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# FEASIBILITY ANALYSIS OF UTILIZING CIVIL CONSTRUCTION WASTE IN PAVEMENT BASES, SUBBASES, AND SUBGRADES: A SYSTEMATIC LITERATURE REVIEW

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## ABSTRACT

*Considering the high rates of generation and heterogeneous composition of construction waste (CW), coupled with their improper disposal, significant challenges arise for public authorities. This study aims to demonstrate the feasibility of employing recycled aggregates, derived from CW in pavement applications through a systematic literature review spanning the past 10 years (2011-2021). The primary objective is to establish that this material meets the necessary physical and mechanical requirements for implementation in base reinforcement and sub-base of pavements, thereby mitigating the environmental impacts caused by the improper disposal of CW. The research was conducted following the PRISMA protocol, applying a series of rigorous steps for the selection of relevant publications related to the addressed subject. This process resulted in the selection of 25 articles from 11 different countries. The analysis of these studies allowed for the identification of the physico-mechanical characterization tests employed across various countries, the observed standards, the types of recycled aggregates utilized, and the comparison of results. These results were deemed satisfactory by all authors, indicating the viability of using Recycled Concrete Waste (RCDW) in granular pavement layers, while adhering to the prevailing standards specific to each region.*

***KEYWORDS:*** *Recycled aggregates. Construction waste. Pavement bases.*

## I. INTRODUCTION

Construction and Demolition Waste (CDW) is generated throughout the lifecycle of civil and infrastructure projects, particularly during the demolition phase [1]. It is widely recognized as a significant challenge for public administration on a global scale. This challenge arises due to factors such as the sheer volume of waste generated and its heterogeneous composition. Utilizing recycled CDW aggregates reduces the consumption of non-renewable resources and avoids filling landfills with construction waste [2].

Moreover, highway construction projects have a significant aggregate demand, making them a potential alternative for replacing natural materials with recycled CDW aggregates. Previous research has demonstrated the considerable potential of CDW for reuse as aggregates in highway construction. Numerous studies conducted worldwide have evaluated the feasibility of utilizing recycled construction waste, specifically recycled concrete aggregates and ceramic materials, in highway construction.

Therefore, this paper presents a systematic review that showcases selected relevant studies, aiming to assess the feasibility of incorporating these materials in pavement layers. The presentation of the paper is organized as follows. In the introduction, the background of the research is presented. Furthermore, in the second part, the methods and methodological procedures applied in the research are presented. In the third part, bibliometric results from the literature review are presented. The fourth part deals with the documentation of the systematic literature review and discussions regarding the studies and the results obtained from the analyzed works. Then, in the last section, are the conclusions and developments in future research.

# II. METHODS

## 2.1. Research Methodological Framework

In the context of a systematic review study, it was conducted following the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analysis). This protocol consists of an evidence-based set of items designed to assist scientific authors in reporting a wide range of articles, thereby enhancing and enabling the replicability of systematic reviews. The process begins with formulating objectives that address a research question, defining keywords, and applying a set of inclusion and exclusion criteria. During the review stage, relevant articles are selected while irrelevant ones are excluded. Lastly, the articles are analyzed according to predefined categories.

To gather relevant articles on the studied topic, the databases of the CAPES Periodicals Portal and Google Scholar were utilized. The CAPES Periodicals Portal was chosen due to its inclusion of numerous databases, such as Web of Science, Scopus, Journal Citation Reports, Engineering Village, MAS, ASTM International, SciFinder, ProQuest, Britannica Academic, Edition, Thomson Reuters, Eighteenth Century Collections Online, and Begell House. Google Scholar, on the other hand, was employed for its broader platform, potentially capturing results not reached by other databases.

The searches were conducted considering works published between the years 2011 and 2021, centered around the following central question: What is the feasibility of employing construction and demolition waste in the construction of bases, sub-bases, and subgrade reinforcement in pavements?

Based on the research question and objective, descriptors (keywords) were defined for the searches, and different combinations were carried out using boolean operators "OR" or "AND," resulting in the expressions presented in Table 1.

**Table 1.** Summary of the combinations of descriptors and boolean operators.

| | | |
|---|---|---|
| **Group 1**<br>General search on the use of construction and demolition waste in pavement | | (“paving” OR “pavement*” OR “pavement layer*” OR “pavement foundation”) AND (“construction waste” OR “recycled construction and demolition waste” OR “RCDW” OR “Construction and Demolition Waste” OR “C&D waste” OR “recycled construction waste” OR “recycled material*” OR “recycled unbound material*” OR “waste material*” OR “waste building material*”) |
| **Group 2**<br>Specific search on the use of construction and demolition waste in granular pavement layers | Subgroup 2a | (“base” OR “sub-base” OR “subbase” OR “subgrade” OR “capping”) AND (“construction waste” OR “recycled construction and demolition waste” OR “RCDW” OR “Construction and Demolition Waste” OR “C&D waste” OR “recycled construction waste” OR “recycled material*” OR “recycled unbound material*” OR “waste material*” OR “waste building material*”) |
| | Subgroup 2b | (“base layer” OR “sub-base layer” OR “subbase layer” OR “capping layer”) AND (“construction waste” OR “recycled construction and demolition waste” OR “RCDW” OR “Construction and Demolition Waste” OR “C&D waste” OR “recycled construction waste” OR “recycled material*” OR “recycled unbound material*” OR “waste material*” OR “waste building material*”) |
| | Subgroup 2c | (“road material*” OR “unbound granular pavement” OR “granular material*” OR “unbound aggregate”) AND (“construction waste” OR “recycled construction and demolition waste” OR “RCDW” OR “Construction and Demolition Waste” OR “C&D waste” OR “recycled construction waste” OR “recycled material*” OR “recycled unbound material*” OR “waste material*” OR “waste building material*”) |
| (*) – Allowing various terms to be captured, as long as they share the same root (term prior to the '*'). | | |

### 2.2. Selection of the Bibliographic Portfolio

The initial search yielded multiple results, and additional exclusion criteria were applied. These criteria included: (1) papers not written in Portuguese, English, or Spanish; (2) papers not pertinent to the pavement field; (3) papers published in journals with an impact factor lower than 0.5; (4) papers lacking peer-review; (5) theses, dissertations, or undergraduate theses. Subsequently, a title and abstract eligibility assessment was conducted, leading to the exclusion of studies that lacked relevance to the research topic. Duplicated papers were also removed from consideration.

To expand the paper portfolio related to the research topic and include additional papers that may have been missed during the previous search procedures, snowball sampling was conducted. This method involved scrutinizing the references cited within the selected papers, aiming to identify supplementary studies of relevance to the research topic, process depicted in Figure 1.

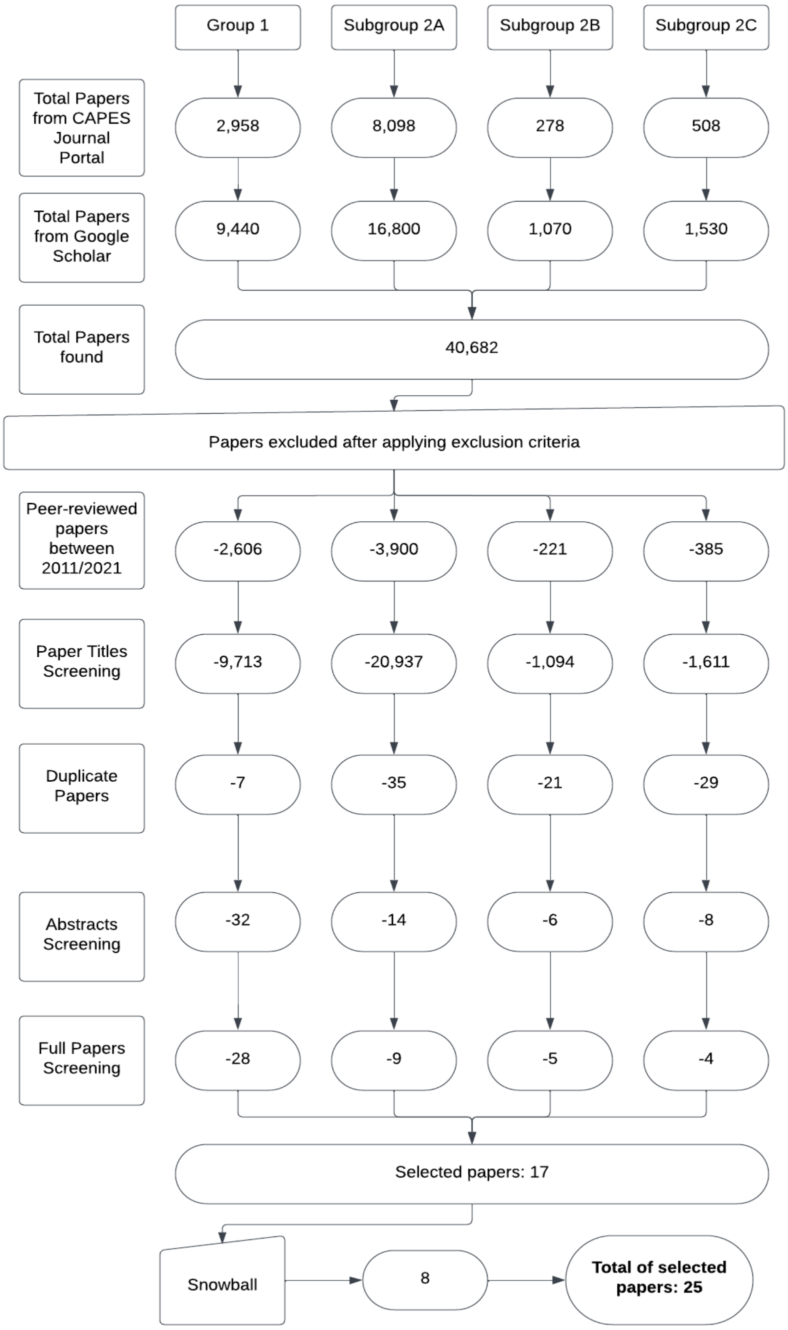

**Figure 1.** Selection process of the studies.

## III. BIBLIOMETRIC RESULTS

The Boolean combinations and selection criteria yielded a total of 25 papers from 11 countries. These papers involved the total of 84 authors, including co-authors. They were published in 12 different journals and encompassed 75 distinct keywords. Additionally, several other factors were examined, such as the number of publications per year, the number of publications per author, the number of publications per journal, and the most common keywords. Table 2 provides comprehensive details regarding the selected papers, including information on the respective journals, publication years, and the corresponding number of papers. Notably, the journal Construction and Building Materials exhibited the highest number of publications pertaining to the research topic at hand.

**Table 2.** Selected papers categorized by journal, year, and number of papers.

| Journal | SJR Impact Factor | Year / Number of Papers | Total | % |
|---|---|---|---|---|
| Construction and Building Materials | 1.777 | (2011/2) (2012/3) (2014/2) (2018/1) | 8 | 32 |
| Journal of Materials in Civil Engineering | 1.055 | (2011/1) (2013/1) (2014/1) (2015/1) (2018/1) | 5 | 20 |
| Materials | 0.604 | (2015/1) (2016/1) (2020/1) | 3 | 12 |
| Advances in Materials Science and Engineering | 0.371 | (2017/1) | 1 | 4 |
| Road Materials and Pavement Design | 1.114 | (2018/1) | 1 | 4 |
| Advances in Civil Engineering | 0.420 | (2019/1) | 1 | 4 |
| Journal of Cleaner Production | 1.921 | (2018/1) | 1 | 4 |
| Journal of Civil Engineering and Management | 0.597 | (2014/1) | 1 | 4 |
| Sustainability | 0.664 | (2020/1) | 1 | 4 |
| Journal of Transportation Engineering, Part B: Pavements | 0.636 | (2021/1) | 1 | 4 |
| Ain Shams Engineering Journal | 0.680 | (2013/1) | 1 | 4 |
| Transportation Geotechnics | 1.175 | (2015/1) | 1 | 4 |

Figure 2 presents the most common keywords found in the selected papers. Among these keywords, "Construction and Demolition" emerged as the most frequently utilized, with a total of 9 occurrences. "Permanent Deformation" and "Resilient Modulus" were also prominently cited, with 7 occurrences each. Additionally, the Keywords with more than 1 observation: (1) “Mixed Recycled Aggregates”, “Recycling,” and “Recycled Concrete Aggregates” were observed 3 times each; and (2) “Recycled Aggregates”, “Recycled Materials”, “Pavement”, “Compaction,” and “Waste” each appeared twice. It is worth noting that the remaining keywords from the selected papers were considered irrelevant for this study as they were utilized only once.

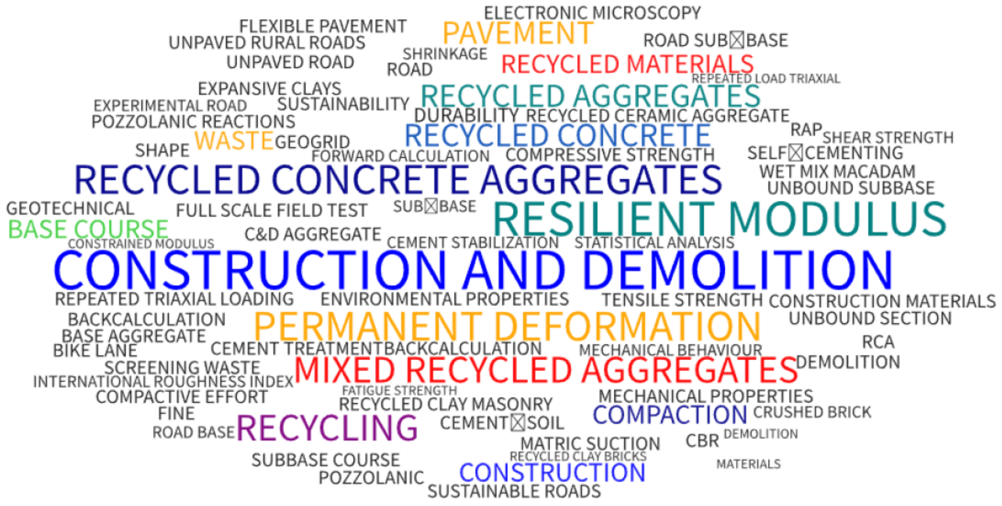

**Figure 2.** Distribution of the most common keywords in the selected papers.

In context of the distribution of publications by country of origin, it is evident that Spain contributed the highest number of papers (eight papers), accounting for approximately 35% of the total publications. Australia followed closely behind, representing around 18% of the publications, with four papers. China and Iran both contributed two papers each, constituting approximately 12% of the total. Other countries yielded negligible results, with only a single publication identified in the last 10 years.

Furthermore, Europe was the continent with the most substantial number of publications in the field of construction waste for pavement applications. Over the past 10 years, Europe produced a total of eight publications, surpassing Asia and Oceania, which recorded 5 and 3 publications, respectively. Consequently, Europe and Asia emerged as the primary references on the selected topic, considering the highest number of publications.

For this study, the analysis focused on papers published within the last 10 years, resulting in a selection of 25 papers for the paper portfolio. Notably, 2012, 2015 and 2018 witnessed the most significant number of publications, with four papers each year. The years 2011, 2013 and 2020 each contributed two papers. The remaining years yielded at least one paper each.

Among the selected papers, two authors have demonstrated the highest degree of relevance: J.R. Jiménez and J. Ayuso. These researchers have been cited as authors or co-authors in 3 papers, representing the highest number of publications within the last 10 years. Following closely is M. López, who has published two papers.

The Universidad de Córdoba in Spain has emerged as the institution with the greatest number of publications, contributing 4 papers within the past 10 years. Notably, this university is also affiliated with the three most frequently cited researchers among the selected papers. Chang'an University in China follows closely behind with two publications.

## IV. DISCUSSIONS

The main objective of the systematic review is to provide the synthesis and analysis of information from the selected and reviewed articles. In this study, which aimed to review works evaluating the feasibility of using construction and demolition waste in pavement, a detailed analysis was conducted on the tests carried out in each study and the corresponding results. Table 3 presents the tests conducted in each of the selected papers.

**Table 3.** Physical-mechanical tests conducted in the selected papers.

| **Referência** | **Particle Size** | **Water Absorption** | **CBR** | **Permanent Deformation** | **Proctor Compaction Test** | **Los Angeles Abrasion** |
|---|---|---|---|---|---|---|
| Leite *et al.*, (2011) | X | X | X | X | X | X |
| Vegas *et al.*, (2011) | X |  | X |  | X | X |
| Barbudo *et al.*, (2012) | X | X | X |  | X | X |
| Cerni *et al.*, (2012) | X | X | X | X | X |  |
| Gabr *et al.*, (2012) |  |  | X | X |  | X |
| Jiménez *et al.*, (2012) | X | X | X | X | X | X |
| Arulrajah *et al.*, (2013) |  |  |  | X | X |  |
| Behirry, A. E. A. E. (2013) |  | X | X | X | X |  |
| Arulrajah *et al.*, (2014) |  |  | X | X | X | X |
| Ayan *et al.*, (2014) |  |  |  |  |  |  |
| Disfani *et al.*, (2014) | X |  | X | X | X |  |
| Diagne *et al.*, (2015) | X |  |  | X |  |  |
| Garach *et al.*, (2015) | X | X | X |  | X | X |
| Jitsangiam *et al.*, (2015) | X |  | X | X |  |  |
| Mohammadinia *et al.*, (2015) | X | X |  | X | X | X |
| Rey *et al.*, (2016) | X | X | X | X | X | X |
| Li *et al.*, (2017) | X |  | X | X | X |  |
| Arisha *et al.*, (2018) |  |  | X | X | X | X |
| Esfahani *et al.*, (2018) | X | X | X | X | X | X |
| Taveira *et al.*, (2018) | X | X | X | X | X |  |
| Taveira *et al.*, (2018) | X |  | X |  | X | X |
| Li *et al.*, (2019) | X |  | X | X | X |  |
| Courard *et al.*, (2020) | X |  |  |  | X | X |
| Zuazo *et al.*, (2020) | X |  | X |  | X |  |
| Alnedawi *et al.*, (2021) |  |  | X | X | X | X |

In Figure 3, a radar chart is presented, illustrating the number of authors who undertook the analyzed tests for this study. The chart highlights the Proctor Compaction Test, which was conducted by 21 of the studies, followed by the CBR test with 20 studies.

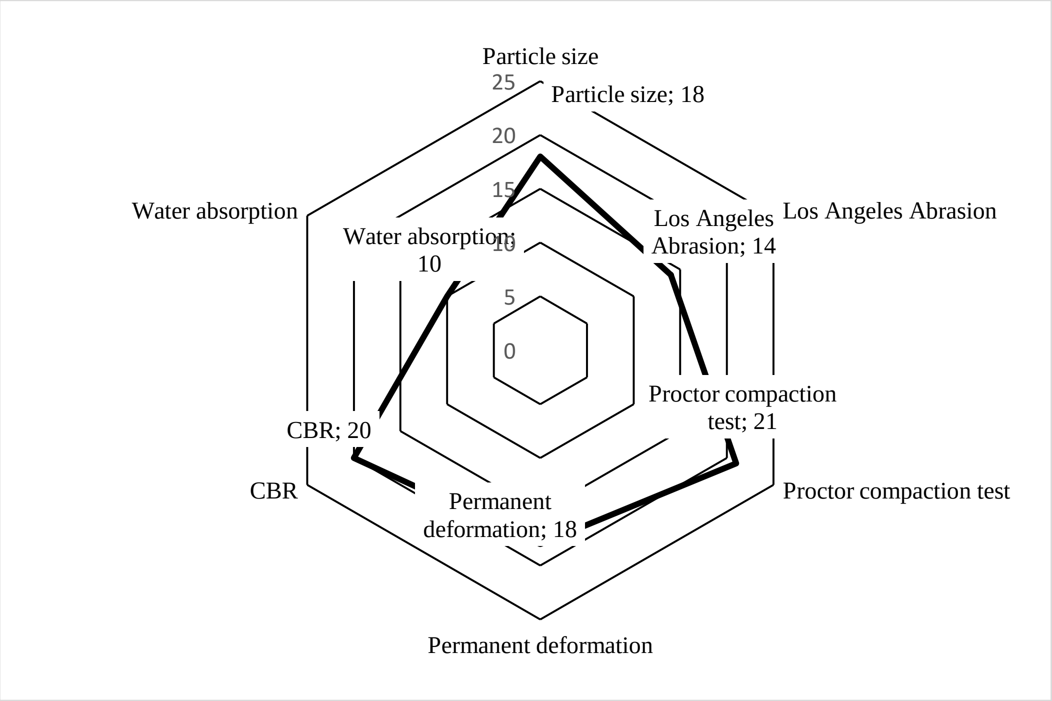

**Figure 3.** Distribution of the most common tests in the selected papers

### 4.1. Materials

Recycling of construction and demolition waste involves several steps, including transportation, component separation, milling, sieving, and material maintenance [3]. To obtain recycled aggregate from this waste, a well-planned production procedure is required, with screening, separation, size reduction, and sieving being crucial steps in the process [4]. To enhance the quality of the recycled aggregates and minimize the environmental impact of the waste, it is important to separate hazardous materials and other impurities (such as plaster, wood, glass, metals, plastic, and excavated soil) during the material selection process.

Two types of recycled aggregates can be generated from construction and demolition waste: recycled concrete aggregates, primarily composed of particles obtained from recycled crushed concrete, and mixed recycled aggregates, produced from recycled masonry and comprising particles of brick, mortar, concrete, asphalt, and plaster [5].

CDW aggregates offer an alternative and appealing material for bases and subbases due to their high resistance and non-swelling behavior [6]. However, the quality of recycled materials can vary considerably and is challenging to control [7]. Guidance regarding the production and application of these aggregates is necessary, and such guidance is typically established through standards.

Given the variation in the type and the quality of CDW based on geographic location [5], the CDW aggregates were analyzed in each of the selected papers, as presented in Table 4.

**Table 4.** Materials utilized in the selected papers.

| Authors | Year | Country | Materials |
|---|---|---|---|
| Arisha, A. M.; Gabr, A. R.; El-Badawy, S. M. and Shwally, S. A. [20] | 2018 | Egypt | Recycled Concrete Aggregate (RCA) and Recycled Clay Materials (RCM) from Masonry Bricks. |
| Li, Y.; Zhou, H.; Su, L. and Hou, H. [18] | 2017 | China | Waste from Residential Construction. |

| | | | |
|---|---|---|---|
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | Construction Waste with no selection process and pre-screening. |
| Cerni, G.; Cardone, F. and Bocci, M. [11] | 2012 | Italy | Construction waste with separation, screening, and removal of impurities. Granular mix in accordance with Italian technical standards. |
| M. A. Esfahani [3] | 2018 | Iran | Material composed of brick, concrete, natural rock, stone, tile, and ceramic. Various mixtures were created, each with different proportions of these components for analysis. |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | Construction waste with separation, screening, and removal of impurities. |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | One aggregate was used without pre-treatment, while another aggregate included only pre-selected types of waste. |
| Li, Z.; Yan, S.; Liu, L. and YANG, J. [9] | 2019 | China | Material composed of brick, concrete, natural rock, stone, tile, and ceramic. Mixtures were created to meet local standards. |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; Sierra, M. J.; Ledesma, E. F. [14] | 2018 | Spain | Utilized an aggregate without pre-treatment and another one only with pre-selected types of waste. |
| Garach, L.; López, M.; Agrela, F.; Ordóñez, J.; Alegre, J. and Moya, J. A. [16] | 2015 | Spain | Three aggregate types were analyzed: natural aggregates, recycled concrete aggregates, and mixed recycled aggregates. |
| Courard, L.; Rondeux, M.; Zhao, Z. and Michel, F. [10] | 2020 | Belgium | Construction recycled aggregates of unknown origin (fine particles). |
| Zuazo, E. T. L.; Zamanillo, Á. V.; Pérez, M. Á. C.; Miguel, Á. R. [29] | 2020 | Spain | Several aggregate types were analyzed: recycled aggregates, concrete aggregates, mixed aggregates, and mixed aggregates from concrete. In addition, concrete, mortar, pre-assembled concrete components, and ceramic materials were studied. |
| Arulrajah, A.; Piratheepan, J.; Bo, M. W. and Sivakugan, N. [22] | 2013 | Australia | Several properties were analyzed. Materials included two types of recycled concrete, mixed aggregates, and aggregates from excavation waste (basalt). |
| Alnedawi, A. and Rahman, M. A. [21] | 2020 | Australia | Analysis of recycled aggregates from reinforced concrete with geogrid. |
| Jitsangiam, P.; Boonserm, K.; Phenrat, T.; Chummuneerat, S.; Chindaprasirt, P. and Nikraz, H. [26] | 2015 | Australia | Two types of aggregates were used: high-strength concrete recycled aggregate and mixed recycled concrete, combined with approximately 5% (by mass) of brick and clean rubble. |

| | | | |
|---|---|---|---|
| Mohammadinia, A.; Arulrajah, A.; Sanjayan, J.; Disfani, M. M.; Bo, M. W. and Darmawan, S. [27] | 2014 | Australia | CDW materials from concrete, mixed materials, and asphalt materials treated with Portland cement. |
| Behirry, A. E. A. E. [13] | 2013 | Egypt | The study used recycled concrete aggregates to investigate and characterize the behavior of the aggregates compared to natural aggregates. This aggregate was later evaluated with cement addition. |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; López-Uceda, A.; Ledesma, E. F. [28] | 2018 | Spain | The study utilized low-quality recycled materials from non-selected CDW, which were mixed with excavated soils. |
| Barbudo. A; Agrela, F; Ayuso. J.; Jiménez J. R. and Poon, C.S. [5] | 2012 | Spain | The study used 31 materials in total. Among these, 4 were well-sorted natural aggregates suitable for practical construction applications, e.g., subbases. The remaining materials were recycled aggregates with varying proportions of bituminous and ceramic components. |
| Disfani, M. M.; Arulrajah, A.; Haguighi, H.; Mohammadinia, A. and Hurpibulsuk, S. [24] | 2014 | Australia | Recycled concrete aggregates (RCA) and crushed bricks (CB) were used, with particle size distributions up to 20 mm. |
| Arulrajah, A.; Disfani, M. M.; Horpibulsu, S.; Suksiripattanapong, C. and Prongmanee, N. [15] | 2014 | Australia | The study analyzed the physical-mechanical properties of aggregates from different types of construction waste: concrete, mixed, asphalt, residual excavation rocks, and waste glass. |
| Gabr, A. R. and Cameron, D.A. [25] | 2011 | Australia | Two mixed products from local suppliers were utilized, along with natural materials as a reference. |
| Diagne, M.; Tinjum, J. M. and Nokkaew, K. [23] | 2015 | USA | The paper presents a lab investigation of recycled clay bricks (RCB) from demolished buildings. These bricks were mixed with recycled concrete aggregates (RCA) for a base layer that was not connected to highway construction. |

### 4.2. Aggregates’ Particle Size

Several studies have conducted granulometric tests to establish the granulometric curves of recycled aggregates. The specific standards employed in each study are outlined in Table 5.

Table 5. Studies and corresponding granulometric tests conducted with Standards.

| **Author** | **Year** | **Country** | **Standards** |
|---|---|---|---|
| Li, Y.; ZHOU, H.; SU, L. and HOU, H. [18] | 2017 | China | - |
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | UNE-EN 933-1: 2006 |

| | | | |
|---|---|---|---|
| Cerni, G.; Cardone, F. and Bocci, M. [11] | 2012 | Italy | EN 13285. Unconsolidated mixes - Standards. European Committee of Standards; 2010. |
| M. A. Esfahani [3] | 2018 | Iran | AASHTO. (1993a). AASHTO Guidelines for designing pavement structures |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | ASTM C136 |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | Technical Standards for Building Highways in Spain PG3 |
| Li, Z.; Yan, S.; Liu, L. and YANG, J. [9] | 2019 | China | JTG E40-2007 |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; Sierra, M. J.; Ledesma, E. F. [14] | 2018 | Spain | UNE 103102: 1995 |
| Garach, L.; López, M.; Agrela, F.; Ordóñez, J.; Alegre, J. and Moya, J. A. [16] | 2015 | Spain | UNE-EN-933-11 |
| Courard, L.; Rondeux, M.; Zhao, Z. and Michel, F. [10] | 2020 | Belgium | European Standard EN 933-1 |
| Vegas, I.; Ibañez, J.A.; Lisboa, A.; Sáez de Cortazar, A. and Frías, M. [19] | 2011 | Spain | Technical Standards for Building Highways in Spain (PG-3) |
| Zuazo, E. T. L.; Zamanillo, Á. V.; Pérez, M. Á. C.; Miguel, Á. R. [29] | 2020 | Spain | UNE EN 933-1 |
| Jitsangiam, P.; Boonserm, K.; Phenrat, T.; Chummuneerat, S.; Chindaprasirt, P. and Nikraz, H. [26] | 2015 | Australia | MRWA Standards (MRWA 2011) |
| Mohammadinia, A.; Arulrajah, A.; Sanjayan, J.; Disfani, M. M.; Bo, M. W. and Darmawan, S. [27] | 2014 | Australia | Standards Australia 1996 |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; López-Uceda, A.; Ledesma, E. F. [28] | 2018 | Spain | UNE-EN-933-1: 2006 |
| Barbudo. A; Agrela, F; Ayuso. J.; Jiménez J. R. and Poon, C.S. [5] | 2012 | Spain | UNE 103-101: 1998 / a1: 2006 |
| Disfani, M. M.; Arulrajah, A.; Haguighi, H.; Mohammadinia, A. and Hurpibulsuk, S. [15] | 2014 | Australia | Standards Australia; AS 1141.11.1-2009 |
| Diagne, M.; Tinjum, J. M. and Nokkaew, K. [23] | 2015 | USA | ASTM D6836 |

Most of the studies included in this research have reported successful experimental results using well-sorted and uniform materials, indicating a minimal presence of excessive fine or coarse particles. These materials have also adhered to the prescribed standards outlined in the respective local guidelines.

However, a few studies deviated from this trend. [8] and [9] encountered challenges with their mixes, resulting in poorly graded aggregates that failed to meet the required standards. This issue arose due to a limited proportion of fine particles. To rectify this, a Proctor compaction test was conducted, which increased the fine material content and ultimately enabled the aggregates to meet the standards. Similarly, [10] observed an increase in the percentage of fine particles when utilizing materials with lower resistance, such as cement slurry and ceramic.

[3] and [4] employed a distinct procedure for obtaining recycled aggregates by designing customized mixtures to enhance the granulometry. [11] performed the separation of concrete and ceramic waste through sieving, followed by mixing them in varying proportions. Furthermore, [3] improved the quality of the obtained aggregate by blending it with natural aggregates.

Therefore, based on the granulometric tests conducted by the researchers, the recycled aggregates exhibit a certain degree of suitability for application in pavement layers.

### 4.3. Water Absorption

Several authors performed tests to measure the water absorption of recycled aggregates. The standards for these tests followed by each study are presented in Table 6.

**Table 6.** Studies conducting Water Absorption tests.

| Authors | Year | Country | Standards | Average values found (%) |
|---|---|---|---|---|
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | Technical Standards for Building Highways in Spain (PG-3) | 9.0 |
| Cerni, G.; Cardone, F. and Bocci, M. [11] | 2012 | Italy | EN 13285. Unconsolidated mixes - Standards. | 7.72 |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | ASTM C127 | 12.2 |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | Technical Standards for Building Highways in Spain (PG-3) | 9.4 |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; Sierra, M. J.; Ledesma, E. F. [14] | 2018 | Spain | Technical Standards for Building Highways in Spain (PG-3) | Unscreened material = 8.0<br>Screened material = 8.9 |
| Garach, L.; López, M.; Agrela, F.; Ordóñez, J.; Alegre, J. and Moya, J. A. [16] | 2015 | Spain | Technical Standards for Building Highways in Spain (PG-3) | 5.01 |
| Mohammadinia, A.; Arulrajah, A.; Sanjayan, J.; Disfani, M. M.; Bo, M. W. and Darmawan, S. [27] | 2014 | Australia | Australian Standard 1141.5 | Concrete aggregate = 7.02<br>Mix aggregate = 6.05<br>Asphalt aggregate = 3.47 |
| Behirry, A. E. A. E. [13] | 2013 | Egypt | Egyptian Standard | 2.25 |
| Barbudo. A; Agrela, F; Ayuso. J.; Jiménez J. R. and Poon, C.S. [5] | 2012 | Spain | UNE-EN 1097-6: 2001 | Concrete aggregate = 8.5<br>Mix aggregate = 12.7 |

The water absorption of an aggregate indicates its ability to retain water. It is one of the key distinctions between natural aggregates and recycled aggregates. Water absorption can significantly influence various properties of aggregates. For instance, a high absorption capacity can weaken the intergranular connections and reduce the mechanical strength.

The elevated water absorption observed in construction waste aggregates is primarily attributed to porous materials such as mortar and ceramic. This finding has been corroborated by [4] and [11].

Considering the substantial water absorption exhibited by recycled aggregates, it becomes crucial to provide adequate water content during the compaction process. This ensures that the material attains the required level of compaction, which guarantees maximum dry density [11].

### 4.4. Proctor Compaction

Proctor compaction tests are commonly conducted to determine the maximum dry density (MDD) and the optimum moisture content (OMC). These tests play a crucial role in characterizing the compaction properties of the materials. Table 7 provides an overview of the studies that have performed Proctor compaction tests to characterize and evaluate aggregates.

**Table 7:** Studies conducting Proctor Compaction tests.

| **Authors** | **Year** | **Country** | **Standards** | **Average values found – MDD (g/cm³) / OMC (%)** |
|---|---|---|---|---|
| Arisha, A. M.; Gabr, A. R.; El-Badawy, S. M. and Shwally, S. A. [20] | 2018 | Egypt | AASHTO | Concrete aggregate = 1.86 / 12.7<br>Mix aggregate = 1.78 / 10.8 |
| Li, Y.; ZHOU, H.; SU, L. and HOU, H. [18] | 2017 | China | JTG E40—2007 | 1.79 / 15.50 |
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | UNE 103501: 1994 | 1.83 / 13.0 |
| Cerni, G.; Cardone, F. and Bocci, M. [11] | 2012 | Italy | EN 13285 | 2.57 / 7.72 |
| M. A. Esfahani [3] | 2018 | Iran | AASHTO T180-D | 2.10 / 12.4 |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | ASTM D1557 | 1.8 / 14.0 |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | UNE 103500: 1994 | 2.21 / 11.5 |
| Li, Z.; Yan, S.; Liu, L. and YANG, J. [9] | 2019 | China | (JTG) E40-2007 | 1.79 / 15.5 |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; Sierra, M. J.; Ledesma, E. F. [14] | 2018 | Spain | UNE 103500: 1994 | Unscreened material = 1.84 / 14.7<br>Screened material = 1.87 / 12.6 |
| Garach, L.; López, M.; Agrela, F.; Ordóñez, J.; Alegre, J. and Moya, J. A. [16] | 2015 | Spain | UNE-EN 103501 | Concrete aggregate = 2.08 / 10.18<br>Mix aggregate = 2.02 / 11.2 |
| Courard, L.; Rondeux, M.; Zhao, Z. and Michel, F. [10] | 2020 | Belgium | CEN EN 13286 | 1.85 / 12.0 |
| Vegas, I.; Ibañez, J.A.; Lisboa, A.; Sáez de Cortazar, A. and Frías, M. [19] | 2011 | Spain | UNE 103501: 1994 | 1.93 / 8.4 |
| Zuazo, E. T. L.; Zamanillo, Á. V.; Pérez, M. Á. C.; Miguel, Á. R. [29] | 2020 | Spain | UNE 103501 | Concrete aggregate = 1.99 / 10.6<br>Mix aggregate = 1.86 / 12.1 |
| Arulrajah, A.; Piratheepan, J.; Bo, M. W. and Sivakugan, N. [22] | 2013 | Australia | AS 1289.5.2.1 | Concrete aggregate = 1.92 / 12.0<br>Mix aggregate = 1.98 / 10.7 |
| Alnedawi, A. and Rahman, M. A. [21] | 2020 | Australia | ASTM D1557 | 1.97 / 11.2 |

| | | | | |
|---|---|---|---|---|
| Mohammadinia, A.; Arulrajah, A.; Sanjayan, J.; Disfani, M. M.; Bo, M. W. and Darmawan, S. [27] | 2014 | Australia | AS 1289.5.2.1 | Mix aggregate 1 = 2.13 / 7.7<br>Mix aggregate 2 = 2.02 / 10..47 |
| Barbudo. A; Agrela, F; Ayuso. J.; Jiménez J. R. and Poon, C.S. [5] | 2012 | Spain | Une 103501: 1994 | Concrete aggregate = 1.93 / 11.6<br>Mix aggregate = 1.86 / 13.1 |
| Disfani, M. M.; Arulrajah, A.; Haguighi, H.; Mohammadinia, A. and Hurpibulsuk, S. [24] | 2014 | Australia | AS 1289.5.2.1 | Concrete aggregate = 2.04 / 11.7<br>Mix aggregate = 1.99 / 12.0 |
| Arulrajah, A.; Disfani, M. M.; Horpibulsu, S.; Suksiripattanapong, C. and Prongmanee, N. [15] | 2014 | Australia | AS 1289.5.2.1 | Concrete aggregate = 1.96 / 12.0<br>Mix aggregate = 2.02 / 10.7 |

The Proctor compaction test is a crucial procedure for compacted soil landfills, serving both for studying material properties and for quality control purposes. This test allows for the determination of maximum density and optimum moisture content, which significantly impact various factors including cost, structural performance, and hydraulic performance of the landfill.

Moisture-density curves offer valuable insights into how changes in moisture content impact material density. Materials exhibiting less pronounced curves can accommodate greater fluctuations in moisture content without causing substantial deviations in compaction density. In contrast, materials with more pronounced curves are highly responsive to alterations in moisture levels, necessitating precise control of moisture content, particularly in close proximity to the optimal range, during the compaction process [12].

Natural aggregates typically exhibit higher maximum density and lower optimal moisture compared to recycled concrete aggregates (RCAs). While the particle distribution of these aggregates is similar, the variation lies primarily in their physical properties, with some aggregates having denser and less porous particles. RCAs, on the other hand, have higher water content, allowing them to absorb nearly double the amount of water compared to natural aggregates. This water absorption characteristic can be advantageous in minimizing water infiltration when RCA is utilized as a base material for highways [13]. These findings are consistent with previous studies conducted by [14], [5], [15] and [11].

The increase in the optimal moisture content and the decrease in the maximum dry density are primarily attributed to the higher roughness and porosity of the materials comprising recycled aggregates, with ceramic materials being the main contributors [14, 5, 11]. [16] support this statement through a comparative study obtained from Proctor tests involving two types of recycled aggregates: (1) composed solely of concrete waste and (2) mixed aggregates with the addition of ceramic waste. Their findings indicate that adding brick increases the optimal moisture content and decreases the maximum dry density. This outcome is attributed to the high water absorption and low density of crushed brick particles. Additionally, the low-density non-hydrated cement particles kept in the mortar increase the optimal moisture content and reduce the maximum dry density [17].

The Proctor tests conducted in these studies involve the fragmentation of recycled aggregates into smaller particles during the process [4, 17, 18]. [17] state that in addition to weak materials such as ceramics, the presence of non-hydrated cement within the mortar generates a weak, porous, and brittle layer, contributing to the breakage of particles during compaction. The application of compaction loadings to recycled aggregates generates finer materials, which can significantly enhance the bearing capacity of the aggregates. This indicates a substantial increase in the content of fine materials after proper treatment, ultimately improving highway performance [4, 18].

In summary, the composition, loading conditions, and water content are crucial factors influencing the physical-mechanical properties of recycled aggregates in Proctor tests. Therefore, it is imperative to thoroughly observe and analyze these properties before utilizing these materials in practical applications.

### 4.5. Los Angeles Abrasion

Several studies have performed the Los Angeles Abrasion test to measure the toughness and abrasion resistance of aggregates, specifically their resistance to surface wear. This test assesses the aggregate grains' ability to withstand frictional forces, and a summary of the studies that conducted this test can be found in Table 8. The primary goal of this test is to determine whether the aggregate can retain its shape and integrity when subjected to crushing, degradation, and disintegration, ensuring that it remains intact and unbroken upon contact.

**Table 8:** Studies that utilized the Los Angeles Abrasion Test.

| Authors | Year | Country | Standards | Average values found (%) |
|---|---|---|---|---|
| Arisha, A. M.; Gabr, A. R.; El-Badawy, S. M. and Shwally, S. A. [20] | 2018 | Egypt | AASHTO | Concrete aggregate = 83.8<br>Mix aggregate = 47.2 |
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | UNE EN 1097-2: 2007 | 31 |
| M. A. Esfahani [3] | 2018 | Iran | AASHTO T96 | 32.5 |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | ASTM C 535-09 | 51.5 |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | PG-3 | 43.5 |
| Garach, L.; López, M.; Agrela, F.; Ordóñez, J.; Alegre, J. and Moya, J. A. [16] | 2015 | Spain | UNE EN 1097-2: 1999 | Concrete aggregate = 32.9<br>Mix aggregate = 36.4 |
| Courard, L.; Rondeux, M.; Zhao, Z. and Michel, F. [10] | 2020 | Belgium | EN 1097-2 | 41.7 |
| Vegas, I.; Ibañez, J.A.; Lisboa, A.; Sáez de Cortazar, A. and Frías, M. [19] | 2011 | Spain | EN 1097-2 | Concrete aggregate = 35<br>Mix aggregate = 39<br>Asphalt aggregate = 15 |
| Alnedawi, A. and Rahman, M. A. [21] | 2020 | Australia | ASTM 2006 | Mix aggregate = 33.1 |
| Mohammadinia, A.; Arulrajah, A.; Sanjayan, J.; Disfani, M. M.; Bo, M. W. and Darmawan, S. [27] | 2014 | Australia | ASTM C131 | Concrete aggregate = 30.8<br>Mix aggregate = 35.47<br>Asphalt aggregate = 20.81 |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; López-Uceda, A.; Ledesma, E. F. [28] | 2018 | Spain | UNE-EN 1097-2: 2010 | Unscreened material = 39 |
| Barbudo. A; Agrela, F; Ayuso. J.; Jiménez J. R. and Poon, C.S. [5] | 2012 | Spain | UNE-EN 1097-2: 1999 / a1: 2007 | Concrete aggregate = 34<br>Mix aggregate = 38 |
| Arulrajah, A.; Disfani, M. M.; Horpibulsu, S.; Suksiripattanapong, C. and Prongmanee, N. [24] | 2014 | Australia | ASTM Standard D4767-11 | Concrete aggregate = 28<br>Mix aggregate = 36 |
| Gabr, A. R. and Cameron, D.A. [25] | 2012 | Australia | ASTM D6928 | 39 |

[16] found a Los Angeles coefficient of 36.40% for mixed recycled aggregates, which meets the Spanish standards (maximum of 40%) for recycled aggregates. In comparison, natural aggregates exhibited a lower coefficient of 24%. The recycled concrete aggregate showed a lower flakiness index

than both natural aggregates and mixed recycled aggregates, which can be attributed to the presence of rounded particles [16].

[19] showed that mixed recycled aggregates containing ceramic rates between 20% and 30% generally exhibited fragmentation resistance ranging from 35% to 40%. In contrast, mixed recycled aggregates with ceramic percentages lower than 5% and asphalt content higher than 8% displayed lower fragmentation resistance, below 35%. The ceramic material had a significant influence on both wear and fragmentation of the recycled aggregate. Interestingly, the study also revealed that an increased amount of generated ceramic fines had a positive effect on consolidating the compacted material, as these fines promoted the pozzolanic reaction [11, 19].

Recycled concrete aggregates exhibited lower flakiness indexes and a lower percentage of broken surfaces. [5] found that among the recycled aggregates, recycled concrete aggregates presented higher abrasion resistance. Furthermore, although the Spanish standards prohibited the use of mixed aggregates and recycled ceramic materials in pavement layers, results from the Los Angeles test indicated that 14 out of the 23 materials studied (i.e., 61%) met the standard requirements, with a coefficient lower than 40% [5].

### 4.6. Permanent Deformation

The resilient modulus is a crucial parameter in the analysis and design of pavements. It plays a significant role in international design methods and its impact on pavement performance is well recognized. The resilient modulus is determined by assessing the stress-strain relationship of a pre-designed pavement structure under traffic loads. This relationship provides valuable insights into the permanent deformation characteristics of different materials. Table 9 presents a compilation of studies that conducted tests to evaluate the permanent deformation of recycled aggregates.

**Table 9:** Studies on Permanent Deformation Tests.

| Authors | Year | Country | Standards | Average values found |
|---|---|---|---|---|
| Arisha, A. M.; Gabr, A. R.; El-Badawy, S. M. and Shwally, S. A. [20] | 2018 | Egypt | AASHTO T307 | - |
| Li, Y.; ZHOU, H.; SU, L. and HOU, H. [18] | 2017 | China | - | 0.66 mm |
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | NLT-338/07 | - |
| Cerni, G.; Cardone, F. and Bocci, M. [11] | 2012 | Italy | EN 13286-7 | - |
| M. A. Esfahani [3] | 2018 | Iran | AASHTO T 207 | - |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | AASHTO TP46 | 4.283 x 10-3 mm |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | NLT 357/98 | 10.3 +/- 2.9 mm |
| Li, Z.; Yan, S.; Liu, L. and YANG, J. [9] | 2019 | China | Creep Test | - |
| Tavira, J.; Jiménez, J. R.; Ayuso, J.; Sierra, M. J.; Ledesma, E. F. [14] | 2018 | Spain | ASTM D4694 - Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device | 9 mm |

| | | | | |
|---|---|---|---|---|
| Arulrajah, A.; Piratheepan, J.; Bo, M. W. and Sivakugan, N. [22] | 2013 | Australia | Austroads 2004 | - |
| Alnedawi, A. and Rahman, M. A. [21] | 2020 | Australia | AASHTO T307 | - |
| Jitsangiam, P.; Boonserm, K.; Phenrat, T.; Chummuneerat, S.; Chindaprasirt, P. and Nikraz, H. [26] | 2015 | Australia | AS 2891.13.1-1995 (Standards Australia 1995) | - |
| Mohammadinia, A.; Arulrajah, A.; Sanjayan, J.; Disfani, M. M.; Bo, M. W. and Darmawan, S. [27] | 2014 | Australia | AASHTO T 307-99 (AASHTO 2007) | - |
| Behirry, A. E. A. E. [13] | 2013 | Egypt | - | 0.88 mm |
| Disfani, M. M.; Arulrajah, A.; Haguighi, H.; Mohammadinia, A. and Hurpibulsuk, S. [24] | 2014 | Australia | Austroads, Comment AG: PT / T053 | - |
| Arulrajah, A.; Disfani, M. M.; Horpibulsu, S.; Suksiripattanapong, C. and Prongmanee, N. [15] | 2014 | Australia | ASTM D4767 | - |
| Gabr, A. R. and Cameron, D.A. [25] | 2012 | Australia | DTEI TP183 | - |
| Diagne, M.; Tinjum, J. M. and Nokkaew, K. [23] | 2015 | USA | Model NCHRP (2004) | - |

Heavy traffic significantly influences the permanent deformation of pavements. The repeated passage of vehicles on highways exerts substantial loads on the pavement, leading to soil compaction and subsequent sinking. [4] It can be argued that there exists a direct correlation between the extent of permanent deformation in pavements and the amount of energy applied during compaction. When soils containing compacted recycled aggregates are exposed to increased compaction energies, they tend to display a noticeable reduction in permanent deformation [4]. It is crucial to closely monitor subgrade compaction during construction as instantaneous deformation accounts for over 80% of the total deformation [9].

This phenomenon is primarily attributed to the brittle nature of recycled aggregates. Under applied loads, the aggregates tend to fracture, generating finer particles and consequently reducing soil voids [11]. Furthermore, recycled mixtures demonstrate superior capability in accumulating lower permanent deformations at specific stress levels, exhibiting better performance compared to natural granular mixes [11].

The positive performance of recycled aggregates in pavement layers facing permanent deformation can be attributed to residual cement reactions [20]. By combining compaction energy with the cement waste reactions, recycled aggregates exhibit remarkable resistance to permanent deformation, rendering them suitable for use in pavement layers.

### 4.7. CBR Tests

The California Bearing Ratio (CBR) test is primarily undertaken to measure the strength of soil subgrades and base course materials for road pavement design. Table 10 presents the studies that have performed CBR tests on recycled aggregates, along with the corresponding standards used to determine CBR values.

**Table 10:** Studies that conducted CBR tests.

| **Authors** | **Year** | **Country** | **Standards** | **Average values found - expansion (mm) / CBR (%)** |
|---|---|---|---|---|
| Arisha, A. M.; Gabr, A. R.; El-Badawy, S. M. and Shwally, S. A. [20] | 2012 | Egypt | AASHTO, ECP e ASTM | Concrete aggregate = - / 152.9 |

| | | | | |
|---|---|---|---|---|
| | | | | Mix aggregate = - / 105.4 |
| Li, Y.; ZHOU, H.; SU, L. and HOU, H. [18] | 2017 | China | JTG D30-2004 | Mix aggregate = - / 34.7 |
| Jiménez, J. R.; Ayuso, J.; Galvín, A.P.; López, M. and Agrela, F. [12] | 2012 | Spain | Technical Standards for Building Highways in Spain (PG-3) | Mix aggregate = 0.01 / 62 |
| Cerni, G.; Cardone, F. and Bocci, M. [11] | 2012 | Italy | EN 13285. Unconsolidated mixes - Standards. European Committee of Standards; 2010. | Mix aggregate = - / 90 |
| M. A. Esfahani [3] | 2018 | Iran | AASHTO T193 | Mix aggregate = - / 73 |
| Leite, F. C.; Santos, R. M.; Vasconcelos, L. K. and Bernucci, L. [4] | 2011 | Brazil | ASTM D1883 / NBR 15115 | Mix aggregate = 0 / 73 |
| Rey, D. I.; Ayuso, J.; Galvín, P. A.; Jiménez, R. J. and Barbudo, A. [8] | 2016 | Spain | Technical Standards for Building Highways in Spain (PG-3) | Mix aggregate = - / 63.7 |
| Li, Z.; Yan, S.; Liu, L. and YANG, J. [9] | 2019 | China | JTG E40-2007 / JTG F10-2006 | Mix aggregate = 0.001 / 97.66 |
| Tavira, J.; Jiménez, J. R.; Ayuso, J.; Sierra, M. J.; Ledesma, E. F. [14] | 2018 | Spain | UNE 103502: 1995 / PG-3 e CRA | Mix aggregate = 0 / 78.7 |
| Garach, L.; López, M.; Agrela, F.; Ordóñez, J.; Alegre, J. and Moya, J. A. [16] | 2015 | Spain | Technical Standards for Building Highways in Spain (PG-3) | Concrete aggregate = - / 58<br>Mix aggregate = - / 25 |
| Vegas, I.; Ibañez, J.A.; Lisboa, A.; Sáez de Cortazar, A. and Frías, M. [19] | 2011 | Spain | Technical Standards for Building Highways in Spain (PG-3) | Concrete aggregate = - / 197.5<br>Mix aggregate = 0.095 / 105.4<br>Asphalt aggregate = - / 12.4 |
| Zuazo, E. T. L.; Zamanillo, Á. V.; Pérez, M. Á. C.; Miguel, Á. R. [29] | 2020 | Spain | UNE 103502: 1995 | Concrete aggregate = - / 193<br>Mix aggregate = - / 164 |
| Alnedawi, A. and Rahman, M. A. [21] | 2021 | Australia | ASTM D1883 | Concrete aggregate with geogrids = - / 195 |
| Jitsangiam, P.; Boonserm, K.; Phenrat, T.; Chummuneerat, S.; Chindaprasirt, P. and Nikraz, H. [26] | 2015 | Australia | Standards MRWA | Concrete aggregate = - / 120<br>Mix aggregate = - / 118 |
| Taveira, J.; Jiménez, J. R.; Ayuso, J.; López-Uceda, A.; Ledesma, E. F. [28] | 2018 | Spain | Technical Standards for Building Highways in Spain (PG-3) | Mix aggregate = 0.1 / 56<br>Mix aggregate selected = 0.1 / 65.5 |
| Barbudo. A; Agrela, F; Ayuso. J.; Jiménez J. R. and Poon, C.S. [5] | 2012 | Spain | UNE 103502: 1995 | Concrete aggregate = - / 100<br>Mix aggregate = - / 74 |
| Disfani, M. M.; Arulrajah, A.; Haguighi, H.; Mohammadinia, A. and | 2014 | Australia | AS 1289.6.1.1-1998 | Concrete aggregate = - / 160 |

| | | | | |
|---|---|---|---|---|
| Hurpibulsuk, S. [24] | | | | Mix aggregate = - / 138 |
| Arulrajah, A.; Disfani, M. M.; Horpibulsu, S.; Suksiripattanapong, C. and Prongmanee, N. [15] | 2014 | Australia | AS 1289.6.1.1 | Concrete aggregate = - / 160<br>Mix aggregate = - / 138<br>Asphalt aggregate = - / 65 |
| Gabr, A. R. and Cameron, D.A. [25] | 2012 | Australia | AS 1289.6.1.1 | Concrete aggregate = - / 180<br>Mix aggregate = - / 112 |

The strength of soil mixed with recycled aggregate is observed to increase with higher compaction loads [4]. According to [12], high CBR values indicate the breaking strength of the recycled aggregates, thus contributing to the improved density of the recycled asphalt and leading to better performance. work performance. This correlation is supported by the apparent CBR values reported in the study.

[16] and [21] mention an increase in bearing capacity, as measured by CBR values, resulting from hydraulic and/or pozzolanic reactions occurring among the various mineral phases within the granular material. The remaining cement in the adhered mortar of fine aggregates from recycled concrete is the primary cause of the self-cementing effect observed in subbases made of recycled aggregates.

The studies conducting CBR tests have demonstrated successful results that comply with the applicable standards in their respective locations.

## V. CONCLUSION

This study has demonstrated the practicality of utilizing recycled aggregates derived from construction waste for the purpose of filling and stabilizing various pavement layers, including base, subbase, and subgrade. Numerous studies have obtained favorable outcomes regarding the physical-mechanical properties of these recycled aggregates, as outlined below:

- Particle size: Most studies yielded successful results in terms of well-sorted and uniform materials. These materials exhibited a balanced distribution of fine and coarse particles, complying with the required standards for their respective locations.

- Water absorption: The disparity in water absorption between recycled aggregates and natural aggregates was found to be significant. Recycled Concrete Aggregates (RCC) displayed a notably higher water absorption rate, primarily due to the presence of porous materials in their composition. Consequently, achieving the desired compaction level and maximum dry density demands a greater amount of water [11].

- Proctor compaction: Several factors play a crucial role during the compaction process of recycled aggregates, including composition, compaction load, and water content. These factors profoundly impact the physical-mechanical behavior of the aggregates, requiring thorough observation and analysis prior to their practical utilization. It should be noted that RCC exhibit higher water content, with the ability to absorb nearly twice the amount of water compared to natural aggregates. Additionally, the application of compaction energy can generate finer materials from the recycled aggregates, contributing significantly to their strength, provided that the compaction energy is appropriately controlled.

- Los Angeles Abrasion: The studies indicate that concrete aggregates among the recycled materials exhibit superior abrasion resistance. Furthermore, ceramic materials exert a significant influence on the wear and fragmentation of recycled aggregates. Notably, the generation of a higher quantity of ceramic fines through fragmentation positively contributes to the consolidation of the compacted material, facilitating the pozzolanic reaction.

- Permanent Deformation: The studies emphasize that pavement resistance is directly linked to the energy levels applied during soil compaction. Soils incorporating compacted recycled aggregates and subjected to higher energy levels exhibit reduced permanent deformation. Moreover, recycled mixes demonstrate a greater capacity to accumulate and exhibit lower permanent deformation under specific stress levels when compared to natural granular mixes. The favorable performance of recycled aggregates in terms of permanent deformation is attributed to reactions from residual cement within pavement layers.

- California Bearing Ratio: The studies reveal a direct correlation between the strength of soils mixed with recycled aggregates and the applied compaction loads. The increase in strength, as measured by the CBR value, is attributed to hydraulic and pozzolanic reactions occurring among the various mineral phases present in this type of granular material. Notably, the self-cementing effect observed in subbases comprising recycled aggregates stems from the cement that remains within the mortar adhering to the fine aggregates of recycled concrete.

In conclusion, this comprehensive analysis of multiple studies unequivocally demonstrates the technical viability of utilizing these materials for enhancing pavement layers. Moreover, this research substantiates the environmental benefits associated with their implementation, specifically in terms of effective waste management practices that mitigate the adverse environmental consequences resulting from inadequate disposal methods.

As suggestions for future work, it is recommended to consider updating the current literature review, incorporating relevant studies published after 2021, and conducting a specific analysis based on the type of recycled aggregate, as they possess distinct characteristics and applications.

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