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Evaluation of the Influence of the Fine Aggregate of Rigid Polyurethane Residue on Mortars

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Abstract- A huge amount of waste and by-products is generated from manufacturing processes, service industries, municipal solid waste, among other activities, and the management of these has become a major environmental concern. The reuse of waste as aggregates in civil construction makes its disposal feasible, and also reduces the extraction and consumption of aggregates from natural sources. One alternative that has been studied is the partial replacement of conventional aggregates with rigid polyurethane foam residues in the production of concrete and mortars. Polyurethane (PU) represents a class of polymers that has broad application in the fields of medicine, automotive and industry. Rigid polyurethane foams (PUF) are used in the thermal insulation of refrigerators, containers, trucks, etc. and their manufacturers are responsible for their final disposal in landfills specified by law due to their toxicity. Thus, this work evaluated the partial replacement of conventional small aggregate by small aggregates from the rigid polyurethane foam (PUF) in the manufacture of mortars. Mortars were made with partial replacement of 10% sand by PUF and the mechanical performance was evaluated in the fresh and hardened conditions of the material with cure times between 14, 28, 126 and 230 days.

Keywords- *Aggregate, Mortars, Rigid Polyurethane Foam, Residue*

I. INTRODUCTION

Solid waste management has become a major environmental concern. Increased environmental awareness and scarcity of landfills and costs have attracted researchers to the possibility of reusing waste and by-products in the production of new materials. Hence, new solutions for sustainable development are required due to high consumption of natural resources, high production of industrial waste and pollution of the environment [1].

Polyurethane (PU) is present in many aspects of modern life, representing a class of polymers that has several applications in the medical, automotive and industrial areas [2]. Rigid polyurethane foams (PUF) are used as thermal insulation in refrigerators, freezers and refrigerated trucks. Due to their toxicity, their manufacturers are responsible for their final disposal in landfills specified by law. However, the reuse of polyurethane waste as a raw material in construction can be a viable alternative for the disposal of this material, which moreover being an economic solution contributes to the environmental issue.

According to [3], the use of polymer materials in civil construction began in 1923, when the first patent referring to paving materials with natural rubber latex was made by L. Cresson. In 1924, V. Lebefure published the first patent with the intention of developing a concrete with cement and polymer. In 1932, the use of synthetic latexes as Portland cement modifiers began. Since the late 1940s, mortars and concrete modified with polymers have been used in different areas such as deck coverings of ships and bridges, paving of sidewalks, slabs, anticorrosives and adhesives.

In the 1960s, concrete and mortars modified with styrenobutadiene rubber, polyacrylic and polyvinyl ester began to be used in several applications. Since that time, the research and development of ceramic matrix composites modified with polymer have had considerable progress. Since then, a large number of publications including books, patents and articles were presented.

In the 1980s, concrete and polymer mortars became the dominant materials in the construction industry. These materials are currently used as popular building materials and various types of polymers can be used in these applications. Therefore, this work aims at the use of industrial waste rigid polyurethane foam in the manufacture of mortars. It is the analysis of the influence of the partial replacement of conventional fine aggregate by polyurethane waste (PUF) on mortars in both fresh and hardened state and at different curing times.

II. METHODOLOGY

A. Materials and equipment

- Portland pozzolana cement CP IV- 32 RS of the brand Cauê, commonly used in the region of Itabira-MG;
- Fine aggregate: washed sand from Itabira - MG;
- Hydrated lime CH-I, pack of 20 Kg;

- Water: from the potable water supply network Serviço Autônomo de Água e Esgoto (SAAE) located in Itabira-MG;
- Rigid Polyurethane Foam Residue (PUF): supplied by Poly-Urethane Ind. e Com. Ltda, located in the city of Ibirité - MG. The company operates in the generation of solutions and creation of technologies for the application and use of polyurethane and specializes in polyols for thermal insulation, blocks and plates of PU, adhesives and coatings. The donated material, shown in Figure 7, deals with shavings obtained during the PUF production process that was processed by the company through the comminution process.

B. *Characteristics of aggregates*

The sand and the polyurethane residue used in this work were the same lots used in the work of [4]. Following, the characteristics of the aggregates that were determined by the characterization tests performed by the mentioned author will be presented.

1) Fine aggregate

The sand used in the formulation of the mortars comes from deposits of building materials from the city of Itabira (MG). This aggregate has a maximum diameter of 2.4mm, fineness modulus of 2.43 and granulometry between the usable zone and the optimal zone, as can be observed in Figure 1.

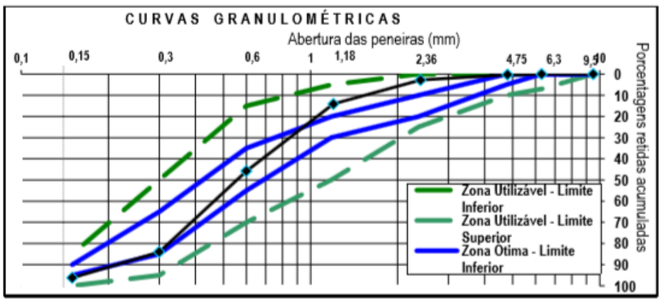

Figure 1. Granulometric curve of the fine aggregate

The absolute specific mass and the unitary mass in the loose state are 2.60 kg/dm^3 and 1.45 kg/dm^3, respectively.

C. *Rigid Polyurethane Foam Residue*

1) Real especific mass

The real density of the PUF used in this investigation was 0,595± 0,004 g/cm3 (by helium gas pycnometry).

2) Unitary mass in the loose state

The unitary mass in the loose state (Mu) of the PUF used in the work was 1300 kg/m³. Therefore, the small aggregate of the PUF studied falls into the light aggregate category, since its specific mass in the loose state is below the limit of 2000 kg/m³, adopted as the maximum reference limit for the Mu of light aggregates.

3) Histogram of frequency of particle size

The fineness of the PUF studied, determined by sieving, presented more than 50% of the grains of the material with granulometry between 425 µm and 212 µm, which is, in general, inferior to the granulometry of the sand adopted in the formulation of the mortars.

III. Experimental Procedure

1) Dosage of the reference mortar and with partial replacement of the fine aggregate by PUF

The trace adopted for making the mortars was 1: 2: 8. Mortars were produced for the preparation of cylindrical specimens measuring 5 cm in diameter and 10 cm in height and to be applied to masonry of a ceramic block and concrete block in substrates with and without roughcast. In this work, the replacement content of 10% of sand by PUF was adopted, in saturated form, because this content presented the best results in the study done by [4]. Besides, according to the author, the water absorption ratio by PUF observed was 50g of PUF for 150 ml of water. Table 1 shows the amount of material, by mass, for the production of mortars without PUF (reference mortar or control mortar) and with PUF.

TABLE I. Consumption of Materials for Production of Mortars

Material Consumption					
Trace	Cement (Kg)	Lime (Kg)	Sand (Kg)	PUF (Kg)	Water (L)
Reference	0,2	0,4	1,6	-	0,5
PUF	0,2	0,4	1,44	0,036	0,5+0,109

2) Preparation of the mixtures for carrying out the tests

The mortars were produced in accordance with ABNT NBR 16541: 2016 (Mortar for laying and coating of walls and ceilings - Preparation of the mixture for carrying out the tests) [5]. The PUF was saturated 24 hours prior to the mixing.

D. *Properties of mortars*

1) Test to determine the water retention of the mortar

The test methodology used to determine the water retention of the mortar was based on the draft of the European standard prEN 1015-8: "Draft European Standard: Methods of test for mortar for masonry - Part 8: Determination of water retentivity of fresh mortar, European Committee for Standardization (CEN) "(1998) [6], due to some limitations of laboratory equipment.

Initially, the empty cylindrical mold was weighed, filled with mortar, its surface scraped with the aid of a spatula (so that it became completely flat) and the whole assembly was weighed again. The mass value of the filter paper and gauze set that would be used in the assay was recorded. Then the surface of the mortar was covered with the filter paper and gauze set. Immediately afterwards, a 2kg weight was placed over the set remaining at rest for 2 minutes, as shown in Figure 14. At the end, the paper / gauze set was withdrawn and again weighed on the Solotest MARK M5202 balance with error ± 0.10 g.

2) Test to determine the consistency index

The experimental procedure to determine the consistency index was performed according to ABNT NBR 13276: 2016 (Mortar for laying and coating of walls and ceilings - Determination of the consistency index) [7].

The mortar was placed on a cone trunk that was subjected to a sequence of blows. The mixture was then poured onto the table upon withdrawal of the cone and deformed by standard drops. Thereafter, the resulting deformation was measured with the aid of a scale. The consistency index was calculated by the arithmetic mean of the three orthogonal diameters of the mortar spread on the table.

3) Test to determine the density

The procedure to determine the density was performed according to ABNT NBR 13278: 2005 (Mortar for laying and coating of walls and ceilings - Determination of mass density and the incorporated air content) [8].

The execution of the test consisted of the introduction of portions of the mortar, immediately after its preparation, into a calibrated cylindrical vessel with an approximate height of 85 mm, an approximate diameter of 80 mm and a capacity of approximately 400 cm³. Three equal layers of mortar were placed in the cylinder and in each layer 20 strokes distributed with a spatula were applied along the perimeter of the mortar, and then the cylinder containing the mortar was subjected to 3 consecutive drops with a height of approximately 3 cm. The vessel was then flushed with the spatula in two passes orthogonal to each other and then the mold containing the mortar was weighed on a scale.

4) Compressive strength test

The compressive strength test was conducted according to ABNT NBR 13279: 2005 (Mortar for laying and covering of walls and ceilings - Determination of tensile strength in flexion and compression) [9]. Cylindrical specimens measuring 5 cm in diameter and 10 cm in height were molded. For each age, 3 reference test specimens (without PUF) and 3 specimens with 10% sand replacement by PUF were molded. The analysis ages were 14, 28, 126 and 230 days.

5) Tensile strength test

The tensile strength test was performed according to ABNT NBR 13.528: 2010 (Inorganic Mortars and Ceiling Coatings - Determination of Tensile Strength) [10]. For the accomplishment of the test, masonry were built in ceramic block and concrete block. The construction site of masonry is characterized by being open and susceptible to inclement weather (rain, sun and wind). The following base conditions were adopted for the substrates: ceramic block base with roughcast, ceramic block base without roughcast, block of concrete with roughcast and block of concrete without roughcast.

IV. RESULTS AND DISCUSSION

1) Water retention

The water retention test results are shown in Table 2.

TABLE II. WATER RETENTION TEST RESULTS

Test: Water Retention		
Trace	Retention	Absorption
Reference	93,14%	6,85%
PUF	91,50%	8,49%

The water retention value of the trace with 10% replacement of the conventional fine aggregate per PU residue in the saturated form is within an acceptable range of proximity to the reference value. The water retention of the mortar decreases with the addition of PUF in the saturated form because the PUF does not absorb the water used in the preparation of the mortar. Compared with the results obtained by [4], water retention is observed to increase with increasing substitution content of PUF in dry form and decreases with increasing substitution content of PUF in saturated form. The decrease in water retention with the addition of PUF in the saturated form was also observed in the results obtained by [11].

2) Consistency Index

The addition of 10% PUF resulted in a gain in the workability of the mortar, verified by increasing the spreading limit at the consistency table, as shown in Table III.

TABLE III. CONSISTENCY INDEX

Test: Consistency Index	
Trace	Spreading Limit
Reference	303 mm
PUF	328 mm

According to [12], there are several factors that can influence the results of this test, such as the way the materials were mixed, the way the mortar was placed and compacted in the conical trunk mold and the rhythm of the blows.

3) Density

The result of the density test of the mortars in fresh state is shown in Table IV.

TABLE IV. DENSITY OF MORTARS

Test: Density of Mortars		
Trace	Density	Percentual Reduction
tenc	2,00 g/cm3	-
PUF	1,86 g/cm3	7,00%

The replacement of 10% of sand by PUF decreased the mortar density by 7% when compared to the reference trace. Therefore, mortar with PUF addition is considered normal mortar, since it has a density of 1.86 g / cm³, and it can be used in conventional applications.

4) *Compressive strength*

The results of the compressive strength test of mortars at the ages of 14, 28, 126 and 230 days are shown in Table V.

TABLE V. COMPRESSIVE STRENGTH

Test: Compressive Strength		
Age	Reference	PUF
14 Days	2,6 MPa	2,1 MPa
28 Days	3,1 MPa	2,8 MPa
126 Days	13,36 MPa	8,71 MPa
230 Days	16,47 MPa	9,85 MPa

It is observed that the compressive strengths increased at each age. At 126 days of cure, the compressive strength of the trace containing PUF was three times greater than the resistance obtained at 28 days, but this trace did not present a significant resistance increase between the ages of 126 and 230 days, since there may be degradation of the polymer in basic medium.

The trace with PUF reached a resistance very close to that of the reference trace at the ages of 14 and 28 days. At the age of 126 days, the compressive strength of the trace with PUF reached 65% of the value reached by the reference trace and, at the age of 230 days, reached 59.8% of the resistance obtained by the reference trace.

5) *Tensile strength*

The test was performed on mortars with a curing age of 49 days and the mean results are shown in Table VI.

TABLE VI. TENSILE STRENGTH OF MORTARS

Tensile Strength (MPa)				
Trace	Ceramic Block with Roughcast	Ceramic Block Out Roughcast	Concrete Block with Roughcast	Concrete Block without Roughcast
Reference	0,23	0,13	0,23	0,11
PUF	0,19	0,1	0,26	0,21

It is observed that the average tensile strength of the PUF trace in the ceramic block panel with roughcast was very close to 0.20 MPa, which is the minimum acceptable value for some type of coating application, according to the cited standard. In the ceramic block panel without roughcast, none of the mortars presented the minimum value of tensile strength.

In the concrete block panel with roughcast, the mean value of tensile strength of the PUF was 0.26 MPa, higher than the value obtained for the reference mortar. According to the standard ABNT NBR 13749: 2013, it would be suitable for use in internal wall coating for application of paint or plaster base.

E. *Final considerations*

The use of industrial waste in cement matrices opens a new field of application in civil construction. The partial replacement of sand by aggregates from rigid polyurethane foam residue in mortars is seen as a sustainable alternative that gives a destination to a product with no added value that would probably be discarded in the environment, in addition to decreasing the use of natural aggregates.

In the fresh state, the behavior of the mortar with 10% of sand replacement per PUF aggregate was satisfactory. The addition of PUF aggregate resulted in a gain in the workability of the mortar, which was verified by the increase of the spreading limit in the consistency table. The value obtained in the water retention test is within an acceptable range of proximity to the reference value. In addition, there was a 7% reduction in mortar density when compared to the reference trace.

The use of the PUF aggregate in mortars leads to loss of compressive strength compared to a mortar of the same formulation (free of PUF), the most relevant comparative loss being with increasing curing time.

Considering mechanical aspects and curing time, the studied mortars can be specified for various uses in civil construction. The compressive strength of the mortar with PUF aggregate at 126 days was superior to the 8 MPa compressive strength value, recommended for class P6 mortars, according to ABNT NBR 13281: 2005.

The PUF trace achieved resistance very close to that of the reference trace at the ages of 14 and 28 days. At the age of 126 days, it reached 65% of the value reached by the reference trace, and at the age of 230 days, it reached 59.8% of the resistance obtained by the reference trace. Thus, it can be concluded that at very advanced curing ages (greater than 126 days) there was not an expressive gain of compressive strength in the mortars with PUF aggregate.

The tensile strength with PUF aggregate was higher than that of the reference mortar in the concrete block with and without roughcast, and very close to the value obtained by the reference mortar in the ceramic block with roughcast. In the ceramic block with roughcast, the mortar with PUF obtained a resistance value very close to 0.20 MPa, which is the minimum acceptable value for some type of coating application. In the concrete block with and without roughcast, the tensile strength of the PUF aggregate was higher than that of the reference mortar, and it is suitable for use in internal wall cladding for the application of paint or plaster base. The cure time may have influenced the results of the test, which was performed with 49 days of cure of the mortar, and the age indicated by the standard is 28 days of cure.

Based on the results obtained in the present work, it is concluded that at very advanced ages of curing there is not an expressive gain in the mortar properties with PUF aggregate. However, its application in cement-based materials can improve the properties of the material such as density, workability and adhesion, without compromising its characteristics. Thereby, its application in mortars is a promising route for the viability of this waste as an alternative material for the construction industry, since the reuse of this type of waste, besides adding value, can reduce the environmental impacts resulted from discards of the generating industry.

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