**PAPER SLUDGE WASTE APPLICATION**

**Highlights**

* Nowadays tons of paper sludge, wood ash and lime are thrown daily in landfills.
* Laboratory tests have shown that adding these three residues it results in a composite with very similar physicochemical to the bricks used in construction.
* The use of this composite shaped as “paper brick” minimizes extraction of natural resources and avoids burning process used in the manufacture of ceramic bricks.

**Abstract**

The present study was developed based on a doctoral paper aimed at formulating a waste composite of paper sludge, wood ash and lime to be used in civil construction, thus lowering environmental impacts generated by landfills. The method used after the characterization of residues was the creation of composites, nine in total, with varied percentages. The next step involved testing compression strength, water absorption and gradation to assess each composite’s performance. As a result, the feasibility of the use of composites in the development of products proved fitfor civil construction. In particular, composite number six displayed a more linear physical, chemical and mechanical behavior, formed by 58% paper sludge, 30% wood ash and 12% lime. The use of the waste researched, in answer to the study, produced a composite that is adequate to the creation of materials applicable to civil construction, allowing minimum environmental impact.

Key words – Paper sludge waste, wood and lime ashes, civil construction, landfill.

**1. Introduction**

Since 1992, Agenda 21 has been encouraging a broad participation of society in discussions involving sustainable development (CIB, 2000).

According to [1], sustainable development aims at the balance between social progress and economic progress through acceptance of the environmental resilience limits. Producing and using materials with a concern with environmental features fully meets that objective.

Population growth leads to an increased consumption of industrialized products, therefore, waste generation as well. This fact results in a buildup of industrial waste and presents an enormously high risk of contamination through inadequate waste transportation or disposal [2] .

At an earlier stage, companies were interested in investing in the production process, with no concern about losses and industrial rejects. This is a big problem today [3].

This article was based on a dissertation that sought to investigate the use of a mix of paper sludge, wood ash and lime in the creation of composites, andto analyze its physical, chemical and mechanical properties that can make civil construction products viable.

The paper industry is responsible for generating large amounts and several types of waste. Brazil, which is the 4th largest pulp producer/11th largest paper producer in the world, has 235 companies in this sector generating 109 thousand direct jobs, of which 66 thousand are in industry as informed by [4].

Wood ash residues are generated in the firing process of steam boilers and are used as substrate components, which are the raw materials in the activated carbon and pozzolanic cement manufacturing. They are also used in the pre-molded industry and in the recovery of degraded areas [5].

Lime, which is a product of great interest to both the industrial and social sectors, according to [6], stands out by its double capacity. It acts both as a chemical reagent and a binder-ligand. The hydrated lime & quicklime are rated among the ten most consumed products worldwide in view of their multiple applications. In Brazil, even though the production is between 5 and 6 million p.a., the per capita consumption is approximately 36 kg/year [6].

**2. Method**

In order to develop this study, two approaches were used: research strategy and strategy development.

## Research Strategy

LIME: GRADATION TESTS BY LASER

WOOD ASH: SIEVE ANALYSIS

IDENTIFY THEIR PHYSICAL-CHEMICALPROPERTIES

CHARACTERIZE PAPER SLUDGE, WOOD ASH AND LIME WASTE

BEGINNING

END

CHECK APPLICABILITY OF NEW COMPOSITE MATERIALS TO CONSTRUCTION

NINE COMPOSITES WITH DIFFERENT PERCENTAGES OF EACH WASTE

WATER ABSORPTION TESTS ACCORDING TO NBR-10836/94

TESTS OF MECHANICAL RESISTANCE TO COMPRESSION ACCORDING TO NBR-5739/94

NATURAL CURING PROCESS AT AGES 1, 3, 7, 14 28 (DRY AND WET) 60, 09, 180 AND 365 DAYS

FIVE SPECIMENS FOR EACH COMPOSITE ACCORDING TO NBR-5738/03

FORM COMPOSITES FOR TESTS

GRADATION:

SIEVE ANALYSIS OF COMPOSITES 3, 6 AND 9

THREE SPECIMENS FOR COMPOSITES 3, 6 AND 9 (28 DAYS OF CURING) ACCORDING TO NBR-9778/05 (BRAZILIANSTANDARD).

FOUND RESULTS COMPARED TO MATERIAL EXISTING IN THE MARKET

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SOIL-CEMENT BRICK

NBR-10834/94

2.2 Strategy Development

The adopted strategy was initially developed through identification and quantification of the ETE's sludge waste, wood ash and lime used in this study, which determined waste quantitative data, generation time and production location, considering seasonality.

In order to check the technically feasible applications, the next step involved developing and preparing specimens. Then, nine composites were prepared with different percentages of paper sludge, wood ash and lime waste, according to table 1.

Table1.

Percentage of waste from ETE sludge, wood ash and lime for each developed composite.

|  |  |  |  |
| --- | --- | --- | --- |
| **Composite nr.** | **Composition** | | |
|  | Sludge (%) | Ash (%) | Lime (%) |
| 1 | 55 | 35 | 10 |
| 2 | 60 | 30 | 10 |
| 3 | 65 | 25 | 10 |
| 4 | 48 | 40 | 12 |
| 5 | 53 | 35 | 12 |
| 6 | 58 | 30 | 12 |
| 7 | 50 | 30 | 20 |
| 8 | 45 | 40 | 15 |
| 9 | 40 | 40 | 20 |
|  |  |  |  |

At first, the paper sludge waste, wood ash and lime waste were mixed according to the percentages established for each composite.

Then, the portion of each mold was weighted as per recommendation of NBR-5738 [7]. Thirteen grams of mix were required for each mold.

The next step involved pouring the mix into a steel (non-absorbent, chemically inert material) casting mold 20 mm wide and 60 mm high.

Mixtures passed through hydraulic press Bovenau ST15 as per recommendation of NBR - 5738 [7], with a strength of 0.4 MPa.

Five specimens were prepared by age for each of the nine composites: 1, 3, 7, 14, 28 (dry and wet), 60, 90, 180 and 365 days, totaling 450 specimens size of 20mm x 20mm.

After the natural curing process at room temperature, specimens were subjected to simple compression tests in MPa as per recommendation of NBR-5739 [8]. This test used an EMIC machine connected to a computer using the Vimarq software. Thus it was possible to automatically obtain values for each sample.

However, water absorption tests carried out in the Laboratório de Análises de Minerais e Rochas (LAMIR) (Mineral Testing Lab) at the Universidade Federal do Paraná (UFPR) (Federal University of Parana) followed NBR-10836 [9].

In this test, a scale with a 0.4% sensitivity of the sample mass, an electric kiln capable of maintaining temperature between 105 ° C and 110 ° C and an immersion tank were used.

Also, three 28-day specimens of composites 3, 6 and 9 were tested according to NBR-9778 [10]. Composite 3 had a higher percentage of paper sludge; composite 6 had an intermediate content of sludge and composite 9 had the lowest paper sludge content, although it had a higher content of lime.

The abovementioned composites 3, 6 and 9 were subsequently tested for gradation and sieve analysis in the same lab above, the LAMIR at UFPR. Two hundred grams of the sample were analyzed and a set of sieves, a disintegrator, a scale of two decimal places, a Jhones divider and a 1500 ml Becker were used.

**3. Results and Discussions**

3.1. Mechanical resistance to compression (compression strength)

Five specimens of each composite at the analyzed age were subjected to compression strength tests. Table 2 presents the average and the standard deviation of each developed composite at the age of 1, 3, 7, 14, 28, 60, 90, 180 and 365 days with different rates of paper sludge, wood ash and lime,

Table 2.

Results for compression strength tests of the developed composites, by age.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Resistance (MPa) x Age (days)** | | | | | | | | |
| **Composites** | **Statistical Parameters** | **1 day** | **3 days** | **7 days** | **14 days** | **28 days** | **60 days** | **90 days** | **180 days** | **365 days** |
| 1 | Average | 4.23 | 7.09 | **11.34** | 13.39 | 8.05 | 9.95 | 10.75 | 11.95 | 10.41 |
| Standard Deviation | 0.32 | 1.08 | 1.16 | 0.85 | 0.60 | 1.43 | 0.42 | 0.70 | 0.99 |
| 2 | Average | **4.84** | 5.82 | 9.80 | 14.05 | 11.35 | 12.11 | 11.71 | 11.84 | 9.79 |
| Standard Deviation | 0.35 | 0.38 | 0.37 | 1.00 | 1.81 | 0.40 | 0.90 | 1.92 | 0.68 |
| 3 | Average | 4.71 | 7.02 | 10.44 | **14.29** | 11.63 | 14.50 | 12.26 | 11.06 | 10.32 |
| Standard Deviation | 0.32 | 1.39 | 1.85 | 0.93 | 1.24 | 1.39 | 3.00 | 2.27 | 0.82 |
| 4 | Average | 3.52 | 5.16 | 8.00 | 10.04 | 9.68 | 9.31 | 10.00 | 9.16 | 7.78 |
| Standard Deviation | 0.48 | 0.67 | 0.21 | 0.78 | 0.79 | 0.89 | 0.73 | 1.60 | 1.41 |
| 5 | Average | 3.32 | 4.77 | 7.61 | 10.45 | 13.25 | 14.70 | 15.07 | 15.91 | 14.08 |
| Standard Deviation | 0.18 | 0.38 | 0.65 | 0.23 | 0.17 | 0.78 | 1.25 | 1.19 | 0.25 |
| 6 | Average | 4.25 | 6.26 | 8.56 | 12.44 | **15.74** | **17.70** | **19.81** | **18.59** | 16.97 |
| Standard Deviation | 0.41 | 0.68 | 0.76 | 0.68 | 1.57 | 1.30 | 0.92 | 1.46 | 0.98 |
| 7 | Average | 3.25 | 5.21 | 8.83 | 9.87 | 12.43 | 13.06 | 14.98 | 16.61 | **17.66** |
| Standard Deviation | 0.27 | 1.01 | 0.70 | 1.38 | 0.37 | 0.37 | 1.09 | 0.94 | 1.40 |
| 8 | Average | 3.86 | **7.60** | 11.30 | 12.83 | 11.91 | 12.66 | 12.88 | 12.69 | 13.29 |
| Standard Deviation | 0.49 | 0.86 | 1.08 | 0.68 | 0.76 | 1.17 | 0.62 | 1.43 | 0.91 |
| 9 | Average | 2.59 | 7.44 | 10.10 | 11.63 | 9.25 | 9.93 | 12.00 | 13.35 | 12.82 |
| Standard Deviation | 0.31 | 0.55 | 0.73 | 0.79 | 0.41 | 0.79 | 1.23 | 0.88 | 1.45 |

An analysis of table 2 for specimens of composites 1, 2, 3 and 4 (higher rates of paper sludge and lower rate of lime) indicates that resistance increases up to 14 days and then it begins to fall.

However, for composites 5, 6, 7, 8 and 9, which contain a lower rate of paper sludge and a higher lime rate, the mechanical resistance reaches peaks until the age of 180 days. It should be noted that composite 6, which has an intermediate amount of paper sludge (58%) and lime (12%), has compression strength values that indicate a more linear growth.

The use of the percentages of paper sludge, wood ash and lime of composite 6 in the development of a new civil construction product - the "paper brick" - allows a satisfactory use of waste from paper sludge and lime in its production.

In order to compare the compression strength results found for the composites in this research, the so-called "paper brick", the values used were those recommended by the Brazilian standard NBR-10834 [11], which established a minimum of 2.0 MPa for soil-cement seal blocks.

An analysis of resistance results for the "paper bricks" indicates that the developed composites presented values above those that are recommended by NBR-10834 [11], according to table 2 on one curing day.

Compression strength tests were also carried out with the nine composites at 28 days of age, dry samples at room temperature, and wet samples immersed in water for 24 hours.

Table 3 shows that composite resistance falls 40% on average when subjected to moisture. Nevertheless, even with this sharp resistance drop, the wet composites still have values that are higher than the recommended by the Brazilian standard NBR-10834 [11], which establishes 2.0 MPa as a minimum for soil-cement seal blocks.

Table 3.

Results for compression strength tests, at 28 days of age, with both dry and wet samples of the developed composites.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | **Resistance (MPa)** | |  |
| **Composites** | **Statistical Parameters** | **28 days - dry** | **28 days - wet** | **Loss of Resistance (%)** |
| **1** | Average | 8.05 | 3.26 | 40.50 |
| Standard Deviation | 0.60 | 0.51 |
| **2** | Average | 11.35 | 4.24 | 37.36 |
| Standard Deviation | 1.81 | 0.33 |
| **3** | Average | 11.63 | 5.08 | 43.68 |
| Standard Deviation | 1.24 | 0.58 |
| **4** | Average | 9.68 | 3.60 | 37.19 |
| Standard Deviation | 0.79 | 0.43 |
| **5** | Average | 13.25 | 5.38 | 40.60 |
| Standard Deviation | 0.17 | 0.20 |
| **6** | Average | 15.74 | 6.72 | 42.69 |
| Standard Deviation | 1.57 | 0.17 |
| **7** | Average | 12.43 | 5.82 | 46.82 |
| Standard Deviation | 0.37 | 0.45 |
| **8** | Average | 11.91 | 4.78 | 40.13 |
| Standard Deviation | 0.76 | 0.28 |
| **9** | Average | 9.25 | 5.05 | 54.59 |
| Standard Deviation | 0.41 | 0.38 |
|  |  |  |  |  |

3.2. Water absorption of composites

As described in Method above, water absorption tests were carried out with composites 3, 6 and 9. These tests were carried out according to NBR 10836 [9], then compared to NBR 10834 [11]. This standard recommends that the average water absorption should be equal to or lower than 20%, and individual values should be equal to or lower than 22% at 28 days of curing.

Table 4.

Results of water absorption tests with composites 3, 6 and 9, at 28 days of age.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | 28 days of age | | | |
| **Composites** | **Specimens** | **Dry weight (g) after 24-hour kiln-drying at 105+5°C** | **Wet weight (g) after 24-hour kiln-drying at 105+5°C** | **Individual water absorption values (%)** | **Average water absorption value (%)** |
| 3 | 1 | 14.94 | 17.43 | 16.66% | 15.23% |
| 2 | 14.88 | 17.03 | 14.45% |
| 3 | 14.82 | 16.98 | 14.57% |
| 6 | 1 | 16.41 | 19.51 | 18.89% | 18.75% |
| 2 | 16.31 | 19.43 | 19.13% |
| 3 | 16.12 | 19.06 | 18.24% |
| 9 | 1 | 19.84 | 24.46 | 23.29% | 23.06% |
| 2 | 19.63 | 23.91 | 21.80% |
| 3 | 19.67 | 24.41 | 24.10% |
|  |  |  |  |  |  |

Table 4 shows that, for composites 3 and 6, both the individual values and the average values found follow the recommendation of the Brazilian standard. However, composite 9 - with a higher rate of lime (20%) and lower rate of the ETE sludge (40%) - does not achieve the recommended values.

3.3. Composite gradation

Gradation tests were carried out with composites 3, 6 and 9. The method of sieving 200 grams of sample was used.

Figures 1, 2 and 3 show gradation test results for composites 3 (Sludge (L) = 65%, Ash (C) = 25% and Lime (Ca) = 10%); composite 6 (Sludge (L) = 58%, Ash (C) = 30% and Lime (Ca) = 12%) and composite 9 (Sludge (L) = 40%, Ash (C) = 40% and Lime (Ca) = 20%).

Fig. 1.

Result of gradation distribution in composite 3 (L=65%, C=25%, Ca=10%).

Fig. 2.

Result of gradation distribution in composite 6 (L=58%, C=30%, Ca=12%).

Fig. 3.

Result of gradation distribution in composite 9 (L=40%, C=40%, Ca=20%).

The results allow to conclude that, as the amount of lime is increased and the amount of sludge is reduced, grain diameter decreases and the percentpassing is also less.

**4. Conclusion**

In this study, nine composites were proposed and composite 6 had a higher linearity in its physical, chemical and mechanical behavior. It contained 58% paper sludge, 30% wood ash and 12% lime production waste.

The results achieved at the end of the study through physical and chemical analyses proved the possibility to replace natural materials with paper sludge, wood ash and lime waste. With this usage, environmental risks are reduced.

Another important result is related to the use of composites in civil construction. Similarly, the physical chemical properties provide the feasibility of waste in the development of a new product to be used in civil construction.

The use of "paper bricks" avoids burning ceramic bricks and reduces the extraction of natural resources. It also contributes to the implementation of a new economic matrix for the production process of materials, the generation of new jobs in the new manufacturing plants and workforce qualification and specialization in the use of industrial waste.

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