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TECHNOLOGICAL CHARACTERIZATION OF CONSTRUCTION MATERIALS FOR ECO-EFFICIENT RECYCLING

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Abstract: The environmental impacts resulting from civil construction activities, involving the notable consumption of natural resources and the generation of waste at increasing rates, are widely observed and discussed by the scientific community and the construction sector. The current demand for recycling construction waste is due both to the scarcity of raw materials in the vicinity of large urban centers and to the notable increase in the costs of disposing of waste in inert landfills. To expand the market for recycled aggregates and ensure their application in various branches of construction, it is essential that these wastes are adequately processed through unitary mineral processing operations. This study aims to evaluate the separability of the phases present in construction and demolition waste, based on the study of the properties of the materials that compose it. Separation basically depends on three factors: the properties of the minerals or phases present, the constructive and variable characteristics of the separator and the specifications of the products to be obtained. The choice of a method or their combination must, therefore, be based on the differentiating property between the phases present and the efficiency of the operation. Therefore, this work aims to characterize cementitious and ceramic materials with different compositions, porosities and compressive strengths to evaluate the possibilities of separating the phases present through differentiating properties to be evaluated, with an initial focus on densitarian and magnetic separation.

Keywords: waste recycling, sustainability in construction, recovery of raw materials.

INTRODUCTION

Due to growing attention to the environmental impacts resulting from construction activities, the consequences of economic growth and population expansion, large quantities of construction and demolition waste (RCD) are produced annually, reaching 850 million tons throughout the world (Mucsi et al., 2021). This waste is deposited indiscriminately in some countries such as Asia, excluding Japan and South Korea and Brazil, causing significant environmental pollution and disposal challenges. Consequently, the imperative to conserve natural resources has intensified, leading to a greater emphasis on waste recycling, as well as playing a role in advancing the concept of a circular economy (Ginga et al., 2020).

RCD waste management is a crucial concern in several countries, with the majority of these wastes being mineral-based and typically constituting more than 90% of their mass (Bianchini et al., 2005). The composition of the RCD is determined by the construction techniques and components used, and can consist of inorganic and organic materials, such as concrete, masonry, excavated earth, glass, plaster, metal, wood, plastics and others (dos Santos Macedo et al., 2019), but mostly includes concrete, brick and ceramic materials (Ulsen et al., 2021).

The composition of RCD is defined by the construction environment in which it is generated, and in masonry construction environments, 90% of waste is red ceramic, which makes up 4.8% of all civil industry (ANICER Annual Report 2015, n.d.). Cementitious materials, cements, mortars and cement pastes, in Brazil, correspond to around 60% of the total RCD (Gomes et al., 2015).

Regarding the use of RCD, currently, in Brazil, it is restricted to the production of non-structural concrete and pavement bases. This limited application is due to the lower quality of concrete made from recycled aggregates compared to concrete made from natural aggregates (Ulsen et al., 2013). This scarce use of RCD is due to its physical and chemical properties, in addition to the presence of porous phases, related to residual hardened cement paste that adhere to the surface of the particles.

This component contributes to the high-water absorption of recycled aggregates, which affects water demand and reduces its resistance (Ulsen et al., 2021).

However, even with the current environmental and process impasses, the condition of the recycled aggregate can be improved through the application of separation forces, which are the forces and processes necessary to release the phases in a material, among which the following stand out: separation by density or magnetic susceptibility.

GOAL

The objective of this study is to qualify the origin and type of construction and demolition waste generated around the world and to characterize recycled concrete aggregates to identify differentiating properties that allow a subsequent recycling process through mineral processing stages using low environmental impact processes.

LITERATURE REVIEW

RCD GENERATION HISTORY

Construction and demolition waste (RCD) is generated during construction, renovation or demolition activities and consists of a set of materials, such as: bricks, ceramic blocks, concrete in general, wood and plywood, mortar, plaster, among others (Angulo et al., 2011).

Historically, raw materials have always been used as needed, however, due to the Second World War, Germany mainly found itself in an adverse situation. There were no sources of raw materials for construction and on top of that the country was completely destroyed. Therefore, to solve both problems, the Germans had to use the materials they had available, thus, Germany became the pioneering country in the area of RCD recycling. Around the 1970s, the great recycling movement came to light, starting in Europe and spreading throughout the world, both to try to mitigate environmental effects and to increase profitability within the same process chain.

Likewise, in the area of civil construction, which has grown exponentially in this century, waste generation has increased proportionally, so construction and demolition waste, being one of the by-products of civil construction, has become an unexplored area with great potential. But only recently has its financial relevance in contributing to a circular and environmental economy, reducing the amount of discarded material, become of interest to construction companies.

Regarding the amount of RCD produced, in 2016, the amount of solid waste in Europe reached 322 million tons, of which 35% was RCD (Taboada et al., 2020).

Therefore, for better use, more research on construction and demolition waste needs to be done and needs to continue improving its quality, resistance, treatment cost and increasing possible uses.

Currently, regarding the use of RCD, both in the Brazilian and international scenario, it is used as pavement bases in most cases (Pâmela Sarto Silva, 2021). In the United States, 600 million tons of RCD were produced in 2018, of which approximately 76% were designated for recycling and the rest for landfills (R. P. Santos & Tubino, 2021). In Asia, excluding Japan and

South Korea, 40% of the total RCD produced was recycled in 2018 (Suárez-Salgado et al., 2018).

In Brazil, the RCD scenario is different, even though there are strict laws on the disposal of solid waste (National Solid Waste Policy - Federal Law nº 12,305/2010) there are many lost opportunities in this area. Regarding the quantity generated, in 2020, more than 44 million tons of RCD were recorded annually, representing 50% by mass of all urban waste and currently only 6.14% of this quantity is recycled (R. P. Santos & Tubino, 2021). Thus, making it essential to understand more about the topic and invest in this area, an example could be starting with recycled cementitious aggregates.

RCD GENERATION AND RECYCLING

During the entire duration of the scientific initiation, the topic of RCD was approached and studied, therefore, a more comprehensive data collection on the topic became necessary. Therefore, data was collected from around the world, through scientific articles, official websites and books on the amount of waste produced, the type and percentage recycled, in addition to analyzing how each country covers RCD recycling and how production is influenced by several socioeconomic factors.

The data collected covers the entire globe (Figure 1), but in some countries it was easier to collect this information than others, due to the fact that they have more authors on the topic. Among the countries, there was a large amount of data from Brazil, the United States, China and the European Union. However, continents such as Africa and Oceania did not have as much available and recent information. Furthermore, all data collected was the most recent possible found in the respective sources, with all data from the European Union being from 2022, from the United States, Brazil and the WANA Region from 2020, the oldest data found is from Canada referring to the year 2012.

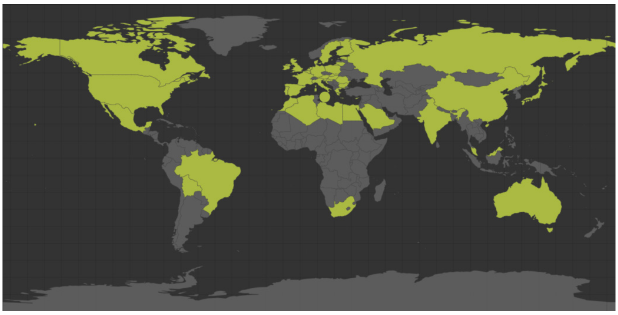


Figure 1: Countries that covered data collection

When researching the amount of RCD generation worldwide, it became clear that in terms of mass there are some countries that generate substantially more, thus being responsible for a large portion of world production.

When conducting comprehensive research into the generation of Construction and Demolition Waste (CDW) on a global scale, it became evident that there is a significant disparity in the amount of RCD produced in different countries. This discrepancy not only reveals the scale of the construction waste problem, but also points to a clear concentration of responsibility in a handful of nations, which take on a substantial portion of the world's production of this type of waste.

RCD production is a crucial indicator of construction and demolition activity in any region. In terms of mass, some countries have stood out notably. These countries not only lead the way in RCD production, but also significantly influence global trends in this sector.

As it was already mentioned in this report, this concentration of production in a few countries can be attributed to a variety of factors, including rapid urban development, the expansion of infrastructure and the dynamics of the real estate market as can be seen in Figure 2. Furthermore, issues

Environmental, regulatory and cultural factors play a key role in how different nations approach RCD management.

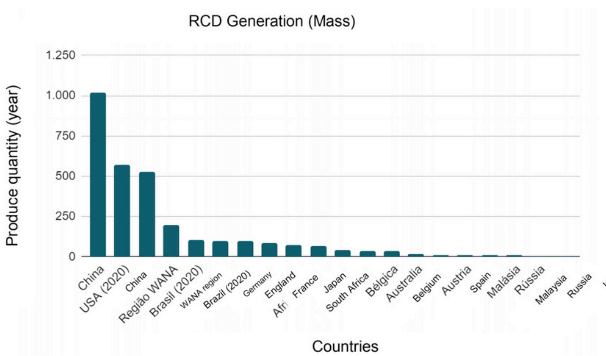


Figure 2 - RCD generation by country

According to the survey results, it is impressive to note that approximately 70% of all RCD generated on a global scale is produced by China, the United States, India, the WANA Region (which comprises countries in the Middle East and North Africa) and Brazil. These countries and regions alone are responsible for a significant portion of global RCD production.

China, with its economic growth and rapid urban development, tops the list as the largest RCD generator in the world. Its demand for infrastructure and civil construction has contributed to staggering volumes of construction and demolition waste. The United States, like China, also has considerable RCD production due to its large population, area, and continuous development of urban areas.

India, with its expanding population and ongoing construction projects, contributes substantially to this statistic. The WANA Region, due to its increasing construction and development activities and unfortunately conflicts that leave urban infrastructure completely destroyed, also represents a large part of global RCD production. Brazil, with its vast territory and ongoing infrastructure projects, completes this group of nations responsible for the majority of construction and demolition waste produced worldwide.

RECYCLING BY COUNTRY

When analyzing the issue of RCD recycling at a global level there is a notable trend, the countries that lead the production of RCD, such as China, the United States, India, the WANA Region and Brazil, are among those that present recycling rates. relatively low recycling rates as seen in Figure 3. Therefore, this reveals how ecologically and economically impactful the issue of RCD recycling is, since all this waste is not being treated in the correct way, damaging the environment and possibly being a waste of possible profits for the countries.

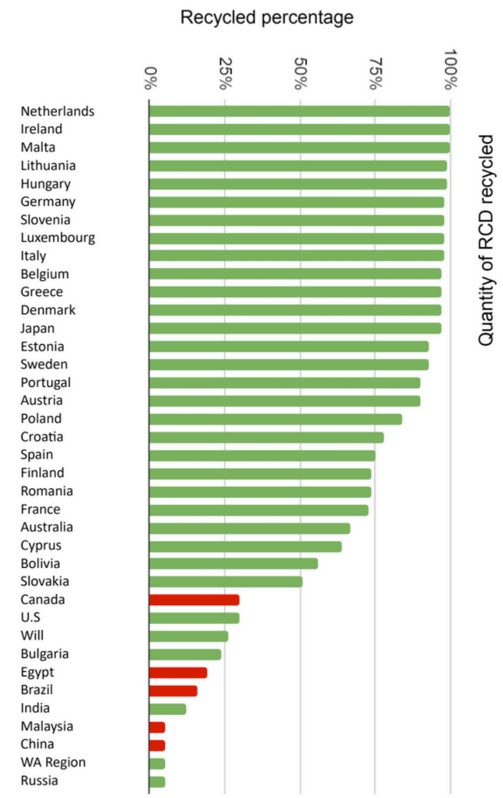


Figure 3 - Construction waste recycling rates by country

In contrast, the European Union (EU) stands out positively with one of the highest RCD recycling rates worldwide. However, it is worth highlighting something essential in this analysis: what each country considers recycling, since a 100% recycling rate, although ideal, is an impossible task. Certainly, in the data shown, countries like Germany that have strict waste management policies are actually recycling this amount of waste. But there are countries that report very high recycling rates when in reality their recycling concept is not standardized.

Given that the information shows very high amounts recycled, research was conducted to really find out how much each country in the European Union is recycling, that is, to find out what each country regulates as recycling.

In the first instance, it was necessary to check the status of legislation on waste recycling in each country. These data were collected from the official European Union article on RCD recycling (Commission, 2017) and presented in Tables: Table 1 and Table 2.

Maturity of RCD Legislation		
Mature Legislation	Existing legislation, but with little application	Developing legislation
Austria	Estonia	Bulgaria
Belgium	Hungary	Croatia
Finland	Ireland	Cyprus
France	Italy	Greece
Germany	Malta	Lithuania
Luxembourg	Portugal	Poland
Netherlands	Spain	Romania
Sweden	England	Slovakia
		Slovenia

Table 1 - Maturity of legislation for RCD recycling in European Union countries

Reliability of information		
Good	Modest	Bad
Austria	Belgium	Bulgary
Denmark	Estonia	Sweden
Germany	France	Cyprus
Netherlands	Hungary	Finland
Poland	Italy	Greece
Portugal	Lithuania	Ireland
Slovakia	Luxembourg	Malta
Slovenia	Spain	Romania
	England	
	Croatia	

Table 2 - Reliability of information provided on construction waste in the European Union

It is observed that several countries in the European Union do not have strict legislation on the issue of RCD recycling, which encompasses the separation of this material, the treatment of the material and the recycling itself. So what leads to such high recycling rates? the answer is landfill.

Several countries consider RCD landfilling as recycling, therefore, in addition to some countries not having good reliability in their reported information, landfilling is the factor that leads to the 100% recycling rates shown in articles and official websites.

Data on GDPs, HDIs, population and generation per year from European Union countries were also collected. In Table 3, it is possible to observe that the countries are organized in descending order in relation to GDP. The conclusion that can be drawn is that in the European Union, a country's GDP follows the amount of RCD generated, with some exceptions such as Belgium, which despite having the 8th GDP, is the 4th largest producer of RCD.

It is also possible to relate the amount of RCD generated per year with the country's population, again following the three largest populations with the three largest generations of waste. Given that to keep up with population growth it is necessary to develop the urban matrix, therefore, more construction materials are needed which lead to the generation of more waste.

Regarding the HDI, it is not possible to make a direct relationship with the generation of waste since the index takes into consideration, many factors such as quality of life, health, economic power among others, these factors are not necessarily linked to the production of RCD of a country.

Countries	HDI	GDP	Population in 2022	Generation/ year
Germany	0,942	4.308.854	83.834.011	100.600.813
France	0,903	2.923.489	66.224.684	86.092.089
Italy	0,895	2.164.745	60.654.734	45.491.051
Spain	0,905	1.492.432	46.411.362	13.923.409
Netherlands	0,944	1.019.889	1.748.000	2.359.800
Poland	0,876	716.305	37.892.016	3.789.202
Sweden	0,947	603.922	10.360.314	2.072.063
Belgium	0,937	589.491	11.833.389	33.133.489
Ireland	0,945	519.776	4.962.574	744.386
Austria	0,916	468.046	9.093.455	12.367.099
Denmark	0,948	386.724	5.866.911	4.400.183
Romania	0,821	299.885	18.776.964	187.770
Finland	0,94	281.411	5.632.815	1.126.563
Portugal	0,866	255.854	10.053.369	603.202
Greece	0,887	222.008	10.302.937	515.147
Hungary	0,846	184.651	9.565.282	2.582.626
Slovakia	0,848	112.418	5.471.777	1.094.355
Bulgary	0,795	85.008	6.804.786	68.048
Luxembourg	0,93	82.154	669.624	803.549
Croatia	0,858	69.380	4.067.000	122.010
Lithuania	0,875	68.031	2.589.292	983.931
Slovenia	0,918	62.191	2.089.331	1.044.666
Estonia	0,89	39.054	1.312.589	1.312.589
Cyprus	0,896	26.705	1.251.488	500.595
Malta	0,918	17.156	445.856	1.738.838

Table 3 - Correlation of GDP, HDI, Population and RCD generation in European Union countries

Data on RCD generation in Brazil for the year 2020 were also collected ("ABRECON Sector Survey 2020: Recycling Construction and Demolition Waste in Brazil," 2022). Among the data presented in Table 4, it is possible to clearly correlate GDP with RCD production, as well as the recycling rate, proportionally countries with higher income produce more and recycle more in the case of the Brazilian scenario.

Figure 4 shows the composition of recycled aggregates in the different regions of Brazil, with cementitious materials being the highest percentage in the North and Northeast regions and mixed aggregates being present in large quantities in all regions, except the North. Regardless of the region, there is the presence of red ceramics in the composition of the aggregates.

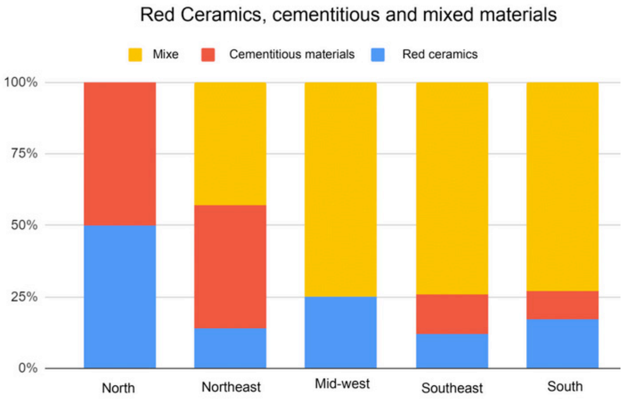


Figure 4 - Composition of recycled aggregate by Brazilian region

CEMENTITIOUS RECYCLED AGGREGATES

In most civil construction environments, the waste generated contains a greater quantity of cementitious materials, since this class of material is the most used in these environments.

The recycled cementitious aggregates commonly associated with civil construction are cement, cement paste and mortar (Silva, 2021) and in Brazil these materials correspond to three-fifths of all RCD produced (Gomes et al., 2015).

Recycling construction and demolition waste (RCD) materials through comminution results in the generation of recycled aggregates. Crushing concrete waste produces fine and/or coarse aggregates that contain approximately 40 to 50% cement paste in their volume, resulting in lower density and greater water absorption compared to traditional aggregates such as sand and crushed stone (Cabral, 2017)

Recycled concrete aggregate is suitable for the production of non-structural concrete, as a general filler, subbase or base for road

Region	Generation RCD (Mt/year)	IDH	PIB (billion)	Quantity recycled (Mt/year)	Recycling rate
North	9,3	0,667	478.173	0,141	2%
Northeast	29	0,663	1.079.331	1,827	6%
Mid West	8,3	0,757	791.251	0,938	11%
Southeast	44,5	0,766	3.952.695	10,865	24%
South	15,1	0,754	1.308.148	3,175	21%

Table 4 - Correlation between RCD Generation, HDI, GDP and recycling rate

construction, and as an aggregate for new concrete. Recent studies indicate that they can be used for more noble purposes and still achieve properties similar to those of reference concretes (Pedro et al., 2017).

The physical and chemical parameters of recycled concrete aggregates are affected by the amount of cement mass present, which in turn has a direct impact on the mechanical properties of recycled concrete. To fully understand this impact, it is crucial to study the anhydrous and hydrated phases of cement. The development of technologies and methods for removing and quantifying the cement mass content in recycled concrete and mixed aggregates is necessary to speed up the process.

When it comes to concrete, it is made up of cement, water, coarse aggregate (usually crushed stone) and fine aggregate (usually sand), and smaller constituents such as filler, and when the cement is hydrated with water, a paste is formed. and the same, it can be an indication of the reactivity of the mixture and the water/cement ratio, in addition to a compound called an additive that helps with the strength of the concrete. Mortar, on the other hand, is a mixture composed of cement, water, inorganic binder (such as hydrated lime) and fine aggregate (commonly, sand), which may or may not contain additives to increase adhesion or to delay or accelerate hardening.

SEPARATION PROCESSES FOR PROCESSING

Construction and demolition waste is made up of several phases of materials and different sizes, therefore, as it is made up of different materials, it is possible to carry out separation processes based on the different characteristics intrinsic to the material. One of the methods used to separate the phases of a material is done through the difference in density between each different material, using a medium of intermediate density.

To apply any density method, the samples undergo wet sieving in order to analyze the density differences between phases of equal particle size. Once the sieving has been carried out, we can apply different separability methods (Ulsen et al., 2013).

Among others, the separation process using heavy liquid is a simple procedure to carry out since it consists of placing the sample in an organic liquid with an appropriate density (an intermediate density between the two phases that you want to separate), causing it to light particles float and heavy particles sink, thus separating the different densities (Ottley, 1986).

Another differentiating characteristic of each material is its magnetic properties, that is, the way it interacts with different magnetic fields and effects. When it comes to the magnetic separation process, it can be done through Frantz magnetic separation, which evaluates the magnetic susceptibility in heavy separation liquids (Grewal & Eng, 2006). The Frantz separator can generate a magnetic flux density of 0 to 20 KG, variable without gaps, and can efficiently process particles between 850 to 74µm. By varying the magnetic field and the lateral feed inclination, the particles that are affected by the magnetic field are separated from those that are inert to the same field and even particles that were not affected by a certain amount of magnetic field can be affected if it increases.

MATERIALS AND METHODS

The experimental procedure developed in the work is presented in Figure 5, and involved the steps of: a) molding concrete specimens, b) characterization in the fresh and hardened state, c) production of recycled concrete aggregates, d) characterization of the products.

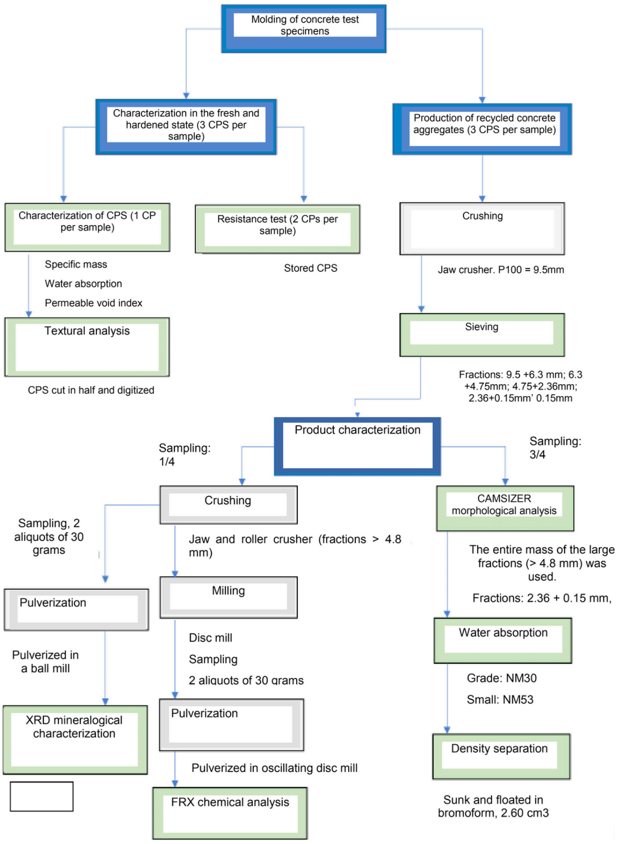


Figure 5 - Flowchart of preparation and characterization of concrete and recycled aggregate

MATERIALS

The materials used for the study were coarse aggregates of granite origin, Portland CPV cement and natural sand, used to manufacture test specimens with different mechanical resistances (different porosities and cement and water content).

The materials used will be characterized in terms of particle size distribution by wet sieving (coarse aggregate and sand), or by laser spreading (cement; due to its very fine particle size). An aliquot of each material was also analyzed from a chemical point of view (chemical composition by XRF) and mineralogical point of view (mineralogical analysis by XRD).

CONCRETE MOLDING

A total of 16 test specimens were prepared with a composition of crushed stone (coarse aggregate), natural sand (fine aggregate) and cement (CPV). The quantities and proportions can be checked through the concrete trace where there is a relationship between the amount of cement: sand, gravel and to calculate the amount of water the w/c ratio (water/concrete) is used.

The concrete molding process was carried out at the Department of Civil Construction Engineering, through an academic partnership established between the group's researchers. 30 kg of two types of concrete were molded, the first with a ratio of 1:1.55:2.45 (w/c = 0.5), and expected strength of 40 Mpa and the second with a ratio of 1:2:3 (w/c = 0.6) and expected resistance of 20 Mpa; 0.15% of the additive cement mass was added to both concretes. Furthermore, the materials were mixed in a concrete mixer (Figure 6) for 2 minutes, with a break in between to remove excess concrete on the blades.

Figure 6 - Concrete mixer used to mix materials

Once the mixing time was over, the slump of the concrete was checked using the cone method; the first concrete had a self-compacting slump and the second had a slump of 23 cm. After this process, the entire mass of concrete was placed in cylindrical specimens measuring 10 cm in diameter and 20 cm in height, as can be seen in (Figure 7) and soon after, on a vibrating table. After one day, the concretes were removed from the specimens and named according to their expected strength; Having done this, all concrete cylinders were placed in a humid chamber (Figure 8), for a period of 28 days so that the rupture could be made. Unfortunately, due to schedule delays during the production of this report, the break has not yet been made, therefore, there are no conclusions or additional data.

Figure 7 - Cylindrical specimens measuring 10cm in diameter and 20cm in height

Figure 8 - Concrete molded and placed in the wet chamber

CHARACTERIZATION OF THE TEST SPECIMENS

The characterization of the specimens in the hardened state involved the determination of compressive strength, specific mass, water absorption and textural analysis.

The compressive strength was determined after 28 days of molding the concrete, two specimens of each strength were removed from the humid chamber and prepared to make the compressive strength measurements. In the first instance, the upper part of a specimen was cut (Figure 9) so that both bases were flat (Figure 10), these specimens were measured with a caliper (diameter and height of the PCs); subsequently, the compression resistance test was carried out in a mechanical press, in which the pressure on the CP slowly increases until it breaks (Figure 11), thus being able to measure how much it resists. The resulting strengths were 26 MPa and 41 Mpa (Figure 12 and Figure 13) close to the expected values (20 Mpa and 40 Mpa).

Figure 9 - CP being cut on the water jet cutting machine

Figure 10 - CP with flat faces for resistance tests to be carried out

Figure 11 - CP after compression in the resistance test

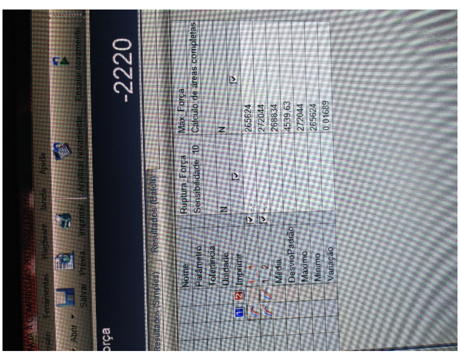


Figure 12 - Data collected on CP strength of 26 MPa

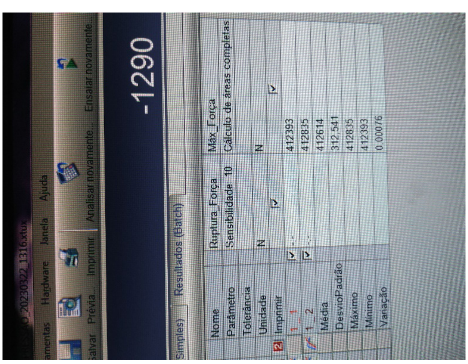


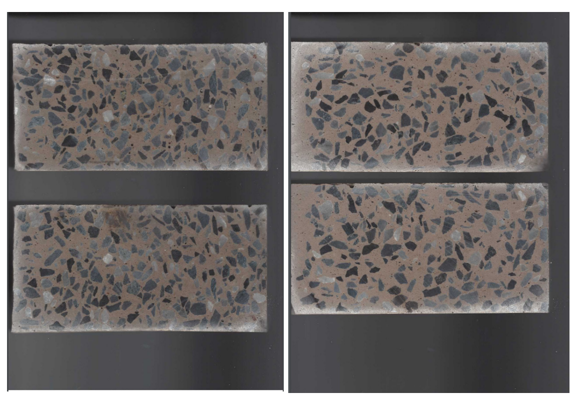
Figure 13 - Data collected on CP strength of 41 MPa

The mass of the specimens was also determined in accordance with the standard (NBR9778) for specific mass, water absorption and permeable void index.

First, on a hydrostatic scale, the submerged mass (Figure 14) of 2 intact CPs was weighed, then, with only the surfaces dry, the weight of the concrete saturated with the dry surface was measured. Finally, after 5 days in an oven at 100°C, the dry masses of the concrete were measured.

Figure 14 - Scale used to measure submerged mass

For the textural analysis of the CPs, an intact CP of each resistance was used, so that the phase distribution could be analyzed; to this end, it was cut longitudinally in a water jet cutting machine, in order to define the crushing condition (Figure 15).



(a) (b)

Figure 15 - Digitized image of CPs with resistance 41 MPa(a) and 26 MPa(b)

PRODUCTION OF RECYCLED CONCRETE AGGREGATES

Three specimens of each resistance were used for crushing, which was carried out using a jaw crusher in a closed circuit with a 9.5 mm sieve, until all material passing through this dimension was obtained. After crushing, all the material was passed through wet sieving in 50x50 cm square sieves, (Figure 16), in which the openings were: 9.5; 6.3; 4.75; 2.36; 1.18; 0.15 and 0.074 mm. After analyzing the particle size distribution, some fractions were composed due to low mass representation. Therefore, the fractions that were used for all analyzes were: -9.5 +6.3mm; -6.3 + 4.75mm; -4.75 + 2.36mm; -2.36 + 0.15mm and -0.15mm.

Figure 16 - Square sieves mounted for wet sieving

CHARACTERIZATION OF RECYCLED CONCRETE AGGREGATE

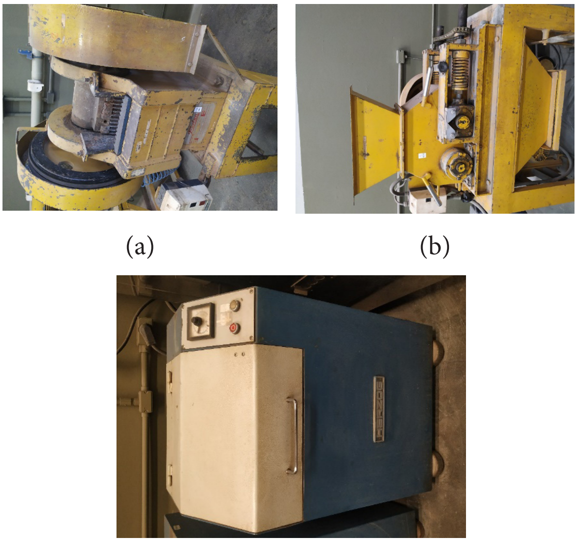
The characterization of the products was carried out by chemical composition (FRX), mineralogical composition (DRX), particle size distribution and particle morphology (Camsizer), water absorption and density separation.

To prepare the products so that they could be characterized and analyzed using the different material characterization techniques that LCT can offer, crushing, sieving, sampling and different spraying were carried out depending on the technique to be carried out.

All fractions underwent CAMSIZER, water absorption, XRF and XRD analyses, therefore, they needed to be sampled and prepared according to the technique's needs.

Therefore, ¾ of the mass of each fraction was divided for CAMSIZER analyzes and water absorption tests. The rest went through comminution, the coarser fractions (-9.5 +6.3mm and -6.3 + 4.75mm) went through the jaw crusher again, (Figure 17), followed by the high-pressure roller crusher, the -4.75 + 2.36mm fraction was only subjected to the roller crusher and the finest samples were sampled directly. After these procedures, 2 aliquots of 30 grams were separated to be pulverized in the ball mill for XRD and TG analyzes to be carried out.

The remainder of the mass was subjected to pulverization in the oscillating disc mill, and two 30-gram aliquots were again sampled, which were destined for the FRX technique.



(a) (b) (c)

Figure 17 – Sample preparation equipment (a) jaw crusher; (b) roller crusher; (c) oscillating ring sprayer

The aliquots pulverized in the ball mill were prepared in steel crucibles so that the analyzes could be performed by the device. The intact fractions that were quartered were subjected to dynamic image analysis, to determine the size of the particles as well as their shape and sphericity.

PARTICLE MORPHOLOGY

The characterization of particle morphology was carried out by dynamic image analysis (Wolfgang Witt et al., 2005; Witt et al., 2008) in real time conducted in CAMSIZER, a machine capable of analyzing the shape and size of particles, which can analyze thousands of particles in minutes. This occurs through photos that are taken of the material that falls from a vibrating conveyor and passes through a screen with a strobe light, so several photos of the material can be taken and the system counts and calculates their size. Because image analysis is non-destructive, the same masses were used so that water absorption could be carried out.

WATER ABSORPTION

The determination of water absorption according to Brazilian and international standards NM 30 and NM 53, which involve the determination of the dry mass of the aggregate, saturated with free water and in the condition of the aggregate saturated with a free surface. For coarse aggregates, according to standard NM 53, each product must remain immersed in water for 24 hours; Then, each particle is dried with a cloth until it reaches the saturated surface dry condition (SSS), that is, without surface moisture. Each of these particles has its mass determined for the SSS condition, submerged mass and also the dry mass after 24 h in an oven at 110C and the dry mass is measured again.

The determination of the SSS for fine aggregates was carried out using a test described by the NM 30 standard. Again, the sample is saturated in water for 24 hours, then it must be dried using an oven, placing it in it for a short time so that the hot air can superficially dry the samples. To check whether the sample has reached the necessary condition, a frustum is made and struck 25 times. If it partially collapses, then the sample is at the ideal point. The mass in the SSS condition and the mass of the sample after drying in an oven must then be determined.

DENSITY SEPARATION

The density separation test in dense liquid to establish a density separability curve employs liquids in increasing order of density. Floated products must be weighed and analyzed, the separation process is repeated successively for sunken products until the highest density considered; the final sunk fraction obtained must also be weighed and analyzed, Figure 18, (Burt, 1999). But in case of this project, due to lack of time, separation of dense liquid was done only in one density. Using bromoform as a dense liquid and ethyl alcohol to adjust densities (solvent). Extra care must be taken as the liquid in question releases toxic vapors and must be handled in a fume hood, using a gas mask and gloves, avoiding any contact with the skin or inhalation.

Figure 18 - Erlenmeyer flask used for the density separation test, respectively (acetone, alcohol and bromoform)

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Figure 19 - Density separation products

MINERALOGICAL CHARACTERIZATION

Mineralogical analyzes using X-ray diffractometry aimed to identify the crystalline phases present in the RCD. The analyzes were carried out using the powder method using an Empyrean diffractometer, Malvern Panalytical (Figure 20), with a copper tube (CuKα), 40 kV and 50 mA. The operating angular range was 2.5 to 70o 2θ, with a step of 0.03o and a time of 3 seconds per step.

The samples used were the sieved, pulverized and quartered fractions for analysis.

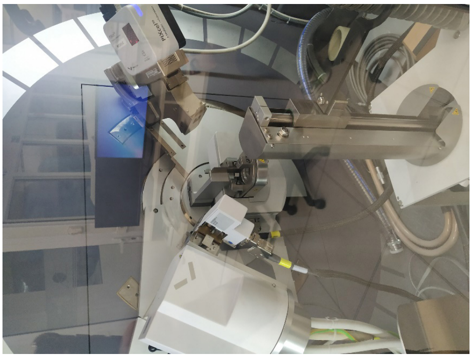


Figure 20- X-ray diffractometer

CHEMICAL ANALYSIS

The technique used for chemical analysis of the samples was X-ray fluorescence spectrometry (XRF) using a Zetium spectrometer, Malvern PANalytical brand. (1g of sample for 7g of flux) with systematic determinations of SiO2, Fe2O3, Al2O3, CaO, MgO, Na2O, K2O, MnO, TiO2, P2O5 and SO3, in addition to fire loss at 1050°C. The insoluble residue (IR) was estimated using the wet method by reacting an aliquot of dry and pulverized material, weighing approximately 20 g, with 100 mL of 20% hydrochloric acid (HCl) solution. Part of the sample, the soluble binders, reacts with HCl; the remaining portion is called insoluble residue, which is essentially composed of clay minerals, quartz and feldspars (Quarcioni et al., 2011).

RESULTS

CHARACTERIZATION OF THE TEST SPECIMENS

To characterize the specimens, information was collected on diameter and height (Table 5) and masses (Table 6) to calculate the properties in the hardened state (Table 7).

Type of CP	Diameter (mm)		Height (mm)
26 MPa	101,16	101,14	194,66
	101,19	101,42	195,45
41 MPa	101,24	101,99	1945,01
	100,77	100,74	193,54

Table 5 - PC diameter and height measurements

Samples (CP)	Type of mass	Measured values (g)	
26	Mi	2177,54	2175,94 g
41		2203,06	2237,06
26	Msat	3748,43	3735,49
41		3765,30	3802,13
26	Ms	3475,0	3470,0
41		3530,0	3580,0

Table 6 – CP masses measured in different states

Concrete	ME (g/cm^3) (2 measurements)		ABS (%)		VP (%)		RC (MPa)
26 MPa	2,212	2,225	7,86	7,65	17,41	17,02	26,8834
41 MPa	2,259	2,287	6,66	6,20	14,57	14,19	41,2614

Table 7 – Properties of test specimens in the hardened state

ME – Specific mass; ABS – water absorption; VP – permeable void index, RC – compressive strength;

$$M_e = \frac{M_s}{M_{sat} - M_i}; \; Abs = \frac{(M_{sat} - M_s)}{M_s} * 100; I_{empty} = \frac{M_{sat} - M_s}{Msat - M_i} * 100$$

CHARACTERIZATION OF RECYCLED CONCRETE AGGREGATE

The sieving data for both recycled concrete aggregates are shown in Figure 21. It is possible to notice that there are no considerable variations between the sievings of both particle sizes, the particle diameter curves are practically identical.

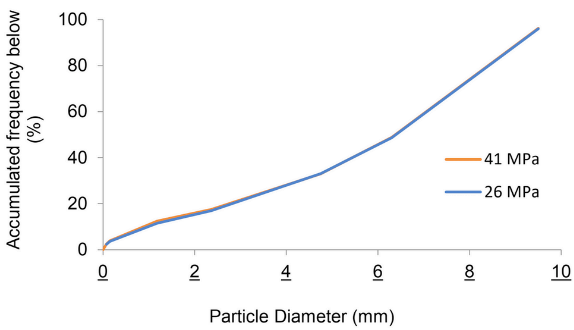


Figure 21 - Result of sieving recycled aggregates

In both cases, the sphericity improves considerably for the fine ones, but remains with a small variation between the other particle sizes.

In the particle morphology data, we can see that both samples show the same trend, with the finer fraction having better sphericity, as seen in Figure 22 and Figure 23. Analyzing the aspect ratio, it is possible to conclude that the particles are less elongated as the particle size decreases as seen in Figure 24 and Figure 25.

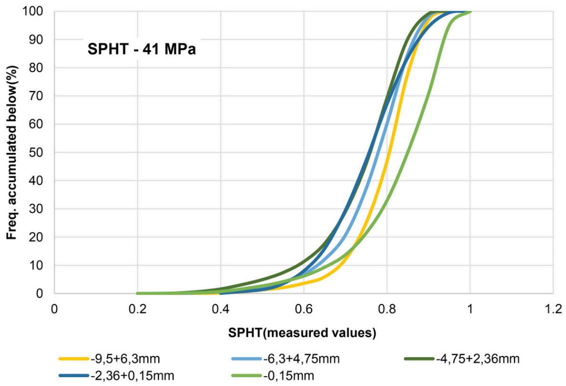


Figure 22 - Sphericity by particle size fraction for sample 41 MPa

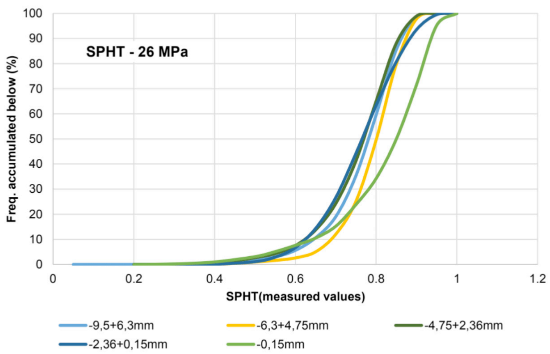


Figure 23 - Sphericity by particle size fraction for sample 26 MPa

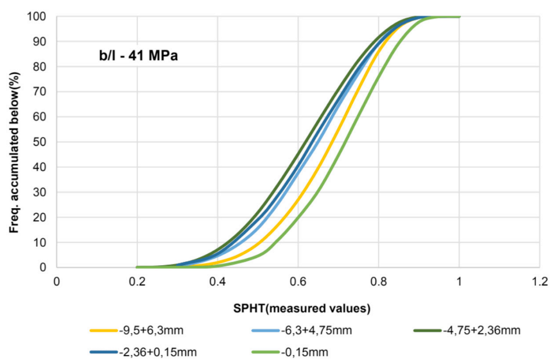


Figure 24 - Aspect ratio per particle size fraction of the sample 41 MPa

CPs	Fraction (mm)	Contents								
		SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	PF
26 MPa	-9,5+6,3	41,8	4,7	3,01	1,92	28,6	0,33	0,79	0,35	18,6
	-6,3+4,75	46,9	3,95	2,68	1,90	26,6	0,24	0,63	0,31	16,5
	-4,75+2,36	50,1	3,84	2,49	1,81	24,7	0,2	0,56	0,31	15,5
	-2,36+0,15	58,9	2,74	1,80	1,55	20,7	0,1	0,34	0,22	12,8
	-0,15	33,4	3,86	2,66	2,39	32,9	0,15	0,43	0,31	22,8
41 MPa	-9,5+6,3	39,3	4,92	3,37	1,95	29,3	0,34	0,81	0,39	19,8
	-6,3+4,75	47,6	4,29	2,91	1,89	25,4	0,27	0,69	0,34	16,1
	-4,75+2,36	51,8	3,32	2,26	1,83	24,6	0,16	0,47	0,27	14,7
	-2,36+0,15	57,0	2,65	1,85	1,71	22,1	<0,10	0,32	0,23	13,1
	-0,15	33,4	4,58	2,46	2,38	33,1	0,17	0,54	0,28	22,5

Table 8 - Contents of different oxides in recycled aggregates

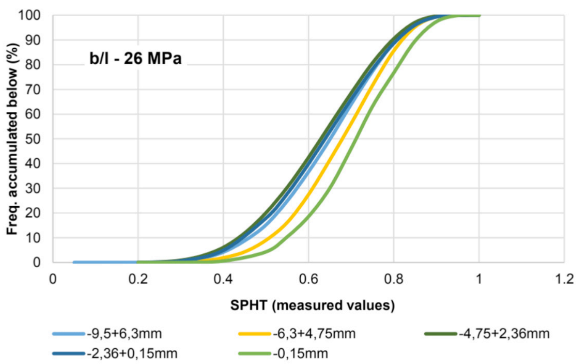


Figure 25 - Aspect ratio per particle size fraction of the sample 26 MPa

Table 8 presents the contents of the main oxides in recycled aggregates, by particle size fraction.

The SiO2 contents are the largest constituents in both resistances and vary noticeably depending on the granulometry, from 33.4% to 58.9%, this is due to the presence of sand in the aggregate composition, in addition to the crushed stone materials.

The behavior of the Al2O3, Fe2O3 and CaO contents have similar behavior in both samples, it is noted that the contents decrease according to the granulometry, but increase again in the -0.15mm fraction, with Al2O3, Fe2O3 having the highest content in the largest grain size and CaO has in the smallest grain size. However, CaO has much higher levels, ranging between 20.7% and 33.05%. Al2O3 contents vary between 2.65% and 4.915%, and 1.8% and 3.37% for Fe2O3.

Both MgO and Na2O have very low levels, both of which are negligible compared to other compounds. Likewise, K2O and TiO2 have low contents and similar behavior, both decrease according to the particle size for the two resistances (percentages).

Finally, the fire loss is systematically lower for the finer fractions, the exception being the small fraction of -0.15 where the greatest fire loss is noted.

The results of mineralogical analysis by X-ray diffraction of the different particle sizes of concrete with a strength of 26 MPa are shown in Figure 26 and that of a strength of 41 MPa in Figure 27.

The main phases identified were a) tectosilicates from natural rocks, b) carbonates and c) phyllosilicates - mica (muscovite/biotite/phlogopite). Comparing the fractions, it turns out:

A. Muscovite increases as particle size increases;

B. Amphibole decreased, albeit slightly, as particle size decreased;

C. Serpentine chlorite increases as the particle size increases;

D. There is no magnetite in the -0.15 mm fraction;

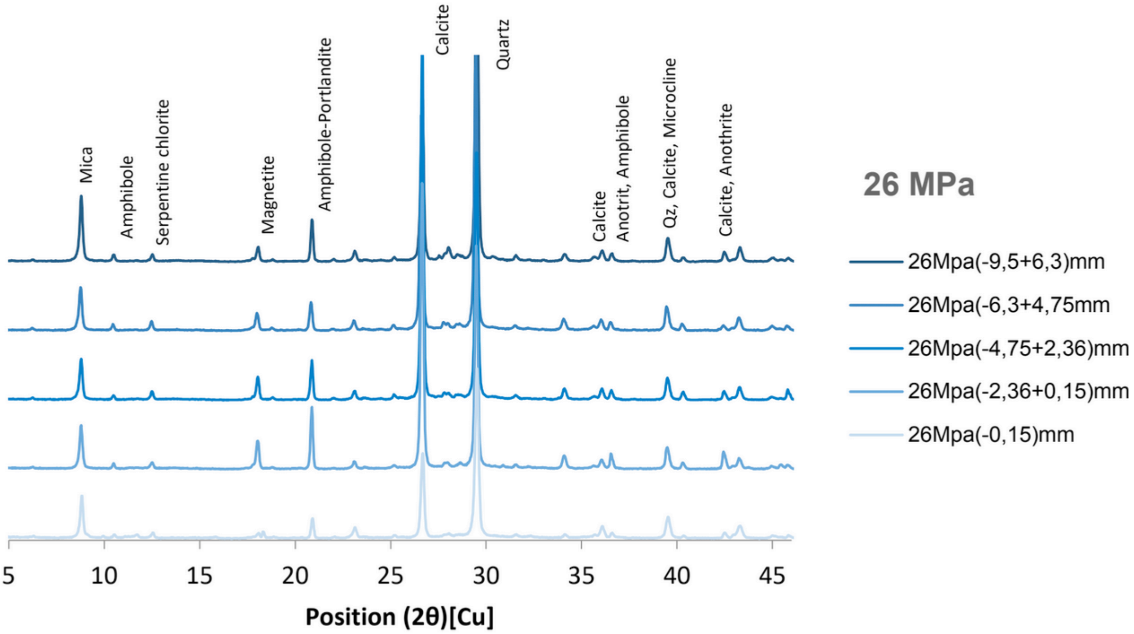


Figure 26 - Mineralogical analysis by diffraction of the 26 MPa sample

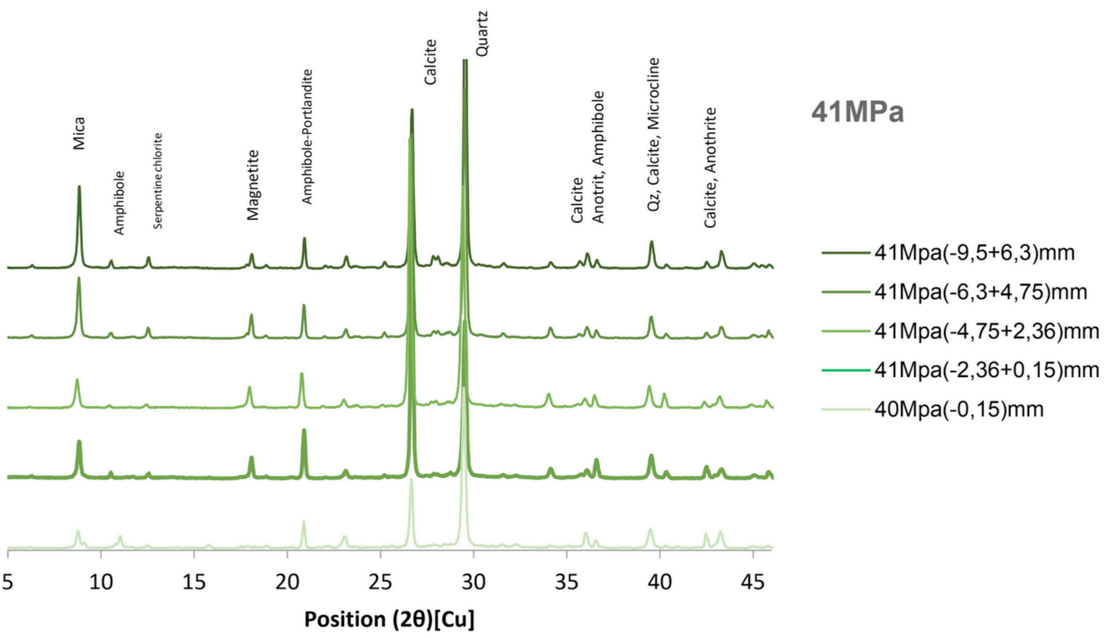


Figure 27 - Mineralogical analysis by diffraction of the 41 MPa sample

E. Quartz decreases as the particle size decreases;

F. Other peaks remain constant in particle size.

The results of the tests to determine water absorption for the various dense liquid separation products of the coarse and fine fractions are presented in Figures: Figure 28 and Figure 29

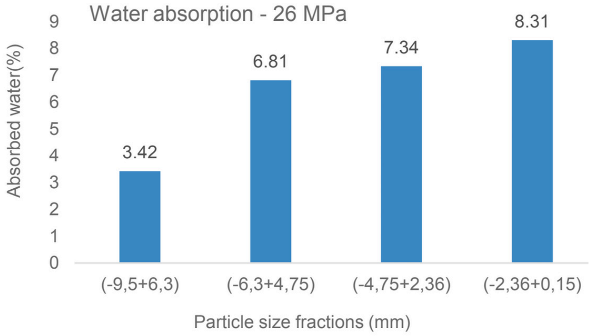


Figure 28 - Water absorption per sample fraction 26 MPa

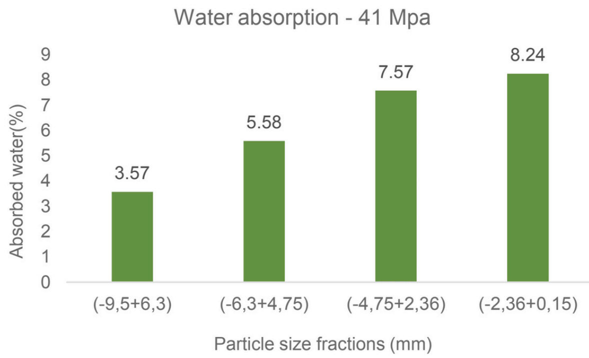
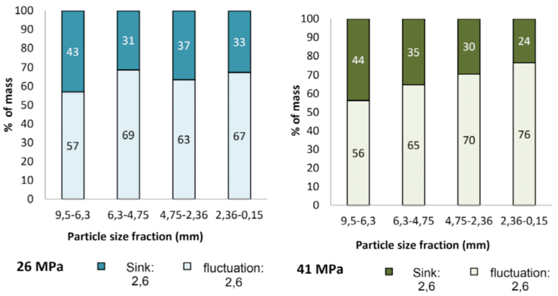


Figure 29 - Water absorption per sample fraction 41 MPa

It can be seen that the water absorption values in the particle size fractions do not have a notable difference when comparing concretes of different strengths.



Concrete 26 MPa Concrete 41 MPa

Figure 30 - Mass distribution of dense liquid separation results

The results of the dense liquid show a constant trend in both recycled aggregates, when the granulometry is smaller, the amount of sunk at 2.6g/cm3 decreases as seen in Figure 30. However, it is noted that the mass percentages of sunk are higher for the aggregate with lower resistance.

CONCLUSIONS

Concrete with different traits and compressive strengths were molded for subsequent production of recycled concrete aggregates. The aggregates produced had a similar particle size distribution (sieving), the finer fractions were more spherical (SPHT closer to 1) and less elongated (b/l closer to 1). From a compositional point of view, there is little variation between the fractions, most notably in relation to the proportion of mica and magnetite (higher concentrations in the coarser fractions). Regarding physical properties, the aggregates showed similar water absorption, however, the aggregates resulting from 26 MPa CPs showed a higher mass proportion of sunken products at 2.6 g/cm3, indicating greater release of the porous cement paste (lower density), especially in fractions below 4.8 mm (fine aggregate fraction).

FINAL CONSIDERATIONS

The bibliographic review process showed the complexity of the topic addressed, but also the opportunities to contribute to the circularity of mineral raw materials. There was an initial laboratory training process that was essential for understanding sample preparation and characterization methods, which will be essential for future activities.

The test specimen molding activities were very interesting and contributed to expanding knowledge in a multidisciplinary area such as this work. Added to this, there is always a team of researchers and laboratory technicians willing to assist with laboratory activities.

The preparation of the partial report was very challenging as it was the first research report carried out, but for the final report, there was maturity both in the bibliographical research and in the description of the methods and results.

SUGGESTIONS FOR FUTURE WORK

To expand the scope of the study, two suggestions for future work were observed: a) select concrete or other mineral materials present in construction waste to expand separability studies; b) expand characterization studies based on the conclusions obtained, such as: thermal analysis to quantify the cement paste in each product, densito-magnetic separation (Magstream system), chemical analysis of the products of densitary separations. The scope expansion proposal deals with evaluating the efficiency of separation methods commonly used in the processing of ores for the separation of aggregates and hardened cement paste.

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