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Recycled Concrete Aggregated for the use in Roller Compacted Concrete: A Literature Review

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ABSTRACT

The using of recycled aggregates from construction and demolition waste (CDW) can preserve natural aggregate resources, reduce the demand for landfill, and contribute to a sustainable built environment. Concrete demolition waste has been proven to be an excellent source of aggregates for new concrete production. At a technical, economic, and environmental level, roller compacted concrete (RCC) applications benefit various civil construction projects. Roller Compacted Concrete (RCC) is a homogenous mixture that is best described as a zero-slump concrete placed with compacting equipment, uses in storage areas, dams, and most often as a basis for rigid pavements. The mix must be sufficiently dry to support the weight of vibratory machinery while still being sufficiently moist to enough paste binder dispersion throughout the mass for efficient compaction. Limited studies into the use of RCC with fine recycled aggregate not from pavements are figured. This study aims to see how well-recycled concrete aggregates (RCA) perform in RCC mixtures. Also how well waste concrete could be used as a fine and coarse aggregate substitute in roller-compacted concrete pavement mixes, to create a good concrete mix in both wet and firm phases. The test results of mechanical properties showed 10% RCA is similar to those in the reference mix in the compressive strength, a 100% RCA ratio reduces compressive strength by almost 30%. Comparing Reference mix and Recycled concrete by 30% replacement, the compressive strength drops by just 6% when the RCA ratio is 30%.

Keywords: Roller compacted Concrete, Recycled Aggregate, Construction and Demolition Waste, Recycled Concrete Aggregates.

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الخرسانة المعاد تدويرها للاستخدام في الخرسانة المرصوصة بالحدل: مراجعة

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الخلاصة

لقد ثبت على نطاق واسع أن استخدام الخرسانة المعاد تدويرها في المشاريع المدنية يوفر تأثيرًا طويل المدى بين العديد من المواد المستخدمة في مجال أنشطة الهندسة المدنية، كما تم تسليط الضوء على إعادة تدوير نفايات البناء والهدم (CDW). على المستوى التقني والاقتصادي والبيئي، تستفيد تطبيقات الخرسانة المرصوصة بالحدل (RCC)من مجموعة متنوعة من المشاريع الانشائية. كانت هناك دراسات محدودة حول استخدام الخرسانة المرصوصة بالحدل (RCC)مع الركام الناعم المعاد تدويره غير المأخوذ من الأرصفة. الغرض من هذه الدراسة هو معرفة مدى جودة أداء الخرسانة المعاد تدويرها (RCA) في خلطة الخرسانة المرصوصة بالحدل. كان الهدف من هذه الدراسة هو معرفة كيفية استخدام نفايات الخرسانة المعاد تدويرها كبديل للركام الناعم والخشن في خلطات الرصف الخرسانية المرصوصة بالحدل. لإنشاء مزيج خرساني جيد سواء كان رطبًا أو صلبًا.

الكلمات الرئيسية: الخرسانة المرصوصة بالحدل، الركام المعاد تدويره، نفايات الأنقاض والبناء، الركام الخرساني المعاد تدويره.

1. INTRODUCTION

RCC is a uniform mix that includes water, sand, gravel, and cement. According to **(Abu-Khashaba and El-Ashaal, 2014; Ashtankara and Chore, 2014; Berga, 2014)**, storage areas that can withstand heavy loads are also available and can be established by RCC. While **(Berga, et al., 2003; Luhr, 2004; Jofre and Kraemer, 2008; Courard, et al., 2010; Zarrinkafsh and Shirazi, 2015; Abbas, 2022)**, recommended as a basis for rigid pavements **(Vancura, et al., 2009)**. The behavior of RCC is generally comparable to that of traditional concrete. However, its mechanical properties, such as its compressive strength, flexural strength, shear strength, and toughness, have remained high for a long time **(Burns, 1976; Jofre, 1993; Delatte, 2007; Kohn and Tayabji, 2003)**. Soil-cement and other earthwork construction principles are comparable to those of RCC buildings. There were early studies done **(Cannon, 1972)** and (**Hall, 1974)**, and the invention of the RCD technology (roller compacted dam), which was pioneered in Japan in the 1970s and 1980s, helped RCC technology improve dramatically in the 1980s. The roller compacted concrete (RCC) paving material was created in the 1980s for heavy-duty applications, such as log sorting yards, tank hardstands, and railroad sorting yards. It is now used for a variety of industrial pavements. It has also found use on highways and parking lots, among other places. The construction of dams and roadways, rehabilitation and modification of existing concrete dams, and overflow protection for embankment dams and spillways are all possible with roller-compacted concrete (RCC), which has become a widely acknowledged material in this industry. Its manufacturing allows. The suitability of consumption materials, cementation material composition, compression levels, and quality control standards all have a role in RCC quality. The mix must be sufficiently dry to support the weight of vibratory machinery while still being sufficiently moist to enough paste binder dispersion throughout the mass for efficient compaction. **(Abu-Khashaba and El-Ashaal, 2014)** RCC has been employed in the following applications as a construction material:

1) Concrete dams: roller compacted concrete has been utilized in building gravity dams and arch dams all over the world and worldwide, and it is the most commonly used for this technique rate. Also, it has been used to raise concrete dams and build structures that meet both static and seismic needs, like bridges.

2) Embankment and spillway overtopping protection: There are a lot of uses for roller-compacted concrete to protect embankment dams from overflowing flows. The stronghold embankment is mainly used as an extra or spillway in case of trouble. Roller-compacted concrete is also being utilized in building service spillways that aren't used very often.

3) Pavements that have been constructed with soil cement, which is commonly used in pavements, are not the same as this. The RCC is typically not covered by any other surface. There have been instances where thicker RCC pavement layers have been employed. When the thickness exceeds 12 inches, multiple layers of RCC are employed to ensure that large weights can be managed.

Slope protection: Slope protection using roller compacted concrete is similar to that obtained with soil-cement, except that some material needs may differ. In the same way as soil cement, roller-compacted concrete can be utilized in the creation of mass concrete foundations **(Choi and Hansen, 2005**).

2. BENEFITS OF RCC PAVEMENT

1. Construction is completed quickly and with minimum effort.
2. High load-carrying ability.
3. Early strength growth.
4. Durable.
5. Low maintenance.
6. Economical.
7. No special forms are required.
8. No reinforcing steel.

RCC with 300 kg/m^3 of cement and 0.35 W/C has high compressive strength and durability **(Tayabji, 1987)**, designed appropriately, 40 N/mm^2 at 3 days for 300 kg/m^3 cement and 0.35 W/C. **(de Larrard, 2001)**. Because RCC is so quick to set, it is used a lot to build roads and dams. The RCC is very cheap to make and put up because it doesn't require much time or money. On the other hand, the bituminous binder does not have very strong compressive strength **(Tremblay, 1997).** It is suited for use as a road covering **(Ouellet, 1998).**

3. MATERIALS USED IN RECYCLED AGGREGATED WITH ROLLER-COMPACTED CONCRETE

3.1 Cement

CP-V-ARI-RS Portland cement was used (Brazilian Portland Cement Association). This cement brand is extremely strong when it's new and can be sulfate-resistant.

Iraqi Lafarge (AlJisr) SRPC (type V) was used by **(Khan and Abbas, 2021).** Physical and chemical tests were done on this type of cement at the National Center for Construction Laboratories and Research (NCCLR). **(Aghayan, et al., 2021)** used Type II cement (moderate cement) in her work. **(Taffese, 2018)** chose Messebo (Portland cement type I) cement since it is an ordinary Portland cement that is produced in the local area. Used Iraqi Taslojah (Portland cement type I).

3.2 Sand

(Fardin and Santos, 2020) utilized RS (river sand) having a grain size of no more than 2.4 mm and PS (pit sand) with a grain size of no more than 1.2 mm. **(Khan and Abbas, 2021)** utilized silica sand powder from an Iraqi Geological Survey factory in Al Tajji city, which was obtained via mechanical grinding of natural silica sand in an electrical mill. The sand is located in Al Anbar Governorate, where the natural silica sand is abundantly available. The specific gravity of silica sand powder (SSP) used in the work was 2.61(unitless). **(Salih and Abed, 2016)** used the porcelanite stone as an aggregate in the RCC pavement. He was brought from an AL-Rutba town in AL-Anbar. It is white and characterized by high permeability and low density.

Table1. Silica sand powder (SSP) chemical composition **(Khan and Abbas, 2021)**

Chemical composition	By weight %
SiO_2	80.4
Al_2O_3	6.54
Fe_2O_3	3.33
TiO_2	0.88
CaO	4.08
MgO	3.10
Na_2O	0.02
K_2O	0.12
SO_3	1.65
Loss on Ignition	8

The chemical and physical tests were performed at the central laboratories of the Iraqi Geological Survey Organization. **Table 1** illustrates the chemical composition of (SSP)Researchers **(Aghayan, et al., 2021)** investigated RCCP (Roller Compacted Concrete

Pavement) mixes that contained ceramic wastes that were utilized as coarse aggregates and passed different sieve sizes (19 mm, 12.5 mm, and 9.5 mm sieves), which were employed as coarse aggregates in the study. Furthermore, the CWP (Ceramic waste powder) was employed in the RCCP as a partial replacement for cement in some areas (passing the No. 200 sieve). **(Taffese, 2018)** used natural sand.

3.3 Recycled Aggregates

(Fardin, and Santos, 2020) used recycled aggregates that were created in the town of Joinville (Brazil) by a treatment plant company. The maximum size of RCA was 25 mm, and natural gravel (NG) has a size limit of 19.1 mm. As a result, screening was performed on particles bigger than 19.1 mm to substitute fractional quantities of natural gravel (NG) for the maximum size of RCA in this experiment. **Fig. 1** shows the distribution of particle sizes, and **Table 2** shows the properties of each one of them. In the RCA, particulate 92.37 percent of the volume was made by mortar or NG particles. In the research **(Taffese, 2018),** it was discovered that recycled concrete could be generated from concrete that has been destroyed, then a universal testing machine's frame was built (UTM) at the Ethiopian Institute of Architecture, Building Construction, and City Development (EiABC) of Addis Ababa University's Materials Research and Testing Center (MRTC). At least 55 years old, the original concrete is estimated to still be in place. As well as the structural part from which the abandoned concrete may provide a few clues about how concrete was made at the time and how strong the original concrete was. Concrete that was blended and compressed by hand is likely to have a high level of strength.

Moreover, there is no documentation to substantiate these claims. A sledgehammer was used to break down concrete waste into smaller pieces. Later, an ordinary hammer was used to break it further down to remove the recycled concrete from the unused cement, and the size should be between 10 and 35 mm. According to **(Lopez-Uceda, et al., 2020),** Roller Compacted Aggregate was created in Cordoba at the treatment factory of Gecorsa Company. Each one of the blocks of concrete was properly cleaned before further processing.

Additionally, mechanically as well as manually, choices were made to sort waste into several categories. Like wooden material, plastic material, and iron. Starting with a 25 mm pre-screening. Afterward, the clean material was transferred to the manufacturing line. After that, it was sent into a crusher, where it was crushed harder. The production control process was carried out following the UNE-EN 13242:2003 Standard. The RCA's sulfate content, water-soluble and acid-soluble, followed the Spanish Code. The RCA used the same size range as the NG (4–20 mm) but a coarser particle size distribution.

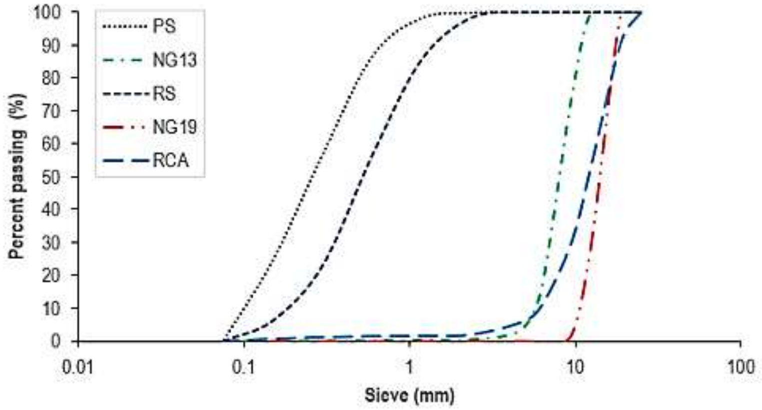

Figure 2. Aggregate particle size distribution **(Fardin and Santos, 2020)**

Table 2. Properties of aggregates **(Fardin and Santos, 2020)**

Properties	River Sand	Natural Gravel 13mm	Natural Gravel 19 mm	Recycled concrete
SSD density (gm/cm^3)	2.63	2.93	2.72	2.19
Water absorption (%)	---	0.27	0.2	7.63
Los Angles abrasion test (%)	---	14.15	12.83	32

3.4 Water

All researchers used tap water, which was used in all the mixing operations.

4. MIX PROPORTIONING METHODS

Recycled compacted concrete was dosed using the maximum dry density technique **(Fardin and Santos, 2020)**. According to Brazilian standards, there must be a cement composition of at least 200 kg/m^3 for the RCC foundation and surface pavements to be implemented. Yet another Brazilian rule that enables aggregates to be recycled, this energy is employed in pavement layers and requires the utilized compaction energy to be the intermediary Proctor energy. At three different levels, roller-compacted aggregates were employed to take the place of natural aggregates in the total mass: 5,15, and 30%. The mixes were called Roller Compacted Concrete (0, 5, 15, and 30) to match RCA's NG (natural gravel) replacement levels. The replacement percentage was set at these percentage levels since it was not suggested to replace much more than 40% of coarse NA in concrete because the mechanical specification of the concrete may decrease if the replacement percentage is much more than 40%. There was a big difference in the mechanical properties of mixtures with 10% RAP (Reclaimed asphalt pavement), and 30% RAP (Reclaimed asphalt pavement), when compared to (Borré's, 2017), observed percentage levels. This shows that RAP had a positive effect on mechanical properties. The percentage of materials required to produce RCC was calculated using Eq. (1). And the quantities of components required to get 1 m^3 of RCC are listed in **Table 3**. Eq. (1) was proposed in the year 1993 because it is part of a Brazilian RCC design process **(Fardin and Santos, 2020)**. This method was also used in other Brazilian RCC research projects. The aggregate quantity was determined using Eq. (1) based on the cement unit (m). The moisture content was set to h = 6.5 % because this is a standard value for OMC (optimum moisture content), and the air void volume was set to V_v = 50 Liter.

$$C = \frac{1000 - Vv}{\frac{1}{\gamma c} + \frac{m}{\gamma ag} + \frac{h \times (1+m)}{100}} \tag{1}$$

where

C is the amount of cement in the mix (kg/m^3).

Vv is the air void volume, γc is the density of cement (g/cm^3).

γ_{ag} is the aggregate density's average weight in (g/cm^3).

m is the aggregate quantity measured in cement units, dimensionless.

h is referred to moisture %.

This test was performed using an intermediate proctor to determine each combination's OMC and highest dry density. This experiment was conducted following Brazilian regulations. Cylindrical specimens with (150-300 mm) diameter were made by casting them in a mechanical compactor with intermediate proctor energy. **(Taffese, 2018)** used five different concrete mix compositions and divided them into two groups based on the required maximum strength: groups 1 and 2. Those in group 1 of the concrete mixtures were constructed to have a compression strength of 25 MPa to the cylinder; group 2 mixes, on the other hand, were meant to have a cylinder compressive strength of 35 MPa. According to ACI 211.1-91, all concrete mixtures are made using a system of weight-based batching. In group 1, there are three concrete combinations: RC-10, RC-10*, and Reference-I were constructed entirely of natural aggregates and served as a controlling or reference mixture for this group. RCA was used in the concrete mixture RC-10 at a ratio replacement of 10% of the total mass of the NCA (natural coarse aggregate). RCA was also used in the concrete mix type RC-10 at a replacement ratio of 10% of the overall weight of the NCA. The difference lies in the processes used during the design of the concrete mixtures.

The concrete mix for RC-10 was created to attain a certain strength class by considering the properties of the natural aggregates. The RCA was then used to replace 10% of the NCA's needed weight to make the desired concrete, which indicates that, except coarse aggregates, the proportions of all the mix constituents in RC-10(recycled concrete 10%) are similar to those in Ref-I(reference mix). When it comes to RC-10, however, the physical characteristics of the RCA were taken into account while designing the concrete mixture. Blended coarse aggregate

(BCA) was used to estimate the BCA's property value, and the NCA and RCA property values had a proportionate effect on the BCA, as given in Eq. (2). Thus, all of the needed parameters for designing the concrete mix were determined using Eq. (2) **(Taffese, 2018)**. Group 2 has two distinct types of concrete: Ref-II (reference mix) and RC-20 (recycled concrete 20%). Ref-II uses NA, which is the group's control mixture. The RCA was used as a partial substitute for the NCA in RA-20. Water-to-cement ratios in various concrete mixtures 1 and 2 were 61% and 55%, respectively. All other f specimens were made using cylinder molds made from steel with a diameter of 15mm and a height of 30mm for tensile and compressive strength tests and a (100mm) diameter disc having a size of (5mm) in length for water absorption rate testing. The specimens were demolded after one day and submerged in water (20 °C) until test time.

$$\text{BCA} = (\text{value of RCA} * 0.10) + (\text{value of NCA} * 0.90) \qquad (2)$$

Table 3. Materials required to produce 1 m^3 of concrete **(Fardin and Santos, 2020)**

Mixture	Cement (kg)	RS (kg)	NG13 (kg)	NG19 (kg)	RCA (kg)	Water (kg)
RCC-0	200	612	816	306	0	210.78
RCC-5	200	606	758	252	101	212.14
RCC-15	200	594	644	148	296	211.48
RCC-30	200	576	480	0	576	209.67

In **(Aghayan, et al., 2021)** research, the concrete mixture design was based on the RCCP codes. Twelve other mix designs were also made, but the natural aggregates and cement were mostly replaced with CWA (ceramic waste aggregate) and CWP (ceramic waste powder), respectively. The RC mix design was used as the control mix design. For example, 10 CWA(10% ceramic waste aggregate)-4CWP(4% ceramic waste powder) represents a 10% aggregate substitution with ceramic waste. In addition, two approaches, soil compaction, and optimal workability are used to compact the RCCP mix design. In this study, however, the optimal workability method was employed to evaluate the RCCP mix design. For all combinations, the water volume was 159 kg/m^3. The slump test was also done using ASTM C143, and the Vebe time and density of RCCP were determined using ASTM C1170 Nonetheless **(Lopez-Uceda, et al., 2016)**. The Better curve was used to dose the mixture to achieve maximum compactness in the aggregate combination and fill the granular skeleton's voids. With respect to each proportion, the total aggregate gradation closest to 50% matches the Better curve; three coarse NA incorporation ratios (in volume) were chosen for the coarse NA (0 percent, 50 percent, and 100 percent). There are 12 RC12 RCC mixtures that showed the mixture composition. To make them, four different series were made, one for each amount of cement used (110, 175, 250, and 350 kg/m^3). Each series had three mixtures with the RCA replacements. The Proctor-modified test was used to determine how much water was needed to make the mixtures. RCA-based mixtures needed more water than NA-based mixtures because the RCA constituents were so porous that they needed a lot of water to mix.

5. CONCLUSIONS

RCA is suitable for usage as a coarse aggregate in RCC due to its low fine particle concentration, 2.2 g/cm^3 specific gravity, 7.63 % absorption of water, and 32% LA (Los Angeles coefficient). Moreover, a high ratio should not be used to replace RCC since they tend to degrade concrete's mechanical qualities. For example, a 100% RCA ratio reduces compressive strength by almost 30%. Comparing Reference mix and Recycled concrete by 30% replacement, the compressive strength drops by just 6% when the RCA ratio is 30%. All RCC mixtures created satisfied the basic criteria of Brazilian regulations, including a cement content of at least 200 kg/m^3 to use for pavement base surfaces, a compression strength of 15 (MPa) with a tensile strength of 1.5 (MPa) after 28 days of exposure. It took 28 days for all the RCC mixtures to meet the minimum compressive strength requirements set by the United States and France, but all of them met the French requirements for splitting tensile strength 1.6 (MPa). The Reference mix and Recycled concrete 15% replacement mixtures had more than the 3.5 (MPa) flexural tensile strength needed for American pavements. All of them met the French requirements for splitting tensile strength. Compared to NCA, RCA had lower physical and mechanical properties (density, compressive, tensile, flexural strength, etc.). The compressive strength of concrete, including 10% RCA was higher than that of concrete containing only natural aggregates. Concrete specimens' split tensile strength containing RCA up to 20% was comparable to that of concrete containing only natural gravel. The hardened concrete specimens that used RCA had a greater absorption rate than those for which typical aggregates were used.

Economic and environmental advantages will accrue from this decision because it will help to save natural resources and cut down on waste disposal and hauling. Because there weren't many studies on CDW in developing countries, if other research institutions or building companies in these countries want to do the same thing, this study can help them. The LCA method's outcomes prove that using these waste materials can help reduce GHG emissions. Emissions from various combinations whose compressive strengths exceeded the lowest permissible compressive strength were then considered. In 15%ceramic waste aggregate specimens, 10 percent and 8 percent of emissions were reduced. In the 25% ceramic waste aggregate and 4% ceramic waste powder specimen, 8%, and 10 % were reduced. Also, 15CWA specimens had a beneficial influence on the warming of the planet. The research cut the GWI (global weaning index) by 9%. Regarding mechanical and physical properties and environmental advantages, 15CWA specimens did the best when compared to other samples.

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