Mortars With Residues From The Recycling Of Propylene And Ethylene Polymers In Substitutions Of The Natural Aggregate

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Abstract:
Background: The application of the concepts of reverse logistics is growing in several industrial branches, given the demands generated by the environmental impacts caused. Looking especially at the civil construction industry, the use of solid waste can guarantee the maintenance and control of the sector, given the potential and forms of insertion by the various industrial layers.
Materials and Methods: Thus, allied to this, we sought to evaluate the use of residues of ethylene and propylene polymers as construction materials. Initially, the residues were characterized by physical and chemical means; these being inserted in the production of cementitious mortars, by substituting percentages of the natural fine aggregate. The replacement contents of the natural aggregate were 0, 5, 10 and 20%, based on a single line and adopted pattern.
Results: The produced mortars were evaluated in the fresh and wet states, where the correlations between contents and types of residues were considered for the analysis relationships of the technological control variables and microstructural interactions.
Conclusion: In view of the analyzes, it was concluded that the polypropylene and polyethylene residues can be used by partial replacement of the fine aggregate, where the form of request and demand will lead to the choice of the type of waste and form of use.
Key Word: Reuse; Plastic waste; Polymer; Cement mortar; Microstructure.

I. Introduction

All materials have specific conditions for use, and if their properties do not meet expectations, they will likely not be suitable for their intended purpose. As a result, these materials may accumulate as waste or even as landfill debris, which, if not properly managed, can become a significant environmental and social issue.

According to the United Nations[1], as outlined in its action agenda for 2030, the goals for sustainable development include reducing the consumption of natural resources worldwide. Therefore, when we find new uses for materials that were previously discarded and seemingly useless, we contribute to reducing waste accumulation, lowering environmental pollutants, and decreasing the need for extracting natural raw materials. In this context of waste utilization, particularly artificial solid waste, there is a notable concern about the high volume of plastic waste generated by society. Due to its large-scale production and long natural decomposition time, most of the plastic produced today will persist in the environment for many years. Thus, it is crucial to develop

technologies that facilitate the reintegration of these materials into the environment or into industries that can use them effectively[2].

In Brazil, the majority (over 80%) of post-consumer plastics end up in landfills, dumps, streets, parks, lakes, rivers, and oceans—accumulating in these locations for decades before they begin to degrade[3].

Given this scenario, this research aimed to evaluate the possibility of incorporating this type of waste into the construction industry. Specifically, it focused on the finer fraction of plastic waste found in the byproducts of the industrial recycling process. This approach applies the principles of reverse logistics to integrate polypropylene and ethylene polymer waste into construction materials. This aligns with the standards set by NBR 10004[4], which classifies plastic waste as non-hazardous solid waste. Additionally, since these materials are chemically stable and inert to cement hydration reactions, they present a viable alternative for producing cement-based composites—materials that, in theory, will not contribute to future structural pathologies.

The plastic

When a material is described as plastic, we immediately associate the word with a product present in our daily lives or simply with a condition of workability, serving as an adjective or qualifier. According to Gorni[5] plastic is present in people's daily lives in various ways, making it probably the most popular material in the polymer family.

Nunes[6] emphasizes that plastic is a polymeric material that remains solid at its usage temperature, typically at or near room temperature. These materials exhibit some structural rigidity under load and are used in a wide range of applications[7].

The Brazilian Plastics Industry Association (ABIPLAST)[8] estimates that Brazil produced 7.5 million tons of plastic resins in 2017, exceeding the combined resin production of all other Latin American countries.

Figure 1: Evolution of Plastic Resin Consumption in Brazil- Fonte: ABIPLAST (PERFIL; 2014, 2015, 2016, 2018)
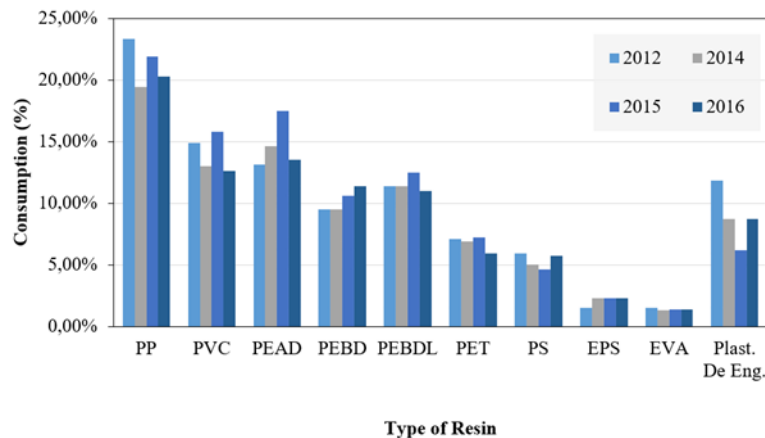

Figure 1 shows the percentage of consumption of the main plastic resins in industrial sectors in Brazil from 2012 to 2016, with polypropylene resins being the most consumed in the national market. According to Nunes[6], this occurs because polyethylene products (HDPE, LDPE, LLDPE) can be classified together, which would make this class of polymeric resins the most consumed during the demonstrated period.

Recycling of Plastic Waste

Starting from the Industrial Revolution and continuing through the 1960s, 1970s, 1980s, and into the late 1990s, a series of agreements, conventions, and laws emerged aimed at making economic development less impactful on the environment and humanity[9].

The search for solutions in waste management reflects societal demand for change motivated by high socioeconomic and environmental costs. When managed properly, solid waste gains commercial value and can be utilized as new raw materials or inputs[3]. In more developed countries, such as those in Europe, the quantity of materials recycled after post-consumption is nearly total. However, in Brazil, this reality has been changing due to the recognition of the energy potential of materials found in waste, leading to the establishment of various recycling industries in several Brazilian urban centers.

Figure 2 demonstrates the availability of the main solid wastes that were discarded in 2019, highlighting that plastic materials stand out among the non-organic waste.

Figure 2: Composition of Discarded Materials, State Solid Waste Plans- Source: MMA (2019) – Adapted
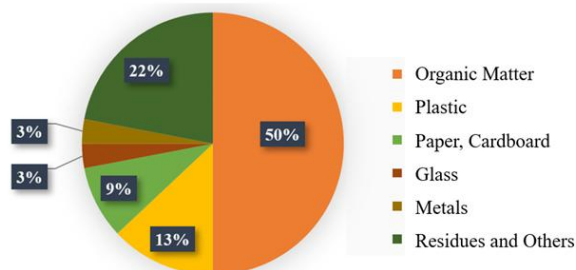
A large part of the plastics produced today will remain in the environment for many years. According to Zanella[2], depending on the type of plastic, their degradation time can vary up to four hundred years. This is because organisms such as fungi and bacteria lack the necessary enzymes to promote faster decomposition in nature.

Some solutions have been developed to reduce the accumulation of plastic waste, such as the creation of biodegradable plastics, which can decompose in about six months, depending on the disposal location. However, studies show that the production of this type of material is relatively high compared to commonly used plastics.

Thus, the best solution for managing plastic waste remains recycling, which generally follows sequential stages within recycling industries: sorting, grinding, agglomeration, extrusion, granulation, and sale of secondary plastic resin.

Recycling plastic waste is not an easy process, as there are various types of plastics with different characteristics and compositions. Therefore, during collection, it is necessary to separate the types of waste and properly dispose of the products. On the other hand, recycling this type of product becomes economically and environmentally viable, as it is believed that the energy contained in 1 kg of plastic is equivalent to that in 1 kg of fuel oil. In addition to recovering energy, recycling also results in a reduction of 70 to 90% of the material's mass, leaving only an inert, sterilized residue[10].

From a socio-environmental perspective, it is estimated that for every ton of recycled material, there is a reduction of 1.53 tons of greenhouse gas emissions in the atmosphere; an average reduction of 1.1 tons of plastic waste disposed of in landfills; an average energy savings of 75%; a conservation of 450 liters of water in production; and the creation of 3.16 jobs for collectors to gather this volume of material each month[11].

II. Material And Methods

Four basic stages were followed to carry out this work. The first stage involved obtaining and characterizing the material samples according to the current national standards for each starting material, except for the cement used, as it was assumed that the material is industrially manufactured and the manufacturer meets the regulatory standards.

The waste materials used here are byproducts from the industrial recycling cycle of plastics, both derived from the grinding stage of the original plastic products but from two different plastic resin matrices, specifically polypropylene and polyethylene polymers. For the sake of better didactic understanding, from this point on, the polypropylene waste was referred to as R-PP, and the polyethylene waste was named R-PE.

For the characterization of the waste, efforts were made to adapt existing tests for fine aggregates. It is important to note that the particle size analysis was conducted as an initial characterization of each of the two types of collected waste, following NBR 7211[12], and it served to inform subsequent decisions in the research regarding the confirmation of the material to be replaced. Additionally, Figure 3, presented below, illustrates the waste materials and compares them to everyday objects, further affirming their apparent similarity to natural aggregate.

Figure 3: Presentation of the Appearance of Plastic Waste.
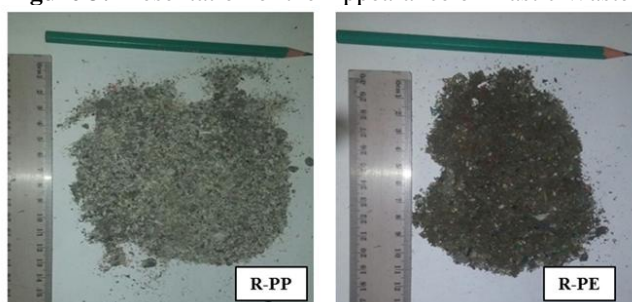
The experimental planning also focused on the possibility of producing a commercial mortar suitable for laying and finishing walls and ceilings that meets the requirements established by NBR 13281[13]. Thus, the study aimed to evaluate the best behavior and interaction of the presented waste through the partial replacement of the fine aggregate in a standard and experimental mix, commonly used in the metropolitan area of Belém-PA, considering the availability and origin of the constituent materials in the mixture.

The defined volumetric basic mix ratio was 1:2.5 (cement:sand), with a water/cement ratio of 0.60. The incorporation of different waste contents was based on the proposed relative percentages of the respective materials. The relative substitution percentages were 0, 5, 10, and 20%, replacing the fine aggregate with R-PP and R-PE waste, with this variation applied to each percentage and type of plastic waste. In these mixes, CP II-F-32 cement was used for the production of the mortars.

For the plastic waste and fractured samples of the produced mortars, analyses of interactions, morphological topographies, and identification of chemical phases (percentage incidence at the predetermined point, through EDS spectrum) were conducted using electron microscopy. The MEV Zeiss model LEO-1430 with IXRF model Sirius-SD EDS was utilized. The samples were previously coated with gold for 90 seconds. The operating conditions were: electron beam current of 90 µA, constant acceleration voltage of 20 kV, working distance of 15 mm, and counting time for element analysis of 30 seconds. Secondary electron images and EDS analyses were obtained at the

Microanalysis Laboratory of the Institute of Geosciences (IG) at the Federal University of Pará (UFPA). Next, Table 01 demonstrates the analysis methodologies for the characterization of the materials used, as well as Table 01 showing the number of mortar samples produced by type and their respective ages for analysis.

Table no 1: Methods for Characterizing the Materials

Characteristic Method Used	Material		Regulatory Reference
Fineness Modulus	Cement Portland (CP II-F-32)		NBR 11579(ABNT, 2012)
Setting Time			NBR 16607(ABNT, 2018)
Specific Mass			NBR 16605 (ABNT, 2017)
Particle Size Analysis	Fine Aggregate (Natural Quartz Sand)	Plastic Waste (R-PP e R-PE)	NBR 7211 (ABNT, 2009)
Specific Gravity			NBR NM 52 (ABNT, 2009)
Unit Weight			NBR NM 45(ABNT, 2006)
SEM/EDS	Plastic Waste (R-PP e R-PE)		-

Table no 2: Summary of Sampling and Analysis Ages

Test	Analysis Age (days)	Total Number of Samples per Test
Consistency Index - NBR 13276 (ABNT,2016)	0	24
Mass Density (fresh state) - NBR13278(ABNT, 2005)	0	24
Mass Density (hardened state)- NBR 13280(ABNT:2005)	28	24
Water Absorption by Immersion - NBR 9778 (ABNT,2005)	28	24
Compressive Strength - NBR7215 (ABNT,2019)	03, 07, 14, 28, 56	120
Flexural Strength - NBR 13279 (ABNT,2005)	07, 28, 56	72
Scanning Electron Microscopy - SEM /EDS	28	10

Additionally, it is worth noting that regarding the sampling, consistency tests were conducted on the fresh state of the mortars. Cylindrical specimens measuring 5x10 cm were also molded to determine fresh mass density, compressive strength, hardened mass density, and water absorption by capillarity and immersion. Furthermore, prismatic specimens measuring 4 cm x 4 cm x 16 cm were prepared to determine flexural tensile strength. For the hardened and fractured samples taken after 28 days (used in the flexural tensile strength test), a microscopic SEM analysis was performed. All the physical analyses mentioned here were conducted at the Civil Engineering Laboratory (LEC) of UFPA.

III. Result And Discussion

Characterization of Aggregates

The particle size analysis, specific mass, and unit weight allowed for the characterization of the waste similarly to natural materials, with the comparison being made to the similarity with natural sand. The results are presented in Table 2 and Figure 4.

Table no 3: Characteristic Results of the Materials

Characteristic	Normative Reference	Unit	R-PP	R-PE	Sand
Maximum Diameter	NBR 7211 (ABNT, 2009)	mm	2,40	2,40	4,75
Fineness Modulus	NBR 7211 (ABNT, 2009)	-	2,49	2,51	2,53
Specific Mass	NBR NM 52 (ABNT, 2009)	kg/dm³	1,05	1,12	2,63
Unit Weight	NBR NM 45(ABNT, 2006)	kg/dm³	0,36	0,38	1,53

**Figure 4:** Particle Size Distribution Curve of the Aggregates
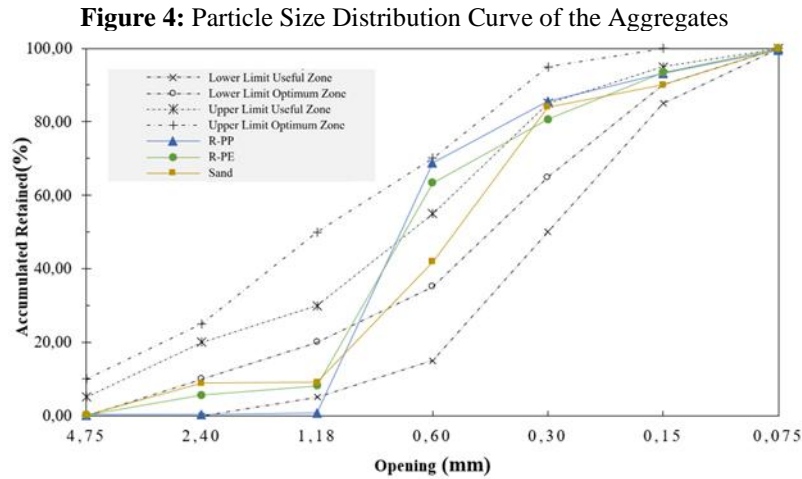
According to the fineness modulus, as per Falcão Bauer[14], this fine aggregate can be classified as well-graded medium-sized, while the R-PP and R-PE residues can be classified as fine to medium aggregates. The apparent specific masses of all the residues demonstrate that they can be classified as lightweight aggregates according to NBR NM 35, as they fall within range 3 of the aggregate grading and correspond to the established limit, making them acceptable as lightweight aggregates for structural concrete with established density.

Moreover, when considering only the absolute values of unit weight, it is observed that the trend of linear variation is practically negligible, unlike natural aggregates. This can be explained by the methodology employed in NBR NM 45[15] and the fact that these are lightweight materials; the particle size distribution and type of material have little impact on these samples of the analyzed plastic residues.

The observation of the surface topography of the studied residues was conducted through images generated from the scanning electron microscopy (SEM) on fractions of each type of material. For each type of sample, qualitative and semi-quantitative analyses of the atomic percentages of incidence of the beams on the surfaces at the marked points for chemical identification were performed, as demonstrated in Figure 5 and Table 3.

Figure 5: SEM Images of Plastic Residue Samples
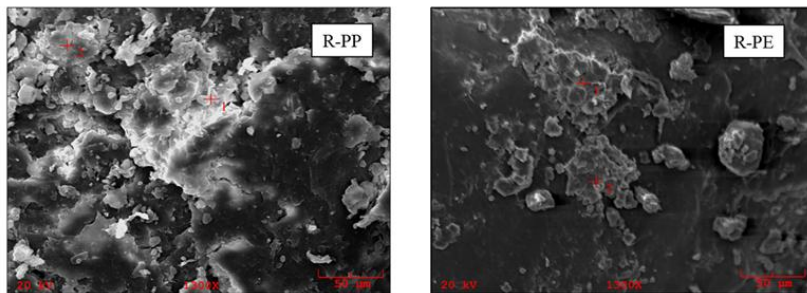
Table no 4: Chemical Elements at Analyzed Points by SEM and EDS Spectrum Readings of R-PP and R-PE Residue Samples.

Chemical Element	% Atomic Incidence			
	R-PP		R-PE	
	Point 1	Point 2	Point 1	Point 2
C	81,35	83,24	81,68	78,96
O	10,36	13,40	6,72	8,68
Al	0,17	0,58	2,42	2,19
Si	1,66	1,22	3,70	3,72
Ca	4,26	0,80	1,65	2,56
Ti	1,74	0,49	1,63	1,01
Fe	0,47	0,27	2,21	2,88

The chemical analysis of the R-PP and R-PE residues identifies similarities with the elements found at the analysis points of the EDS spectra. There is a significant concentration of carbon compared to the other identified elements, which show low incidence percentages. This can be explained by the primary resin formation

characteristics of the residues and the identified elements likely originating from the cleaning process or small fragments of the grinding machinery. Regarding the surface analysis, it is noted that fragments are deposited on top of each other, along with a noticeable variability in sizes and shapes, likely resulting from the blades that promote the grinding of the material in the recycling plant.

Technological Testing of Mortars
Fresh State

Based on NBR 13276[11], consistency was evaluated through spreading, with comparisons made using a 0% replacement content for different usage types. Figure 6 presents the results found for mortars produced with the replacement of fine aggregate by fractions of R-PP and R-PE residues, where the average results were statistically compared among the produced samples.

Figure 6: Spreading for the replacement of fine aggregate with fractions of plastic residues.
(Significant variance when P < 0.05; two-way ANOVA with repetition. Average results and standard deviations marked, P-value for interactions between the substitutions).
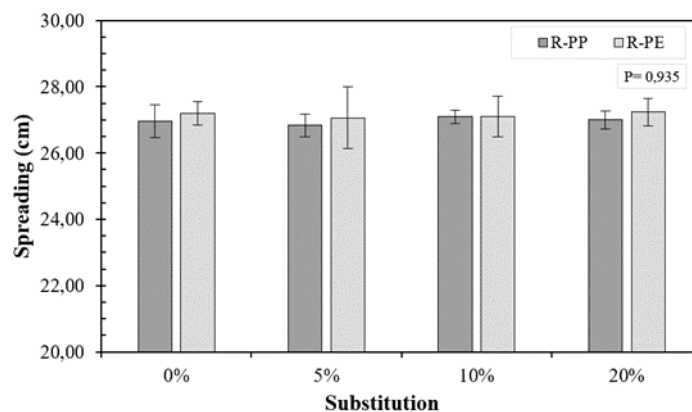

Figure 6 demonstrates that the interactions remain constant as the percentage of aggregate substitution increases. The analysis of variance in the interactions shows that there is no significant variation in the results obtained for the different substitution levels.

This result occurs, probably, due to the similarities found in the grain size distribution for the samples of R-PP, R-PE, and the analyzed natural sand. However, this contrasts with the findings presented in Mello's[16] studies, which included recycled high-density polyethylene particles as an alternative for substituting percentage levels of natural aggregates in Portland cement mortars. Thus, it is believed that this difference may be linked to the use of superplasticizer additives in the mixes of the cited work, which is in opposition to the absence of any additives in the mixes of the mortars produced in this research.

When analyzing only the substitutions, it is noted that the residues exhibit characteristics of non-absorption and non-retention of water; therefore, this influences the behavior of the spreading and, consequently, the consistency of the mortars, emphasizing the functionality of simple space filling while maintaining the cohesion of the mortars without segregation that visibly interferes with consistency.

Still in the fresh state, Figure 7 presents the average result for the produced mortars. These were statistically compared at the same substitution levels of aggregates with plastic residues.

Figure 7: Fresh state mass density for the substitution of fine aggregate with fractions of plastic residues.
(Significant variance when P < 0.05; One Way ANOVA. Average results marked, P-value for each substitution).
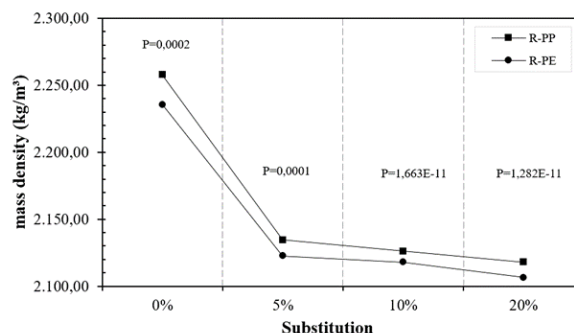
For the different replacement levels of sand with R-PP and R-PE waste, there is a significant difference in the produced mortars, which reflects a behavior already expected when comparing the specific weight of plastic waste with natural aggregate; as the percentage of waste increases, the mass densities decrease. When comparing only the materials, the plastic waste used corresponds to only about a quarter of the apparent specific weight of natural sand, which justifies the significant drop in results from the level of 5% to 20%.

Regarding the differences found for the mortars based on types of plastic waste, it is believed to be similar to the conclusions drawn in the research developed by Passos and Carassek[17], due to the nature of the formation of the waste, as well as the shape and surface that may have influenced the densities when the replacement levels are equivalent.

Para os diferentes teores de substituição da areia por resíduos de R-PP e R-PE percebe-se que há diferença significativa para as argamassas produzidas, o que reflete um comportamento já esperado se comparado o peso próprio dos resíduos plásticos com o agregado natural; onde, à medida que o percentual de resíduos aumenta as densidades de massas decrescem.

Endured state

Based on NBR 13280[18], the values of mass density in the hardened state of the mortars were determined, with comparisons made from the 0% content for the different substitution types. Figure 8 presents the average results found for mortars produced with the substitution of fine aggregate by fractions of R-PP and R-PE residues; it also shows the evolution of the curves and demonstrates a comparison of the variance analysis for the mortars produced with the same substitution rates.

Figure 8: Mass density in the hardened state for the substitution of fine aggregate by fractions of plastic residues. (Significant variance when P < 0.05; One Way ANOVA. Average results marked, P-value for each substitution).
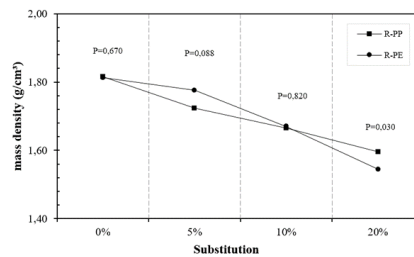

It is noticeable that there is a significant decrease in mass density as the percentage of substitution increases, which is also an expected result when compared to the findings presented by Aguiar Neto [19], who also substituted aggregates with plastic residues in the production of cementitious matrix composites.

Furthermore, when substituting fine aggregate with fractions of R-PP and R-PE residues, it can be observed that when the substitution content is kept constant and only the types of residues are modified, significant variance appears only for the 20% substitution level of fine aggregate. Thus, it is evident that the behavior of density changes from the fresh to the hardened state of the mortar, highlighting the probable presence of free water absorbed, which evaporates during drying.

The water absorption by immersion, obtained based on NBR 9778[20] and presented in Figure 9, demonstrates the average results of the total values found for each sample and type of residue, as well as emphasizes the analysis of variance.

Figure 9: Water absorption by immersion for the substitution of fine aggregate with fractions of plastic residues. (Significant variance when P < 0.05; Two-way ANOVA with repetition. Average results and standard deviations marked).
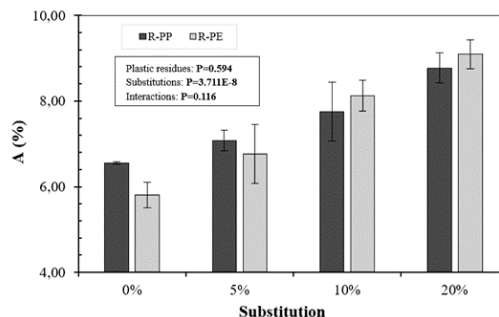
The analysis of variance shows that there is significant variance only at the substitution percentages, where the interactions at the same substitution percentages of fine aggregates with the residues R-PP01 and R-PE02 are equal. However, it is observed that the absorption rates increase as the substitution content increases.

Thus, it is believed that this increase occurs due to the evaporation of free water present in the mixture, as Metha and Monteiro[21] emphasize that capillary voids can grow according to the amount of water present, even though the saturation degree of the aggregates can be practically null. However, as mentioned by Do Val and colleagues[22], in the solid-liquid interaction, water can be adsorbed on the surface of the residues, and after drying, it increases the volume of voids, which consequently increases with the degree of incorporation of the residues.

When analyzing the results obtained for the axial compression of the mortars at the specified ages, comparisons are made for the substitutions based on the type of residue at the determined substitution levels for the natural aggregates.

The evolution of the average curves of axial compression strength of the analyzed mortars is shown in Figure 10, which also demonstrates the analysis of variance for the interactions at identical percentages of fine aggregate substitution.

In general, as noted by Mehta and Monteiro[21] regarding the mechanical behavior of cementitious matrix composites, it is observed that in all samples, the strengths achieved increase with the age analyzed.

Figure 10: Axial compression strength for the substitution of fine aggregate with fractions of plastic residues. (Significant variance when $P < 0.05$; Two-way ANOVA with repetition. Average results indicated, P-value for interactions).
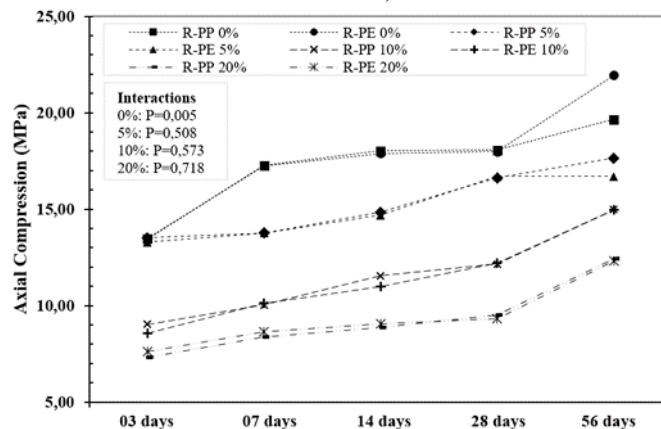
The results show an increase in the axial strengths achieved for the mortars produced with R-PP waste as a substitute for aggregates at different proportions. However, the best results are those with a null substitution degree, and as the proportions increase, the results show a decrease at the same ages, with a decline in results ranging from 35% to 37%, considering the total variation within the highest age and the greatest percentage difference.

For the mortars produced with R-PE waste, similar trends in proportions substituting the aggregates as demonstrated by the previous waste were observed, but the results obtained were lower when compared to the substitution percentages of the various wastes. The decline in the results from the null substitution samples to those with R-PE varies from 43% to 45%, considering the total variation within the highest age and the greatest percentage difference.

This overall behavior demonstrated by the analyzed plastic wastes can be considered expected, as it resembles the findings of Martins, Marcantonio, and Lenine[23], where partial substitution of fine aggregate with plastic waste resulted in a loss of compressive strength compared to the control mix.

The flexural tensile strengths of the mortars were obtained for the specified ages, following the guidelines prescribed in NBR 13.279[24]. The comparisons were made for waste types and usage substitutions.

The data presented here are the average results obtained, with Figure 11 showing the evolution of flexural tensile strengths for the mortars produced by substituting fine aggregate with fractions of R-PP and R-PE plastic wastes, comparing them through the interaction of variance of the means.

For all analyzed mortars, within the substitution percentages, there is an improvement in results as the analyzed age progresses. This emphasizes the good interactions between the phases of waste, aggregates, and paste; as noted by Mehta and Monteiro[21], the density of the transition zone improved over time.

Generally, the best results are those with a null substitution rate. According to Mano[25], this is primarily influenced by the mechanical properties of the composites due to the random dispersion during the application of force.

Figure 11: Flexural tensile strength for the substitution of fine aggregate with fractions of plastic waste. (Significant variance when P < 0.05; Two-way ANOVA with repetition. Average results marked, P-value for interactions).
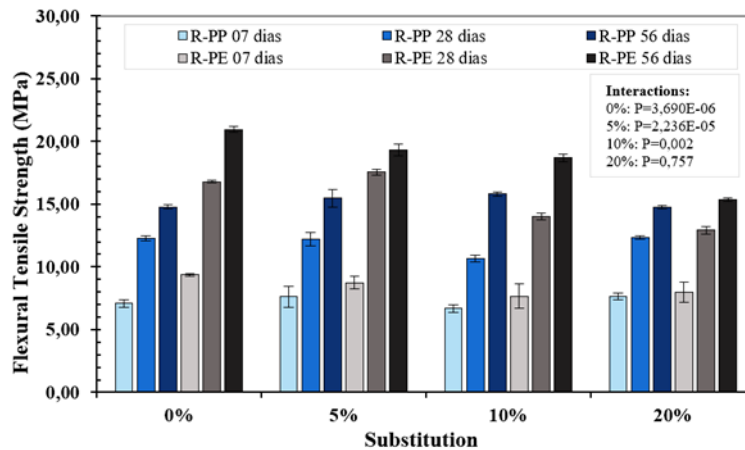

In the highest ages analyzed for the mortars produced with R-PP, it is observed that the best result was achieved with the incorporation of 5%. For the mortars with R-PE, this same behavior is maintained for the flexural tensile strengths when not considering the nullity for the substitution of natural aggregates.

Furthermore, for the substitution of the fine aggregate with fractions of the R-PP and R-PE residues, comparisons within the substitution contents indicate that, except for the highest substitution level, there are significant variances for the analyzed percentages. Additionally, the best results for flexural tensile strength are found in the mortars produced with ethylene polymer residues, considering their nature. As noted by Mano[25], Nunes[6], and Callister Jr. and Rethwisch[7], due to the atomic arrangement model, polyethylene has greater toughness than polypropylene.

As highlighted in the physical characterizations presented, the images obtained through SEM showed good interactions between the plastic residues and the other constituent materials of the mortars, as seen in Figure 12. For all samples, there was an absence of fissures in the residues, along with good integration with the cement pastes. The residues with finer granulometry visually exhibited the best integration.

Figure 12: SEM Images of Mortar Samples
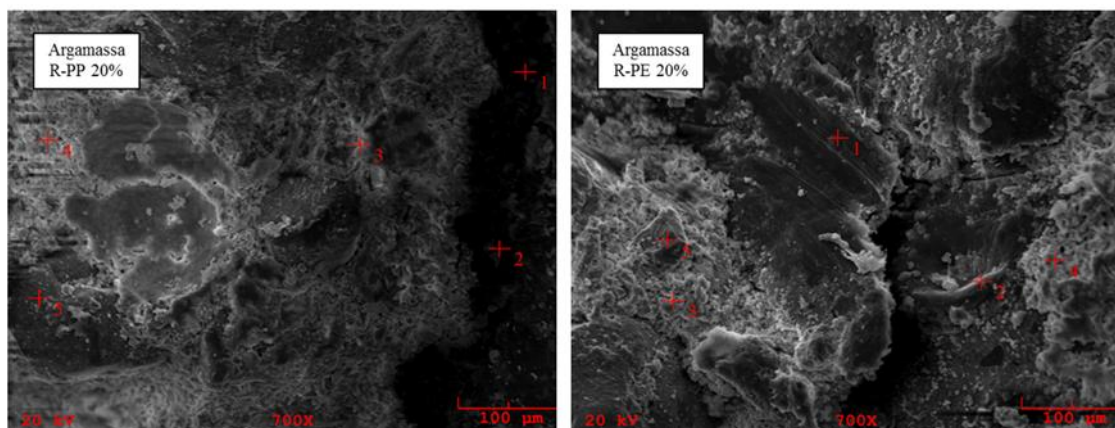
As previously mentioned and due to the good interaction between the materials, at the designated points shown in Figure 12, for each type of mortar produced with different types of plastic waste, a qualitative and semi-quantitative analysis of the atomic percentages of beam incidence on the surfaces at the designated points was performed in each sampling. This served for chemical identification and, consequently, the identification of the constituent material of the mortar. Thus, the results presented in Table 4 are representative of the EDS spectrum readings at the mentioned points.

Table no 5: Chemical elements at the points analyzed by SEM/EDS on the mortar samples.

Chemical Element	% Atomic Incidence									
	Mortar (R-PP 20%)					Mortar (R-PE 20%)				
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 1	Point 2	Point 3	Point 4	Point 5
C	76,76	56,18	4,30	8,94	3,80	93,40	70,83	3,05	2,67	23,53
O	18,12	22,35	47,92	59,39	45,78	5,67	21,38	32,90	22,70	26,57
Al	0,18	0,50	0,95	1,17	0,29	0,02	0,37	2,12	0,45	0,43
Si	1,20	2,86	6,48	4,96	49,64	0,14	1,36	7,14	3,33	41,56
Ca	2,53	13,75	39,59	24,92	0,37	0,50	5,37	53,48	69,79	7,59
Ti	1,05	2,84	0,16	0,06	0,05	0,14	0,24	0,25	0,16	0,09
Fe	0,16	1,51	0,59	0,56	0,07	0,13	0,46	1,06	0,91	0,23

Evaluating Figure 11 and Table 4, according to the incidence percentages in both mortar samples, it is identified that points 1 and 2 correspond to the plastic residues, as the material is a hydrocarbon and presents a high carbon content. Points 3 and 4 represent the cementitious paste, given the higher percentage of oxygen and calcium. Point 5 represents the fine aggregate, as the silicon content showed a high percentage. Visually, roughness on the surface of the residues, variations in topography, and material overlaps can be observed. It is worth noting that the darker regions represent voids, which are likely a result of the drying process and can be interpreted as pores not filled with solids.

IV. Conclusion

This research aimed to assess the feasibility of using two types of plastic waste, specifically polyethylene and polypropylene, incorporated into Portland cement-based composites, which were included as a partial replacement for natural aggregate during the production of mortars.

Chemical characterizations of the waste samples revealed the presence of metal percentages, which are believed to originate from machinery in the recycling industry or contamination during collection. However, the percentage indices of incidence are low and do not support their utilization. Physical characterizations indicate that R-PP and R-PE waste can be classified as lightweight aggregates based on specific and unit mass, with grain sizes similar to natural sands.

The decreases in dry and wet specific masses of the mortars occurred due to the lower specific weights of the plastic waste compared to conventional materials, which is consistent with the literature. This may be considered for use in simple coating and leveling of structures when the mortars are not subjected to significant stresses.

All mortars produced with the waste, at different levels and substitutions, exhibited higher water absorption during immersion as the waste content increased. Therefore, it is believed that the incorporation of these materials is not favorable for elements that may be subjected to occasional submersion in water, as the values obtained suggest greater porosity of the produced products, leading to increased susceptibility to pathologies caused by weathering.

Regarding the axial compressive strength of the mortars, there were decreases in the results achieved as the substitution percentages increased for all types of substitutions. However, the results obtained with the mortars produced with 5% R-PP were higher than the others, showing similarities to the mortars with zero percentage in the early ages, which may be considered for elements subjected to controlled stresses, within the ranges found in this research's samples. For flexural tensile strength, the results showed a decline in values compared to the control samples, although at a 20% substitution level, the results for both waste types were similar.

The microscopy of the fragments of the mortars demonstrated good interactions between the waste and the other constituents of the mortars, indicating good adhesion and homogenization. Thus, it can be said that even with the incorporation of plastic waste, the mortars maintained cohesive characteristics.

Therefore, it is concluded that polypropylene and polyethylene waste, as studied here, can be utilized in civil construction as a partial replacement for fine aggregate, where the type of demand will determine the choice of the type and method of use. It is also noted that polypropylene waste meets the demands more efficiently, but the use of either of the two analyzed wastes presents alternatives for reducing accumulations that cause pollution and environmental impacts.

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