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Treatment method for cement bags and probable reuse: Study with mortar

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Método de tratamento para sacos de cimento e provável reuso: Estudo com argamassa

RESUMO

Considerando a possiblidade de esgotamento de recursos naturais, a disposição inadequada de resíduos sólidos na construção e, o mais importante, a busca de estratégias para reduzir a emissão de gases como o CO_2, este estudo tem como objetivo apresentar uma metodologia voltada para minimizar o impacto ambiental causado pelo descarte de sacos de papel kraft contaminados com cimento Portland, assim como o consumo de areia. Isso se alcança por meio do tratamento dos sacos com hidróxido de sódio (NaOH), processamento e transformação em um subproduto de baixa granulometria, substituindo parcialmente a areia na produção de argamassa de revestimento. O subproduto obtido foi caracterizado e introduzido na argamassa em proporções de 2% e 4% em relação à massa de areia. As propriedades das argamassas foram observadas nos estados frescos e endurecidos. Os resultados demonstram que o uso de papel kraft tratado pode reduzir o consumo de recursos naturais, fornecendo uma alternativa sustentável e técnica para a eliminação de sacos contaminadas com cimento Portland. Na fase atual do estudo, observou-se uma redução na densidade da argamassa e um aumento na fluidez de 12% e 2%, respectivamente. Além da viabilidade técnica quanto a resistência mecânica, foi estabelecido um método para eliminar sacos contaminados com cimento Portland, reduzindo o consumo de areia. No cenário atual, os sacos de cimento ainda são indispensáveis e este estudo é uma contribuição que pode ser evolutiva sustentavelmente.

PALAVRAS-CHAVE: Argamassa. Resíduos sólidos. Sacos de cimento.

Treatment Method for Cement Bags and Potential Reuse: Study with Mortar

ABSTRACT

Considering the potential depletion of natural resources, the improper disposal of solid waste in construction, and, most importantly, the pursuit of strategies to reduce emissions of gases such as CO_2, this study aims to present a methodology designed to minimize the environmental impact caused by the disposal of kraft paper bags contaminated with Portland cement, as well as the consumption of sand. This is achieved by treating the bags with sodium hydroxide (NaOH), processing, and transforming them into a low-granularity by-product, partially replacing sand in the production of rendering mortar. The obtained by-product was characterized and introduced into the mortar in proportions of 2% and 4% relative to the sand mass. The properties of the mortars were assessed in both fresh and hardened states. The results demonstrate that the use of treated kraft paper can reduce natural resource consumption, providing a sustainable and technical alternative for the disposal of cement-contaminated bags. At the current stage of the study, reductions in mortar density and increases in fluidity by 12% and 2%, respectively, were observed. In addition to its technical feasibility regarding mechanical strength, a method was established to dispose of bags contaminated with Portland cement while reducing sand consumption. Given that cement bags remain indispensable at present, this study offers a contribution that can evolve sustainably.

KEYWORDS: Mortar. Solid waste. Cement bags.

Método de tratamiento para sacos de cemento y posible reutilización: Estudio con mortero

RESUMEN

Considerando la posibilidad de agotamiento de recursos naturales, la disposición inadecuada de residuos sólidos en la construcción y, lo más importante, la búsqueda de estrategias para reducir la emisión de gases como el CO_2, este estudio tiene como objetivo presentar una metodología destinada a minimizar el impacto ambiental causado por la eliminación de sacos de papel kraft contaminados con cemento Portland, así como el consumo de arena. Esto se logra mediante el tratamiento de los sacos con hidróxido de sodio (NaOH), su procesamiento y transformación en un subproducto de baja granularidad, que sustituye parcialmente la arena en la producción de mortero de revestimiento. El subproducto obtenido fue caracterizado e introducido en el mortero en proporciones del 2% y 4% en relación con la masa de arena. Las propiedades de los morteros se observaron en estados frescos y endurecidos. Los resultados demuestran que el uso de papel kraft tratado puede reducir el consumo de recursos naturales, proporcionando una

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alternativa sostenible y técnica para la eliminación de sacos contaminados con cemento Portland. En la etapa actual del estudio, se observó una reducción en la densidad del mortero y un aumento en su fluidez del 12% y 2%, respectivamente. Además de la viabilidad técnica en cuanto a la resistencia mecánica, se estableció un método para eliminar sacos contaminados con cemento Portland, reduciendo el consumo de arena. En el escenario actual, los sacos de cemento siguen siendo indispensables, y este estudio es una contribución que puede evolucionar sostenible.
PALABRAS CLAVE: Mortero. Residuos sólidos. Sacos de cemento.

GRAPHIC ABSTRACT

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1 INTRODUCTION

The contamination of kraft paper bags with Portland cement represents a significant environmental problem in terms of the amount discarded, reverse logistics and costs associated with proper disposal (Alves, 2021). At the same time, the high demand for consumption of natural resources can make sand a scarce material worldwide. According to the report of the United Nations Environment Programme (UNEP, 2019), 50 billion tons of sand are extracted annually, making it the second most consumed resource in the world. In Portugal, Waste Management Operators (WMOs) are currently establishing means of reusing construction and demolition waste, transforming it into aggregates for less demanding applications. On the other hand, the European Green Deal (COM, 2019) encourages the exploration of new technologies to prevent pollution in the disposal of solid construction waste.

Accurate quantification of waste often fails to identify the types of waste that are discarded without ample reuse options, such as kraft paper bags contaminated with Portland cement. The disposal of solid waste is also a problem in other countries, such as Brazil: According to the National Cement Industry Union (SNIC, 2022), the country reached a national production of almost 66 million tons of Portland cement in 2021, with almost 66% distributed in bags. Considering standard 50 kg bags, it is estimated that Brazil's cement production discarded approximately 870 million bags contaminated with Portland cement in 2021, often improperly disposed of or incinerated, generating gas emissions (Ma *et. al* ., 2019).

Improving the performance of mortar by using waste generated in its own production can generate economic value, reduce the consumption of existing natural resources, reduce pollution and contribute to the sustainability of the construction industry. For mortar made with Portland cement, this research presents the production and application method of a by-product, presenting results in comparison with a reference mortar.

2 METHODOLOGY

2.1 Obtaining the by-product

The cement bags were purchased from the Construction Laboratory (LC) of the Instituto Superior Técnico (IST) of the University of Lisbon between July and August 2022. Approximately 20 common Portland cement bags (25 kg) made of kraft paper were reserved for transformation into the by-product. The by-product was obtained through the following process: the cement bags were cut into square pieces with sides of approximately 8 cm and immersed for a period of two hours in a water solution with a sodium hydroxide (NaOH) concentration of 10%. Subsequently, the bags were left to rest and then dried in an Icamo oven for 6 hours at 100 °C. Finally, the bags, with the paper cellulose swollen (by the effect of NaOH) and hardened (by the effect of the cement residue), were crushed with a Moulimex blender with 4 blades and 300 W of power. Figure 1 shows the steps of the process used to obtain the by-product:

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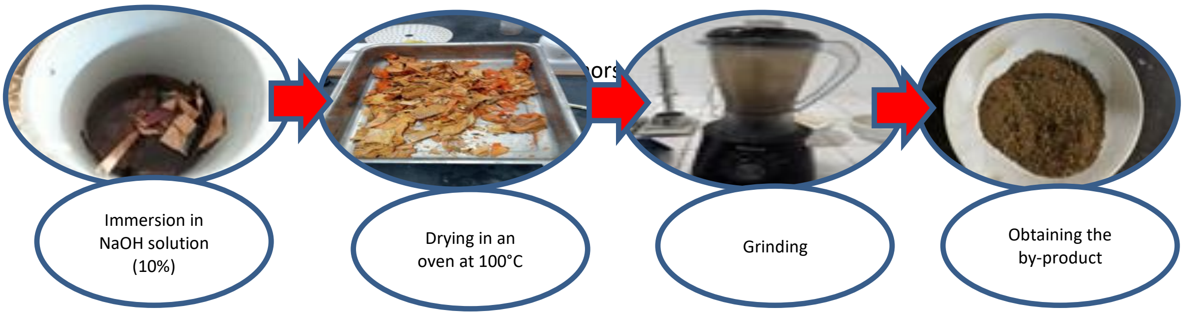
Figure 1 - Immersion in NaOH (a), Drying (b), Grinding (c) and obtaining (d)



Source: Prepared by the Authors, 2022.

The by-product was characterized according to its particle size distribution using five sieves with openings ranging from 0.125 to 1.6 mm (Fig. 2). The density of the predominant particle size distribution was determined using a container with a capacity of 100 cm³. Additionally, the by-product was analyzed in the laboratory by infrared spectroscopy, using a Fourier transform infrared spectrophotometer (FTIR) model IRAffinity-1 Shimadzu.

Figure 2 – Checking the grain size

Source: Authors, 2022.

2.2 Mortar experiments

Three different types of plastering mortars were defined based on experiments carried out by Soares *et al*. (2020), Alves *et al*. (2021), Touahri *et al*. (2021), Morais *et al*. (2022) and Soares *et al*. (2024). The Reference mortar ("R") was produced with a standard dosage in the proportion of 1:4 (cement:sand). For the other mortars, the proportions of 2% and 4% of sand in the standard dosage were replaced by the mass quantities of the by-product. These mortars were called C2 and C4, respectively. For all mixtures produced, Portland cement SECIL CEM I 42.5, calibrated sand and a water/cement ratio of 0.55 were used.

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The mortar production and testing processes were carried out in accordance with the European Union technical standards (Grade 1).

Grade 1 - Main EU reference standards for mortars

Standard	Title	Year
EN 1015-2	Test methods for masonry mortar - Part 2: Bulk sampling of mortars and preparation of test mortars	1998
EN 1015-3	Test methods for masonry mortar - Part 3: Determination of consistency of fresh mortar (by flow chart)	1999
EN 1015-6	Test methods for masonry mortar - Part 6: Determination of apparent density of fresh mortar	1998
EN 1015-11	Test methods for masonry mortars - Part 11: Determination of flexural and compressive strength of hardened mortars.	2019

Source: Prepared by the Authors, 2022.

In the fresh state, the results of each mortar were checked regarding volumetric mass (on the scale and in a container with a capacity of 140 cm³) and slump, which was assessed using a consistency table with a drop height of 12.5 mm and a digital caliper (6 in. - Digimess-100.174BL). The tests in the hardened state were carried out after 28 days of curing.

After the healing period, the following tests were performed:

a) Density;

b) Flexural tensile strength;

c) Compressive strength;

d) Capillary water absorption.

The sample masses were checked on a scale with an accuracy of 0.1 g. Mechanical resistance tests were carried out on a hydraulic press - traction and compression - Perta - Form Test.

In the capillary absorption test, after drying for 7 days at 50°C in an 11-liter Icamo oven, the samples from the previous tests were immersed in a 1 cm deep layer of water. They were weighed at intervals of 3, 6, 24, 48 and 72 hours. The percentage of absorption in relation to the initial mass was calculated using the following equation:

$$AA = \left(\frac{m_{sat} - m_s}{m_s} \right) \times 100$$

Caption:

AA is Water Absorption (%);

m_s is the mass of the oven-dried sample (g);

m_{sat} is the mass of the saturated sample in each interval (g).

3 RESULTS

3.1 Characterization of the by-product

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3.1.1 By-product particle size distribution and density

Regarding the particle size distribution, evaluating a sample of approximately 730 g of the by-product, a total of 457 g was retained in the meshes between 0.250 mm and 0.50 mm. Table 1 presents the results of the analysis of the particle size distribution.

Table 1 - Composite Particle Size Distribution Analysis

Meshes (mm)	Mass (g)	Correspondence (%)	Accumulated (%)
1.60	0	0	0
1	101.8	14,13	14,13
0.50	267.9	37.20	51.33
0.25	189.5	26.31	77.64
0.125	142.9	19.84	97.48

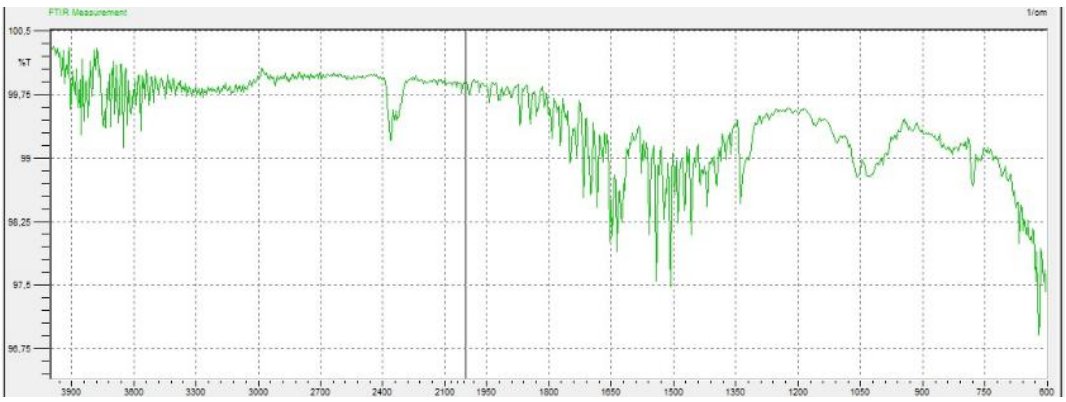
Source: Authors, 2022.

The portion with particle size distribution between 0.25 mm and 0.5 mm represented more than 62% of the sample, had a density of 0.45 g/cm³ and was selected for the mortar experiments as it was the most abundant part of the by-product.

3.1.2 Spectroscopy

The by-product is mainly composed of crushed cellulose (Brown *et. al.* , 2007), Portland cement residue (mainly CaO and SiO_2) (Myers, 1984) and NaOH residue, presenting a mixture of odors characteristic of these components. The results of the Fourier Transform Infrared Spectroscopy (FTIR) test showed frequencies mainly between 1510 cm^{-1} and 1540 cm^{-1} (Fig. 5), indicating characteristics closer to the Nitro and Alkene groups, which are less reactive compounds (NO_2 and C=C functional groups), according to the spectra interpretation scheme for organic substances in the infrared region (Donald *et. al.* , 2008).

Figure 5 – Spectroscopy results



Source: Authors, 2023

This means that the by-product, which has a heterogeneous composition on a macroscopic scale, also contains hydrocarbons, which have their own characteristics as chemical compounds. The compounds present in the by-product may be responsible for potential effects on the mortar, both in the fresh and hardened state.

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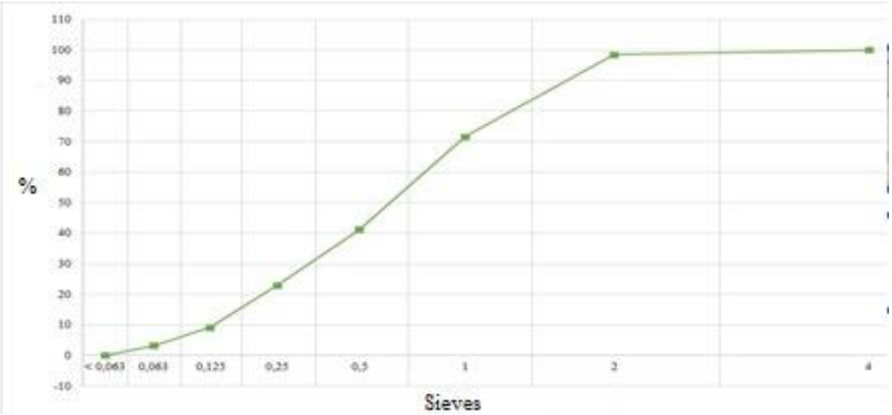
3.2. Mortar

3.2.1. Aggregate Characteristics (Sand)

The particle size distribution curve showed a predominance between 0.25 and 2 mm (Fig. 6), and the specific weight (or apparent density) was calculated at 1467 kg/m³. The volumetric mass of the saturated and oven-dried particles showed results of 2,593.37 kg/dm³ and 2,580.21 kg/dm³, respectively, allowing the calculation of an absorption rate of 0.5%.

Figure 6 – Sand granulometry results



Source: Authors, 2022

It was considered that the sand used had granulometry and physical characteristics in accordance with the requirements of NP EN 13139:2010 – Aggregates for mortar, guaranteeing the type of sand proposed in the dimensioning of the mortar mixture.

3.2.2 Characterization of Mortar in the Fresh State

The slump of the three types of mortars showed similar behavior in the consistency table test (Fig. 7), with good workability being observed in the molding of the test specimens. The density and slump results are presented in Table 3.

Figure 7 - C2 consistency test

Source: Authors, 2022.

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Table 2 - Apparent density and consistency results

Type	Density (g/cm³)	Consistency (mm)
R	2.23	180
C2	2.11	195
C4	1.95	214

Source: Authors, 2022.

It was observed that the mortars with the by-product presented lower volumetric masses. The most significant reduction was in the C4 mortar, which presented a 14% drop in relation to the R mortar. The results follow the parameter that the EN 1015-2 (1998) standard recommends for fresh mortars (apparent density > 1200 kg/m³ or 1.2 kg/m³).

Only mortars R and C2 met the consistency requirements according to EN 1015-3 (1999), which is 175mm +10mm. However, it was noted that the partial replacement of sand by the by-product led to progressive fluidity according to the proportion of the by-product. This can be justified by the compounds and quantities of fine materials present in the by-product (cement residues and NaOH).

3.2.3 Characterization of Mortar in the Hardened State

3.2.3.1 Density

The mortars with the by-product were lighter than the reference mortar (Table 3).

Table 3 - Mass results in the hardened state

Type	Density (g/cm³)	Standard Deviation
0	2.19	3.54
C2	2.10	4.10
C4	1.93	6.30

Source: Authors, 2022.

The density reduction was an expected result proportional to the increase in the by-product content, considering that the replaced sand was denser. The average mass reduction in relation to the standard mortar showed an improvement ranging from 4% (C2) to 12% (C4).

3.2.3.2 Tensile strength in bending and compressive strength

In the results of the flexural strength assessment, obtained through mechanical tests, it was observed that samples C2 and C4 presented an average reduction of 10% and 21%, respectively, in relation to the Reference mortar (R), and the standard deviations were not considered significant (Table 4).

Table 5 - Results of flexural tensile strength tests

Type	Media (MPa)	Standard Deviation
R	2.25	0.04
C2	2.02	0.06
C4	1.77	0.08

Source: Authors, 2023.

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The type of cement increased the compressive strength of mortar R; however, in the samples that used the by-product, the strengths decreased significantly. It was observed that the higher the content of the by-product, the lower the compressive strength. Compared to R, samples C2 and C4 showed an average reduction in compressive strength of 77% and 78%, respectively (Table 5).

Table 5 - Results of compressive strength tests

Type	Media (MPa)	Standard Deviation
R	24.04	2.46
C2	6.44	1.49
C4	4.89	0.20

Source: Authors, 2023.

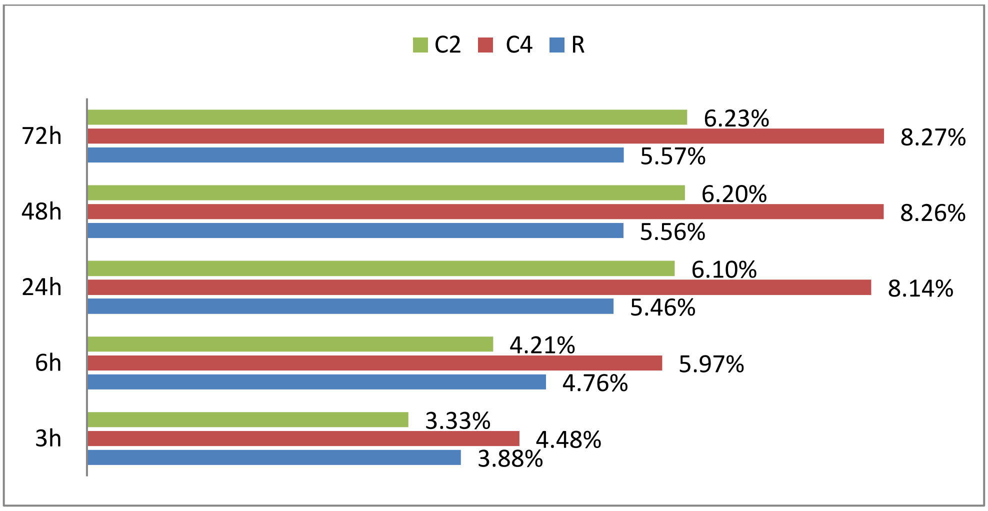
For mortars containing by-product, the compressive strength showed more disparate results in relation to the tensile strength test. An analysis between the characteristics of the by-product and the type of Portland cement used, which was SECIL CEM I 42.5, is suggested. However, they complied with the minimum required by standard EN 998-1:2013 Plastering and Rendering Mortars, which requires a minimum of 0.4 MPa.

Regarding the uncertainty of the verifications, the Standard Deviations calculated in Tables 3, 4 and 5 were not considered significant within the verified context.

3.2.3.3 Capillary Absorption Test

Initially, in the first 3 hours, mortar C2 presented the best result in terms of capillary absorption rate. Finally, the test results showed that the Reference mortar (R) presented the best performance, with 5.57% at 72 hours. Sample C2 obtained a result closer to mortar R, reaching 6.23%, while sample C4 presented a result of 8.27% (Fig. 9 and 10). This means that greater absorption is confirmed due to the voids occupied by the cellulose in the by-product.

Figure 9 - Graphic representation of the sample absorption test



Source: Authors, 2023

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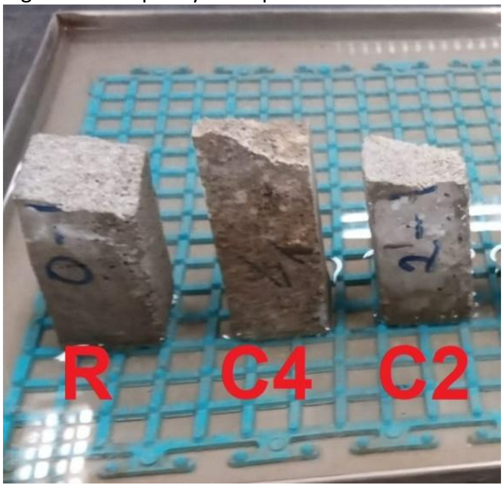
Figure 10 – Capillary absorption test after 72 hours



Source: Authors, 2023

4 DISCUSSIONS

A method for reusing kraft paper bags contaminated with Portland cement was presented, demonstrating its partial replacement in the proportion of sand in the mortar. The by-product obtained was characterized by a particle size between 0.25 and 0.50 mm and a density of 0.45 g/cm³. The spectroscopy test showed that the material presented the presence of Nitro and Alkene groups, in addition to being composed of NaOH residue, Portland cement and cellulose. At this stage of the study, it was considered that the by-product presented impurity characteristics that resulted in the reduction of the compressive strength of the mortar, since the sand was considered adequate according to NP EN 13139:2010. Future work will be able to characterize the by-product more accurately and evaluate its potential effects on the mortar, as well as the costs of this innovation.

Regarding flexural tensile strength, all three types of mortar demonstrated equilibrium. There was a significant reduction in compressive strength in relation to mortar R. It was observed that the higher the content of the by-product, the lower the compressive strength. More tests with lower content of the by-product are suggested to collect more data.

It was agreed that the ideal mortar type in this study was C2, as it showed improvements in most tests compared to the other two mortars, and the average compressive strength of 6.44 MPa could be a valid requirement because the maximum required for the coating is 6 MPa (EN 998-1:2013). In addition, this type of mortar consumed part of the bags contaminated with Portland cement and had the potential to reduce the consumption of natural aggregates. In the capillary absorption test, greater absorption was observed in mortars C2 and C4, which can be justified by the cellulose present and can be analyzed with more criteria in future studies.

In future studies, the influence of the residual NaOH content in the by-product and its impact on the alkalinity of the mortar can also be evaluated. Regarding the by-product (Fig. 11), an expectation was created for the development of a possible component derived from packaging contaminated with cement, which is close to an effective validation for use in mortars. It can also be studied for applications in other materials as an alkali-activated binder (due to the

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liquid residue of the NaOH solution) and replacing cement with a more sustainable binder, as well as the use of the by-product in concrete, void filling and cement slabs.

Figure 11 - Established by-product

Source: Authors, 2023

If each sand-consuming process could save at least the 2% considered optimal in this study, the annual consumption indicated by the United Nations Environment Programme (UNEP, 2019) report could see a reduction of around 1 billion tons of sand per year. This would represent a volume of more than 680 million cubic meters of the type of sand used in this study. The proposal also presents technology that can contribute to solid waste reuse plans, such as the Paris Agreement (COM, 2019). Finally, the method can minimize gas emissions caused by the disposal of paper bags contaminated with cement, each emitting around 0.022 g of CO_2 in its life cycle (Ma *et. al.* , 2019).

5 CONCLUSION

The development of this research allowed the analysis and adaptation of contaminated kraft paper from cement bags for the production of mortar, carrying out several technical tests. The results were analyzed and viability was observed regarding the reuse of paper in mortar and reduction of sand consumption. Cement residues and decomposition time are environmental issues for this work, but they can be a technical and economic solution for mortars with limited compressive strength. The methodology of this study may be refined in the next research cycles.

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