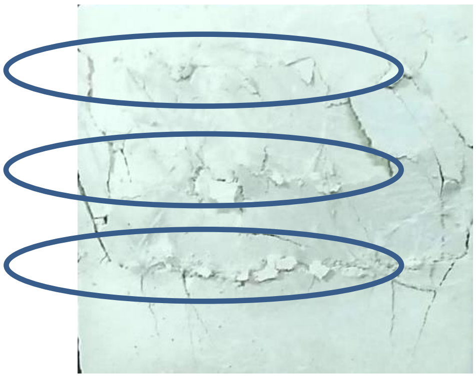

Fig. 11. The damage form of the gypsum composite reinforced by plastic sack waste

4 Conclusion

The results showed that the density of the gypsum composite reinforced with plastic sack waste varied depending on the number of layers of the sack as reinforcement in the composite. The maximum density of the gypsum composite reinforced with sack waste is 1164 kg/m3, which is less than the specific gravity of the control sample, which is 100% gypsum. The mechanical properties of flexure and compression show a progressive decrease with increasing incorporation of plastic sack waste into the gypsum composite. Against the control sample, the flexural and compressive strength of the gypsum composite reinforced with four layers of plastic sack waste fibers decreased by 53.90% and 52.55%, respectively. However, all grades are above the minimum required in standard EN 13279-2. The failure type of fiber delamination with the matrix is the main failure in gypsum composites reinforced with fiber layers from plastic sack waste. This failure was due to the very weak interface of the gypsum and fiber layers.

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Reference

[1] I. Mawardi and H. Lubis, *Proses Manufaktur Plastik dan Komposit*. Penerbit Andi, 2019.

[2] I. Mawardi, A. Azwar, and A. Rizal, "Kajian Perlakuan Serat Sabut Kelapa Terhadap Sifat Mekanis Komposit Epoksi Serat Sabut Kelapa," *J. POLIMESIN*, vol. 15, no. 1, pp. 22–29, 2017.

[3] U. N. E. Assembly, "Addressing single-use plastic products pollution" (UNEP/EA.4/L.10, 2019)," 2019.

[4] U. Nations, "Sustainable development goal 14," 2018.

[5] S. B. Borrelle *et al.*, "Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution," *Science (80-.).*, vol. 369, no. 6510, pp. 1515–1518, 2020.

[6] U. N. E. Assembly, "UNEA resolutions: Marine litter and microplastics (1/6, 2/11, 3/7, 4/6)," 2019.

[7] S. Kaza, L. Yao, P. Bhada-Tata, and F. Van Woerden, *What a waste 2.0: a global snapshot of solid waste management to 2050*. World Bank Publications, 2018.

[8] K. A. De Oliveira, C. A. B. Oliveira, and J. C. Molina, "Lightweight recycled gypsum with residues of expanded polystyrene and cellulose fiber to improve thermal properties of gypsum," *Mater. Construcción*, vol. 71, no. 341, pp. e242–e242, 2021.

[9] M. I. Romero-Gómez, P. Rubio-De-Hita, M. A. Pedreño-Rojas, M. J. Morales-Conde, And F. Pérez-Gálvez, "Recycling Of Low-Density Polyethylene Waste To Produce Eco-Friendly Gypsum Composites," *Waste Manag. Environ. Impact XI*, vol. 257, p. 73, 2022.

[10] A. S.-A. González, M. del Río Merino, and P. V. Sáez, "Lightweight construction material made with gypsum and

exruded polystyrene waste," in *Proceedings of the II International congress on sustainable construction and eco-efficient solutions: Seville 25-27 may 2015*, 2015, pp. 434–442.

[11] S. Karaman, S. Şahin, H. Günal, and I. Örüng, "Stabilization of waste pet bottles with Gypsum," 2006.

[12] M. Álvarez, D. Ferrández, C. Morón, and E. Atanes-Sánchez, "Characterization of a New Lightened Gypsum-Based Material Reinforced with Fibers. Materials 2021, 14, 1203." s Note: MDPI stays neutral with regard to juris dictional claims in published, 2021.

[13] A. San-Antonio-González, M. D. R. Merino, C. V. Arrebola, and P. Villoria-Sáez, "Lightweight material made with gypsum and EPS waste with enhanced mechanical strength," *J. Mater. Civ. Eng.*, vol. 28, no. 2, p. 4015101, 2016.

[14] M. del Rio Merino, P. V. Sáez, I. Longobardi, J. S. C. Astorqui, and C. Porras-Amores, "Redesigning lightweight gypsum with mixes of polystyrene waste from construction and demolition waste," *J. Clean. Prod.*, vol. 220, pp. 144–151, 2019.

[15] Y. Ghernouti, B. Rabehi, B. Safi, and R. Chaid, "Use of recycled plastic bag waste in the concrete," *J. Int. Sci. Publ. Mater. Methods Technol.*, vol. 8, pp. 480–487, 2011.

[16] A. K. Jassim, "Recycling of polyethylene waste to produce plastic cement," *Procedia Manuf.*, vol. 8, pp. 635–642, 2017.

[17] ASTM C473, *Standard Test Methods for Physical Testing of Gypsum Panel Products*. West Conshohocken, PA, USA: ASTM International, 2015.

[18] ASTM C 472, *Standard Test Methods for Physical Testing of Gypsum, Gypsum Plasters and Gypsum Concrete*. West Conshohocken, PA, USA: ASTM International, 2009.

[19] M. del Río Merino, P. Villoria Sáez, J. Santa Cruz Astorqui, A. Rodríguez Sánchez, and C. Porras Amores, "Lightweight gypsum mortar with construction waste to be used as coatings with improved superficial hardness," 2017.

[20] J. A. Flores Yepes, L. M. Serna Jara, A. M. Gabarrón, A. M. Codes Alcaraz, and J. J. Pastor Pérez, "Analysis of Additives in Gypsum Coatings Based on Melamine, Polycarbonate Salts, Polycarboxylate, and Polycarboxylic Acids," *Coatings*, vol. 11, no. 10, p. 1204, 2021.

[21] U. E. 13279-2, "Construction plasters. Part 2: Test methods," 2006.