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Granulometric and Gravimetric Combined Method for Construction and Demolition Waste Characterization

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ABSTRACT: Construction and Demolition Waste (CDW) arises from activities such as construction, demolition, reclamation, repair, and excavation. CDW has a wide range of potential applications, including use in pavement base and sub-base layers, mortar and block production, daily landfill cover, erosion control, and more. However, inadequate disposal may lead to contamination with other waste types, and the heterogeneity and variability of CDW frequently result in its rejection by the market. This paper presents a methodology for CDW characterization based on the combination of granulometric and gravimetric analyses, applied to recycled aggregates obtained from a CDW treatment plant located in Bauru, São Paulo State, Brazil. Four samples were collected from different stockpiles and processing ages, identified as CDW1, CDW2, CDW3, and CDW4. The material was quartered, homogenized, and weighed. Granulometric analysis was carried out using a set of sieves (25, 19, 12.5, 9.5, 6.3, 4.8, 2.4, 1.2, 0.6, 0.3, 0.15, and 0.075 mm), first with a vibrating apparatus, followed by manual refinement. The retained masses were weighed, and the materials separated for gravimetric analysis. Fines were analyzed by sedimentation using the fraction passing the smallest sieve, supplemented with additional sample portions. Gravimetric analysis was performed immediately after sieving through visual and tactile inspection and manual separation. On average, the predominant materials were concrete (44.01%), gravel (18.63%), mortar (15.76%), clay bricks and blocks (13.90%), ceramic materials (4.03%), and composites (1.21%). The remaining materials accounted for 2.31%. Due to the presence of potentially non-inert components such as plastics and glass, it is recommended to complement the characterization with chemical and leaching tests. The proposed combined methodology may also be applicable to other types of dry residues, such as domestic recyclables.

KEYWORDS: Geoenvironmental Characterization, Sustainable Engineering, Recycled aggregates, CDW, Waste valorization.

1 INTRODUCTION

Environmental impact can be defined as "any alteration in the physical, chemical, and biological properties of the environment, caused by any form of matter or energy resulting from human activities that, directly or indirectly, affect: the health, safety, and well-being of the population; social and economic activities; the biota; the aesthetic and sanitary conditions of the environment; and the quality of environmental resources" (CONAMA, 1986).

In this sense, while the construction industry is valuable for development, it can also bring environmental harm through resource depletion, pollution, energy consumption, and waste generation (Marques Neto, 2003). So, construction and demolition waste (CDW) represent a significant problem for basic and environmental sanitation.

Regarding its applicability, although commonly used for paving, CDW has various sustainable purposes, including landfill material, reuse in pavement bases and sub-bases, mortar production, block manufacturing, erosion control, and others. However, improper disposal, potential contamination with other types of waste, and the heterogeneity and variability in CDW properties often create resistance to its acceptance in the market.

Furthermore, sustainability is based on a three-pillar concept of social, environmental, and economic aspects. In this context, CDW is relevant to sustainable development, as it affects environmental impacts, and its recycling chain generates jobs, income, and mitigates social issues (Nagalli, 2014).

Therefore, it is essential to balance the construction industry's demand for materials and reduce environmental impacts, emphasizing the importance of managing this waste by transforming "debris" into raw material, enabling its reintegration into the market. Advancing more effectively in improving reuse and recycling methods helps address this problem by proposing alternatives that are technically, environmentally, and economically viable. Understanding how construction waste behaves and is characterized as a material is crucial.

To scientifically contribute to a better understanding of CDW as a construction material and its technical and environmental viability, this paper presents a method for granulometric and gravimetric evaluation for CDW characterization, based on tests conducted with recycled aggregates obtained from a processing plant in Bauru, São Paulo State, Brazil.

1.1 *CDW Management in Brazil*

Brazilian Law 12.305/2010 refers to the National Policy on Solid Waste (PNRS), which governs solid waste management in Brazil. It defines CDW as that generated from construction, demolition, renovation, repairs, and excavation activities (Brasil, 2010).

Regarding its gravimetric composition, CDW includes various materials, such as wood, concrete, plastic, soil, and mortar, among others. Typically, 60% to 70% of this material is of mineral origin (Marques Neto and Schalch, 2010). Thus, CDW can be understood as a heterogeneous mixture of materials, with material volumes varying greatly according to the construction techniques of the projects from which they originate (Nagalli, 2014). Marques Neto (2009) emphasizes this variability by comparing the quantity of constituent materials in debris from different regions of Brazil.

In Brazil, the recycling of the CDW gained increased attention after the publication of CONAMA Resolution No. 307 in 2002. This resolution establishes guidelines, criteria, and procedures for the management of CDW, aiming reduction of the environmental impacts. It also requires municipalities to develop a Construction and Demolition Waste Management Plan (CDWMP). It also presents classifications, allowing CDW to be reused or recycled as concrete, ceramic, and asphalt aggregates (Class A); recyclable for other uses, such as paper, plastic, metal, glass, wood, and gypsum (Class B); non-recyclable (Class C); and contaminated or hazardous (Class D). According to Brazilian regulations, waste generators are classified as either large or small based on the volume of waste produced. Large generators are responsible for managing the waste they produce, while municipalities oversee waste from small generators and provide infrastructure such as voluntary drop-off points, known as "Ecopoints" and Transfer and Sorting Areas (TSA) (Brazil, 2002). In terms of regulation, in 2004, the Brazilian Association of Technical Standards (ABNT) published a set of standards providing specifications and guidelines for the management of CDW, including:

- NBR 15.112/04 - Construction and bulky solid waste - Transfer and sorting areas - Guidelines for design, implementation, and operation.
- NBR 15.113/04 - Construction solid waste and inert waste - Landfills - Guidelines for design, implementation, and operation.
- NBR 15.114/04 - Construction solid waste - Recycling areas - Guidelines for design, implementation, and operation.
- NBR 15.115/04 - Recycled aggregates from construction solid waste - Execution of paving layers - Procedures.
- NBR 15.116/04 - Recycled aggregates from construction solid waste - Use in paving and preparation of non-structural concrete - Requirements.

NBR 15.116 was revised and updated in 2021 and now permits the use of recycled aggregates (obtained from the processing of Class A construction materials) for structural applications in Portland cement mortars and concrete, establishing specific requirements and testing methods for this purpose.

1.2 *Regional Aspects*

The municipality of Bauru, located in the State of São Paulo (SP), Brazil, with an estimated population of 380,000 (IBGE, 2020), has established a municipal framework for construction and demolition waste (CDW) management in accordance with local ordinance, operating eight Ecopoints and two recycling plants city-wide.

In 2022, the amount of CDW generated in Brazil was approximately 45 million tons (ABREMA, 2023). Lamônica (2020), in a study diagnosing CDW management in Bauru (SP), presented estimates of CDW generation in the municipality, with an average weight of 210,873 tons delivered to receiving facilities in the city in 2019.

1.3 *Characterization Aspects*

Many studies focus on using CDW as recycled aggregates for pavement base and sub-base layers. For this purpose, ABNT NBR 15115:2004 specifies granulometric limits that must be reached. According to these granulometric specifications, the maximum characteristic grain size should be 63.5 mm, the percentage of material passing through a 0.42 mm sieve should be between 10% and 40%, and the minimum uniformity coefficient is 10 (ABNT, 2004).

Previous studies have reported important granulometric characteristics of CDW. Jiménez (2011) described a well-graded but non-uniform distribution in recycled concrete aggregates (RCA), dominated by fine gravel and sand. Santos (2007) observed low granulometric variability in CDW, with a typical gravelly-sandy texture due to standardized processing.

Building upon these findings, Carmona Wilches et al. (2025) compiled and classified CDW into specific categories based on material type: AR (recycled aggregates), with subgroups AR_A (recycled asphalt aggregate), AR_B (recycled brick aggregate), and AR_C (recycled concrete aggregate). Two broader mixed categories were also introduced: MCW (mixed CDW composed of concrete, brick, ceramic, glass, and asphalt, excluding plastic, paper, wood, and metal) and MCDO (mixed CDW and others, including a wider variety of constituents such as plastics, wood, metals, and paper). Figure 1 presents this classification alongside a synthesis of grain-size distribution curves reported in various studies, structured by CDW type and by continent—AF (Africa), AS (Asia), EU (Europe), and SA (South America). According to the authors, the comparative analysis revealed significant heterogeneity in particle size distributions, attributable to variations in material origin, composition, processing methods, and regional reuse practices. This variability, as they concluded, hinders the establishment of standard granulometric ranges, which remain largely defined by local regulatory frameworks and the performance requirements of specific applications.

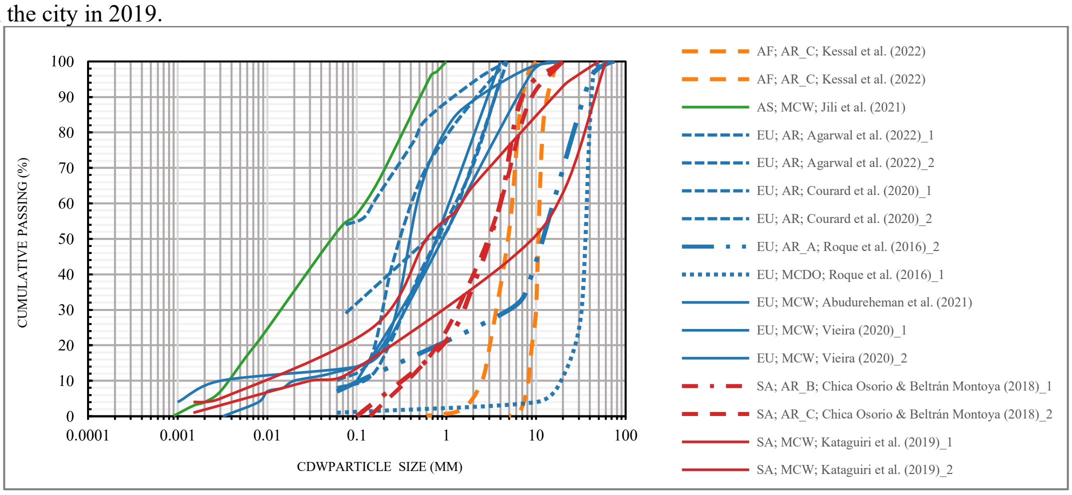


Figure 1. Synthesis of grain size distribution curves of recycled construction and demolition waste (CDW), classified by type and continent. Data compiled and adapted by Carmona Wilches et al. (2025) based on multiple literature sources.

2 MATERIALS AND METHODS

2.1 *CDW Sampling*

Construction and demolition waste (CDW) was manually pre-sorted at the Portal Viverde Rays recycling facility in Bauru (SP), to remove contaminants—metals, wood, glass, and gypsum—prior to sampling the processed-material stockpiles. The objective was characterizing the typical recycled residue generated by the plant. Four sampling campaigns were conducted between 2023 and 2024 (June, September, February, and March), and the samples were identified as RCC1 through

RCC4. RCC1, RCC2, and RCC3 were derived from the same processing stream within the plant and were crushed using a nominal crusher opening of 25 mm, whereas RCC4 was processed with a larger crusher opening, producing particles ranging from 38 mm to 50 mm. A composite sampling approach based on targeted sub-sample collection was applied.

The sampling design followed the guidelines of ASTM D6009-19, which provides technical procedures for sampling solid waste in unconsolidated stockpiles and was complemented by ASTM D4687-14(2022) and ASTM D5956-21, addressing sampling planning and the management of heterogeneity in waste materials. In each campaign, 10 sub-samples were collected from representative zones of the pile (surface, base, center, and sides), then homogenized and reduced in volume by quartering to obtain the final composite samples. This methodology ensured the representativeness and consistency of the material for gravimetric and particle size distribution analyses.

2.2 *Grain Size Distribution and Combined Gravimetric Analysis*

The granulometric analysis of the recycled CDW was conducted in the Materials Laboratory of the São Paulo State University (Unesp) using the sieving method, in accordance with ABNT NBR 17054 (Aggregates – Determination of Granulometric Composition – Test Method). The procedure employed a set of sieves arranged in descending mesh sizes (25, 19, 12.5, 9.5, 6.3, 4.8, 2.4, 1.2, 0.6, 0.3, 0.15, and 0.075 mm). Sieving was initially performed using mechanical equipment and subsequently refined manually by the operator. After sieving, the material retained on each sieve was weighed, and the fractions were also separated for gravimetric analysis.

The sedimentation test for the fine fraction of the CDW was performed in accordance with ABNT NBR 7181:2016 (Soil – Grain Size Analysis). The material used corresponded to the portion passing through the sieves ("bottom"), supplemented with an additional portion of the respective sample to meet the minimum quantity required by the standard. For the RCC4 sample, however, the maximum amount of fines available was 29.12 g.

For each sample, the average moisture content was determined based on triplicates dried in an oven at 105 °C for 24 hours (except for RCC4, which was analyzed in duplicates due to the limited availability of fine material). The materials were left in a deflocculant solution overnight to allow homogenization with distilled water until the following day. Hydrometer and thermometer readings were recorded for each measurement.

Finally, the specific mass of solids was determined using a volumetric flask for two samples composed of a mixture of materials from different stockpiles - that is, a combination of materials from RCC1, RCC2, RCC3, and RCC4. The moistures were measured in triplicates, and the temperatures were taken at the base, middle, and top of the flask for samples AM1 (solid mass *ms* of 55.21 g) and AM2 (solid mass *ms* of 69.33 g), and the volumetric flasks with (solid and water) were weighed. The specific mass of the water considered was 0.9977 g/cm³.

The samples were processed in a crusher (TE 2 CSM rubble crusher) in the materials laboratory, and the crushed material was sieved through a 4.8 mm sieve, using the passing material. At this stage, it was proposed to conduct another granulometric test (sieving through a 2.0 mm sieve and sedimentation of fines) for samples RCC1 and RCC4.

Gravimetric analysis consists of raising the quantities of a specific material present in the sample, identifying its typology. It was carried out immediately after sieving through tactile and visual analysis of the materials present, which underwent manual separation. The classified portions were weighed to obtain the percentages of each material.

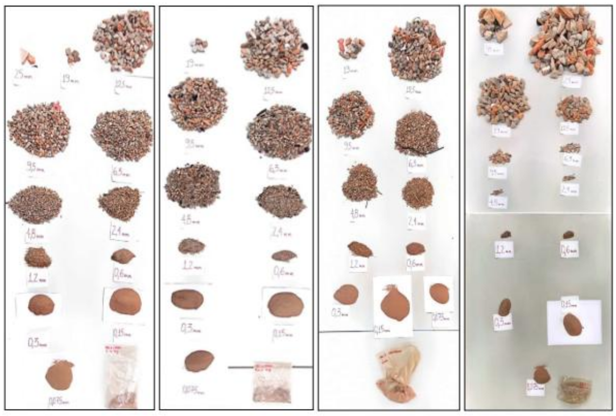


Figure 2. Configuration obtained from the sieving of samples RCC1, RCC2, RCC3, and RCC4, from left to right respectively (representation not to scale).

Figure 3. Separation of materials from samples RCC1, RCC2, RCC3, and RCC4 (from left to right) (representation not to scale).

3 RESULTS AND DISCUSSION

3.1.1 *Gravimetric composition*

In this analysis, it is important to acknowledge the presence of inaccuracies, as the procedure was carried out through manual separation using tactile-visual inspection. This approach often made it difficult to accurately identify materials, especially given their reduced dimensions after processing and sieving for grain size distribution determination. In many cases, it was challenging to distinguish between materials—for example, between "gravel" and segregated gravel particles derived from crushed concrete, or between "rendering mortars" and mortar remnants from concrete crushing.

The mass percentages for each category (concrete, mortar, clay bricks and blocks, etc.) were calculated to identify the presence of undesirable materials in the composition of recycled aggregates, such as wood, glass, gypsum, branches, and leaves. Although these materials were previously removed at the processing plant, small amounts were still found in the samples. Items such as gloves, electronic waste, and various plastics were also identified. RCC1 showed the highest amount of such materials (2.61%), followed by RCC2 (2.32%), while RCC3 and RCC4 exhibited lower values of 1.44% and 1.39%, respectively.

Concrete and mortar, along with clay bricks and blocks (crushable waste Class A under the Construction and Demolition Waste Management Plan (CDWMP), were the predominant materials (Figure 8). Concrete remained the most abundant component, ranging from 51.57 % in RCC1 to 36.91 % in RCC4.

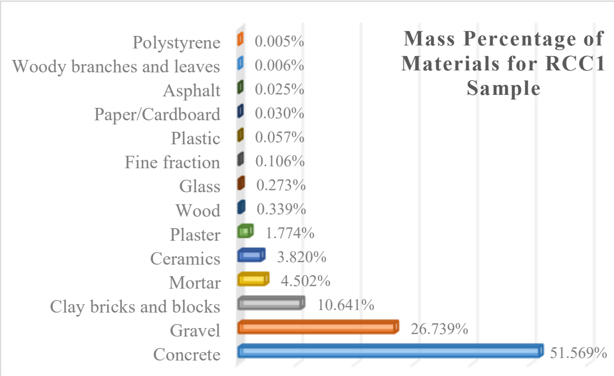


Figure 4. Mass Percentage Composition of RCC1 Determined by Gravimetric Analysis Following Granulometric Sieving.

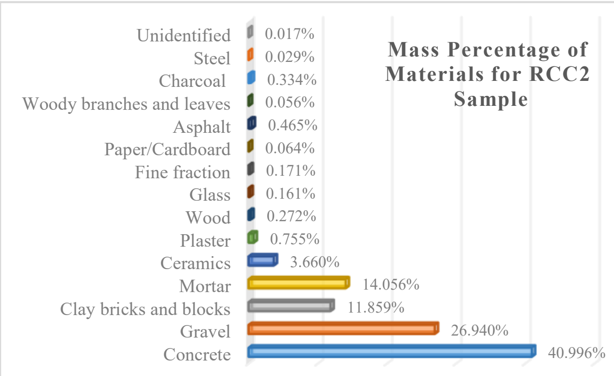


Figure 5. Mass Percentage Composition of RCC2 Determined by Gravimetric Analysis Following Granulometric Sieving.

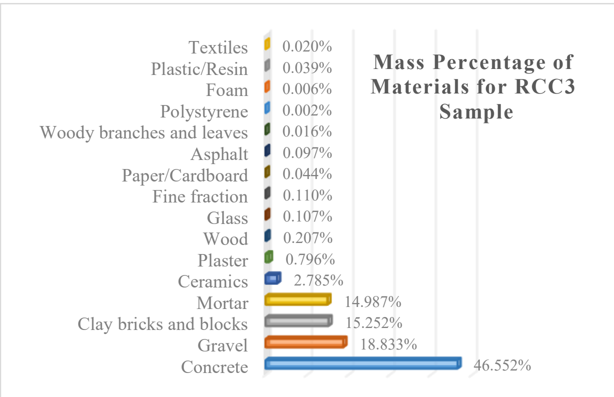


Figure 6. Mass Percentage Composition of RCC3 Determined by Gravimetric Analysis Following Granulometric Sieving.

In RCC4, the coarse fraction was greater than in the other samples - due to less processing at the plant - which allowed identifiable mortar and ceramic-block fragments to remain after crushing. This sample also exhibited reduced separation between aggregate and mortar, explaining its higher mortar content, and it had the highest proportion of ceramic materials. Overall mass percentages of Class A materials summed to 97.271 % in RCC1, 97.511 % in RCC2, 98.408 % in RCC3, and 96.993 % in RCC4, with RCC3 exhibiting the highest proportion of Class A waste.

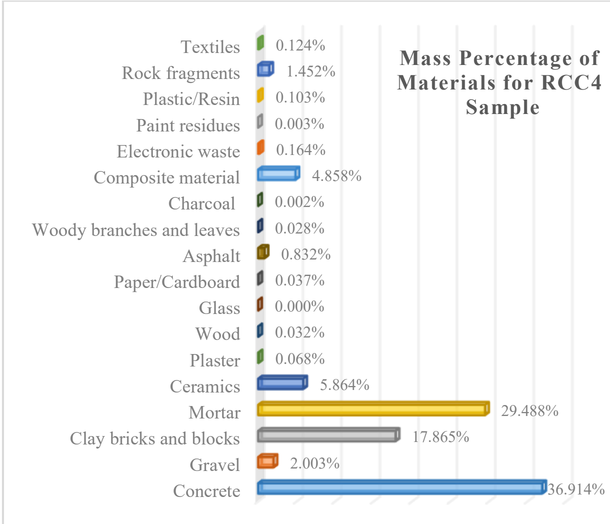


Figure 7. Mass Percentage Composition of RCC4 Determined by Gravimetric Analysis Following Granulometric Sieving.

3.2 *Gran size distribution*

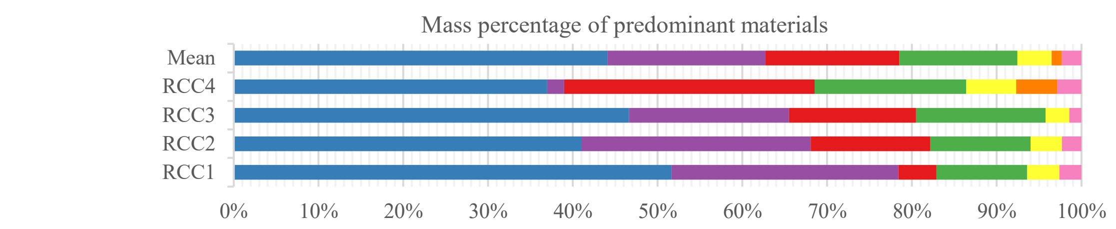
The specific gravity of the solids in the material passing the No. 200 sieve (0.075 mm) was ρ_s = 2.702 g/cm³, a value comparable to those reported by Leite (2007) and Nascimento et al. (2020), who found 2.74 g/cm³ and 2.689 g/cm³ for mixed-type recycled aggregates, respectively.

All evaluated samples were texturally classified as gravel, accounting for approximately 87% in RCC1, RCC2, and RCC3, and 98% in RCC4. The higher gravel content observed in RCC4 is attributed to its larger initial processing size (38–50 mm) compared to the other samples (25 mm). This sample also exhibited the most uniform grain-size distribution, as evidenced by its low uniformity coefficient (Cu), indicating a poorly graded material in its as-received condition from the recycling plant.

Although RCC1, RCC2, and RCC3 presented Cu values greater than 6, their curvature coefficients (Cc) exceeded the optimal range of 1 to 3, which also led to their classification as poorly graded materials. Consequently, the as-received RCCs supplied by the Portal Viverde Rays facility were generally characterized as poorly graded.

However, a secondary crushing stage applied to RCC1 and RCC4 resulted in a marked improvement in gradation, as illustrated in Figure 9. Crushed RCC1 exhibited a more continuous curve, with increased fine and intermediate fractions. Similarly, RCC4, originally composed of coarse and uniform particles, presented a broader and more balanced grain-size distribution after reprocessing. These improvements are supported by increased Cu (>4) and Cc (>1) values, indicating that the crushing process effectively enhanced the granulometric characteristics of both materials, thus improving their suitability for geotechnical and pavement applications.

Among the as-received samples, only RCC3 met the granulometric criteria established by ABNT NBR 15115:2004 for use in pavement layers. RCC4, in its original condition, deviated the most from these specifications; however, after the secondary crushing process, its improved properties suggest it may become suitable for such applications.



	RCC1	RCC2	RCC3	RCC4	Mean
Concrete	51.57%	41.00%	46.55%	36.91%	44.01%
Gravel	26.74%	26.94%	18.83%	2.00%	18.63%
Mortar	4.50%	14.06%	14.99%	29.49%	15.76%
Clay bricks and blocks	10.64%	11.86%	15.25%	17.87%	13.90%
Ceramics coatings	3.82%	3.66%	2.79%	5.86%	4.03%
Composite materials	0.00%	0.00%	0.00%	4.86%	1.21%
Other materials	2.61%	2.32%	1.44%	2.84%	2.31%

Figure 8. Comparative mass-percentage composition of the predominant materials - concrete, mortar, gravel, clay bricks and blocks, and ceramic coating - in the RCC samples.

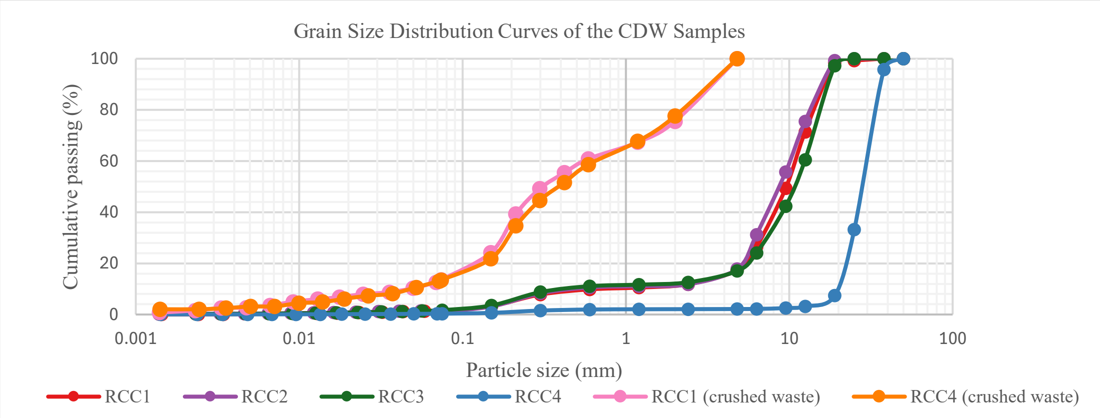


Figure 9. Granulometric curves obtained from the sieving and sedimentation of the recycled aggregate collected from the plant and granulometric curves obtained from the sieving and sedimentation of the fines from crushed material RCC1 and RCC4 (compaction test).

Table 1. Verification of the coefficient of uniformity and passing percentage on the 0.42 mm sieve concerning the limits established by the standard for pavement applications.

Parameter	RCC1	RCC2	RCC3	RCC4
Coefficient of uniformity (Cu)	*18*	20	30	1,5
Passing material 0,42 mm (%)	*9,5*	9,5	10	1,8

Note: The grain size limits for the use of recycled aggregate for paving purposes recommended by NBR 15115:2004 are a percentage of passing material on the 0.42 mm sieve between 10% and 40% and a minimum uniformity coefficient of 10.

4 CONCLUSIONS

Construction and demolition waste (CDW) recycled at a processing plant in Bauru (SP), which receives material from the city’s largest waste generators, was evaluated for particle size distribution and material composition.

On average, gravimetric analysis showed that the predominant materials were concrete (44.01 %), gravel (18.63 %), mortar (15.76 %), clay bricks and blocks (13.90 %), facing ceramics (4.03 %), and composite materials (1.21 %); all other constituents totaled only 2.31 %, indicating a very low proportion of non-Class A materials under the Construction and Demolition Waste Management Plan (CDWMP). Although the use of recycled construction waste is economically advantageous, its technical and environmental viability must also be demonstrated. Potential contamination by heavy metals, asbestos, or chemical residues could disqualify a waste stream from Class A status - required to ensure low environmental impact, safe application, and consistent aggregate quality.

Therefore, the combined method using gravimetric and granulometric analysis promotes an efficient and detailed characterization. Specific gravimetric analysis should be complemented with chemical characterization and leaching tests to identify not only inert components (concrete, mortar, gravel, and red ceramics) but also any glass, plastics, or other contaminants present.

5 ACKNOWLEDGEMENTS

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