

Strength Evaluation of Roller-Compacted Concrete using Waste Clay-Brick as Aggregate

Abdullah Al-Ani

Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq
abd.raed2301@coeng.uobaghdad.edu.iq (corresponding author)

Zena K. Abbas

Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq
dr.zena.k.abaas@coeng.uobaghdad.edu.iq

Received: 20 February 2025 | Revised: 29 March 2025 | Accepted: 19 April 2025

Licensed under a CC-BY 4.0 license | Copyright (c) by the authors | DOI: <https://doi.org/10.48084/etasr.10642>

ABSTRACT

The primary aim of this laboratory study was to develop a Sustainable Roller-Compacted Concrete (S-RCC) that meets strength requirements by incorporating waste building materials. Specifically, waste Clay-Brick (CB) was used as a partial volume replacement for Fine Aggregate (FA) at two levels (15% and 30%) and for filler at 50%. The waste CB was manually broken with a hammer, further crushed using a mechanical crusher, and sieved to produce recycled sand. In addition to conventional water curing, three curing methods were evaluated: water spray, a liquid membrane-forming compound (Sika Antisol-WB), and damp burlap curing. The objective was to determine the most effective curing technique applicable in both laboratory and field settings. The results revealed that the S-RCC mixture containing 15% CB as FA replacement and 50% as filler replacement improved compressive, flexural, and tensile strength by 10.26%, 8.85%, and 7.75%, respectively, after 28 days of normal curing compared to the Reference Mixture (RM). Similarly, the mix with 30% CB as an FA replacement and 50% as a filler showed improvements of 6.29%, 5.42%, and 4.75% in compressive, flexural, and tensile strength, respectively. These enhancements are attributed to effective internal curing, as the highly absorbent nature of waste CB enables gradual water release, promoting hydration and improving the mechanical performance of this zero-slump concrete.

Keywords-RCC; waste-clay-brick; external curing methods; internal curing

I. INTRODUCTION

Roller-Compacted Concrete (RCC) is a stiff, zero-slump concrete that requires mechanical compaction using rollers to achieve the necessary density. Due to its high strength and durability, RCC can be placed directly in areas exposed to traffic [1–4]. Compared to conventional concrete, RCC offers both environmental and economic advantages. Traditional concrete typically contains about 15% cementitious materials, whereas RCC mixtures reduce this to approximately 12% [5–7]. This lower cement content contributes to reduced construction costs and shorter building times, making RCC a cost-effective alternative to conventional jointed plain concrete pavements [8–10]. As a form of "green concrete," RCC also supports environmental sustainability. It requires less energy to produce and emits lower levels of carbon dioxide, resulting in a more sustainable and durable construction material [11–13]. RCC technology integrates principles from soil compaction, asphalt paving, and concrete paving, offering a rapid and cost-efficient pavement solution [14–16]. Its construction methods resemble those used in asphalt pavement engineering, employing asphalt pavers and compaction using vibratory rollers or rubber-tired rollers [17]. RCC is versatile and can be

used as both a surface and base layer. When utilized as a base layer, it often requires similar cement content to that of dry lean or standard concrete mixtures [17–21]. For top-layer applications, a compressive strength in the range of 28 MPa to 41 MPa at 28 days is typically required [22]. In recent years, the focus of highway infrastructure development has shifted toward sustainability by minimizing the use of non-renewable resources [23]. More sustainable pavements can be achieved through innovations in paving techniques, optimized mixture design, and increased use of recycled materials [24]. In line with these goals, this study aims to produce high-strength S-RCC by partially replacing FA with 15% and 30% waste CB, and replacing limestone filler with 50% waste CB, sourced from demolished buildings and brick factories.

II. MATERIALS USED

A. Combined-Aggregate (C)

Combined aggregate of 5% was prepared according to [14, 25], to determine the percentage of fillers, Coarse Aggregate (CA) by 55%, and FA by 45%.

- CA: The mixture contains crushed stone aggregate (19.5 mm) of a maximum particle size. Particle sizes of 19.5 mm, 12.5 mm, and 9.5 mm were selected for CA, and the particle distribution was ascertained by sieve analysis.
- FA: The mixture contains particle sizes of 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and 0.075 mm FA, and the particle distribution was ascertained by sieve analysis.
- Filler: The mixture contains crushed limestone aggregate with particles passing through 0.075 mm sieve, which were selected for the limestone filler. The gradation curve of the aggregate in the mixture utilized in the study is depicted in Figure 1, and its limitation specifications were created in compliance with [14]. Figure 2 shows the gradation of the aggregate in the mixture.

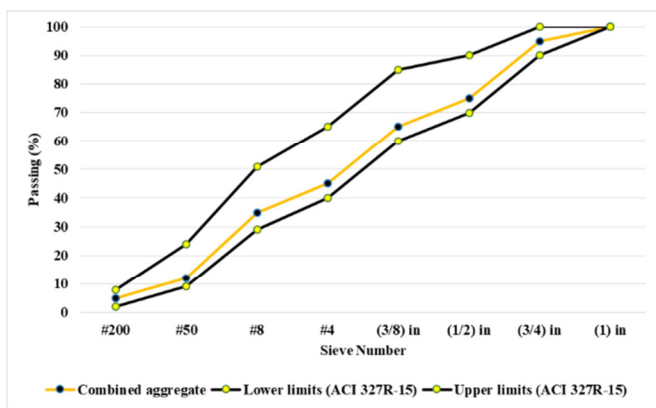


Fig. 1. C gradation.

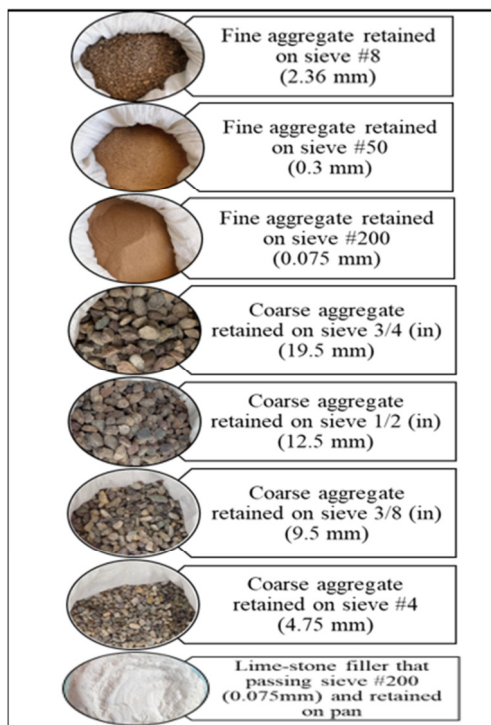


Fig. 2. Aggregate gradation.

B. Cement

Ordinary Portland Cement (OPC) type I [26] was used in the research. Table I presents the chemical characteristics and physical properties of the used cement.

TABLE I. CHEMICAL CHARACTERISTICS AND PHYSICAL PROPERTIES OF CEMENT

Chemical composition		[29]	Physical composition		[29]
SiO ₂	20.72	-	Specific-surface area	368 (kg/m ²)	260 (min)
Al ₂ O ₃	4.40	-	Initial-setting time	1:05 (hr: min)	0:45 (min)
Fe ₂ O ₃	3.10	-	Final-setting time	2:50 (hr: min)	6:15 (max)
Ca-O	61.43	-	Autoclave-expansion	0.038 (%)	0.8 (max)
Mg-O	2.08	6% (Max)	3-day compressive strength	23 (MPa)	12 (min)
SO ₃	2.14	≤ 2.3 for C ₃ A ≤ 8%	7-day compressive strength	27 (MPa)	19 (min)
IR	0.54	1.5 %	Main-compound (Bogue's equation)		
LOI	2.85	3% (Max)	C ₃ A = 6.41		-

C. Water

The mixes were created utilizing a water supply from Baghdad city, as it met the requirements of [27].

D. Waste Materials

Waste CB was taken from the laboratories to be used in the production of sustainable S-RCC as a substitute for FA by 15%. The same mixture was utilized as a substitute for limestone filler (FB-15) by 50% and for (FB-30) by 30%. Figure 3 displays the crushing and grinding process of waste materials by a machine. This process was carried out in the Baghdad-Iraq-Building Research Center. Table II presents the test absorption and specific gravity for recycled materials according to [30], and the bulk density according to [31].



Fig. 3. The process of crushing and grinding waste CB.

TABLE II. CLAY-BRICK PROPERTIES

Properties	Result
Specific-gravity	1.5
Absorption	27 %
Bulk-density	1290 (kg/m ³)

E. Curing Methods

Normal and advanced curing methods were selected, allowing an evaluation of the impacts on the durability of S-RCC under realistic curing conditions:

- Liquid-membrane-forming compound curing [28].
- Damp-burlap-curing [29].
- Water spraying.
- Normal curing in a water tank with a temperature of 23±2 °C.

III. CASTING AND MIXTURE CONTENT

S-RCC is characterized by its relatively dry consistency. To achieve maximum density in accordance with the guidelines in [14], proper compaction is critical, while the key factor influencing compaction is the moisture content of the mix. To evaluate the relationship between moisture content (%) and dry density (kg/m³), the Alternate Proctor Test [32] was employed. This compaction method is used to determine the OMC and the corresponding maximum dry density of the S-RCC mix. The test involved preparing five samples with varying moisture contents ranging from 4.5% to 8.5%, increasing in 1% increments, to generate a five-point Proctor curve. The step-by-step procedure of the Alternate Proctor Test is illustrated in Figure 4.

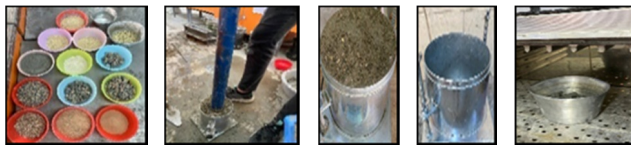


Fig. 4. Alternate-proctor-test phases: (a) preparation of ingredients and mixing, (b) tamp utilization, (c) mold weight, (d) sample drying.

TABLE III. MIXING QUANTITY FOR S-RCC IN (1m³)

Materials	Weight
Cement (kg)	279.7
Water (kg)	90.5
(Water/cement) ratio	0.323
Saturated surface dry (SSD) 85% of FA (kg)	708.6
SSD replaced with FA by 15% of waste CB (kg)	112.0
SSD 50% of lime-stone filler (kg)	52.3
SSD replaced with lime-stone filler by 50% of waste CB filler (kg)	69.2
Materials	Weight
Cement (kg)	287.5
Water (kg)	69.4
Water/cement ratio	0.241
SSD 70% of FA(kg)	599.8
SSD replaced with FA by 30% of CB filler (kg)	230.4
SSD 50% of lime-stone filler (kg)	53.7
SSD replaced with lime-stone filler by 50% of CB filler (kg)	71.2

The material proportions for 1 m³ of S-RCC are presented in Table III, and the water-to-cement ratio of the mixture was selected according to the OM-C. S-RCC has a significantly drier texture compared to ordinary concrete, necessitating a specific compaction process during application. The cylinder and prism specimens are compressed using a Vibratory-Hammer (VH) and Compressing Plate (CP) following the preparation and mixing of the ingredients, as shown in Figure

5. The VH and CP specified in [33] were used to execute this technique. Table IV presents the specifications of the produced VH and CP for cylindrical and prism molds. Finally, the prepared S-RCC samples were cured.

TABLE IV. MANUFACTURING SPECIFICATIONS OF VH AND CP FOR CYLINDER MOLD AND PRISM MOLD

Specification-(ASTM 1435)		Picture
VH	Power input: 1500 Watts, 2200 impacts per minute	
	Weight 8.8 kg	
CP for the cylinder	Diameter 149 mm	
	Weight 3 kg	
CP for the prism	Dimensions 98 mm × 498 mm	
	Weight 9.3 kg	

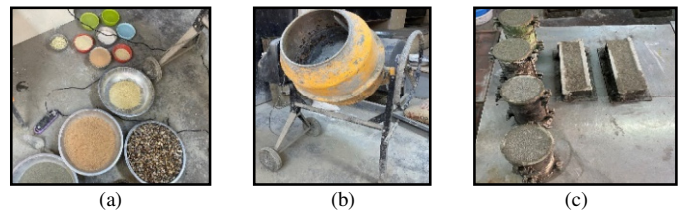


Fig. 5. Sample preparation techniques: (a) material preparation, (b) mixer, (c) method of compaction for cylinder mold and prism mold.

IV. CURING

Four methods of curing are used for the splitting tensile strength test, the compressive strength test, and the flexural strength test for prism S-RCC specimens and cylinder S-RCC specimens. As depicted in Figure 6, the samples were exposed to both spray-by-water and normal-curing for a day after casting and then left for 7 days, 28 days, and 90 days. However, the spray-by-water curing was an ongoing process having lasted for three days where the samples were sprayed twice a day (8:00 AM and 2:00 PM).

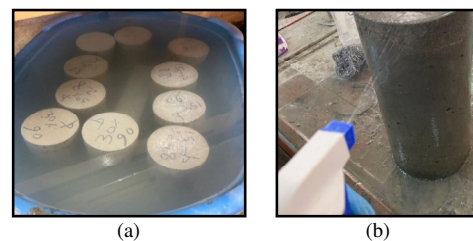


Fig. 6. Samples curing: (a) normal-curing, (b) spray-by-water.

As shown in Figure 7, the samples were coated with liquid-membrane-forming compound curing (Sika-Antisol-WB) for a while (two hours after casting) and then sprayed after being taken out of the mold. The curing process was carried out for three days, and the samples were then left for 7 days, 28 days, and 90 days.

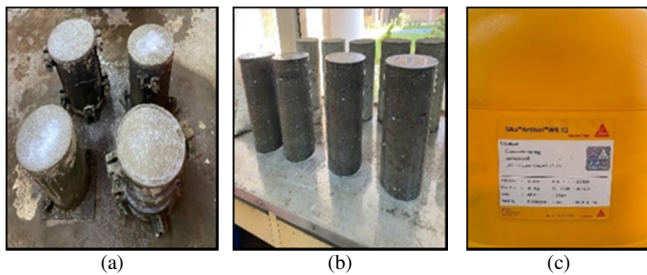


Fig. 7. Liquid-membrane curing: (a) after the first moist, (b) after being taken out of the mold, (c) Sika-Antisol-WB.

To avoid material separation through concrete handling and curing, the polyethylene material used in the damp-burlap treatment needs to be securely bonded to the burlap. As portrayed in Figure 8, the curing process was carried out for 3 days, and the room was left for 7 days, 28 days, and 90 days.

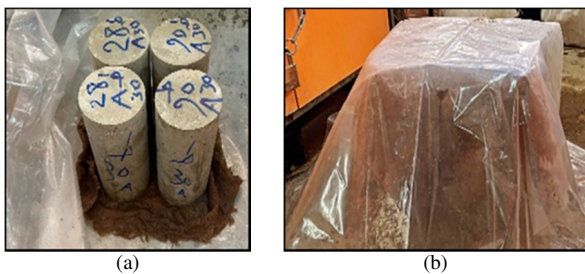


Fig. 8. Curing damp-burlap: (a) damp-burlap white and polyethylene sheet with samples, (b) after casing.

V. TEST METHODS

In many studies, the most effective criterion for assessing the quality of concrete is its mechanical properties. Compressive, flexural, and tensile strength tests were conducted to examine the effects of curing methods and the results are presented in Table V.

TABLE V. MECHANICAL PROPERTIES OF THE SAMPLES*

Strength- tests	Mold type	Layers Number	Picture
Compressive strength test according to (ASTM C39)	Cylinder 15 cm x 30 cm	4 layers	
Tensile strength test according to (ASTM C496)	Cylinder 15 cm x 30 cm	4 layers	
Flexural strength test according to (ASTM C78)	Prism 10 cm x 10 cm x 40 cm	2 layers	

* After 7, 28, and 90 days

VI. RESULTS AND DISCUSSION

The laboratory results showed that the compressive, tensile, and flexural strengths of RM decreased when FA and filler were replaced with waste CB. However, the S-RCC mixture with 15% FA replacement and 50% filler replacement (FB-15) demonstrated higher strength than the RM. It also performed better than the S-RCC mixture with 30% FA replacement and 50% filler replacement (FB-30). This strength improvement is attributed to effective internal curing. Waste CB, used as FA and filler, has high water absorption. It absorbs water during mixing and gradually releases it within the concrete. This internal water supply enhances hydration, especially in the Interfacial Transition Zone (ITZ) of zero-slump concrete, which leads to better mechanical performance. For the internal curing to be effective, the material must absorb water well and release it easily under pressure [34]. Studies have shown that finely crushed waste CB (passing sieve No. 4) creates osmotic pressure between itself and the surrounding mortar. This pressure helps the CB release absorbed water slowly, promoting continued hydration. As hydration continues, pores are filled with hydration products, improving the concrete's structure [35]. When the waste CB content increased to 30%, strength still improved compared to RM. However, the gain was less than that of FB-15. This was likely due to a weaker ITZ. The ITZ is the region where aggregate meets cement pastes and is usually the weakest part of the concrete. In Recycled Aggregate (RA) mixtures, the ITZ exists between old mortar, new mortar, and the original aggregate. This complex interface can be more fragile than in natural aggregate mixes [36, 37].

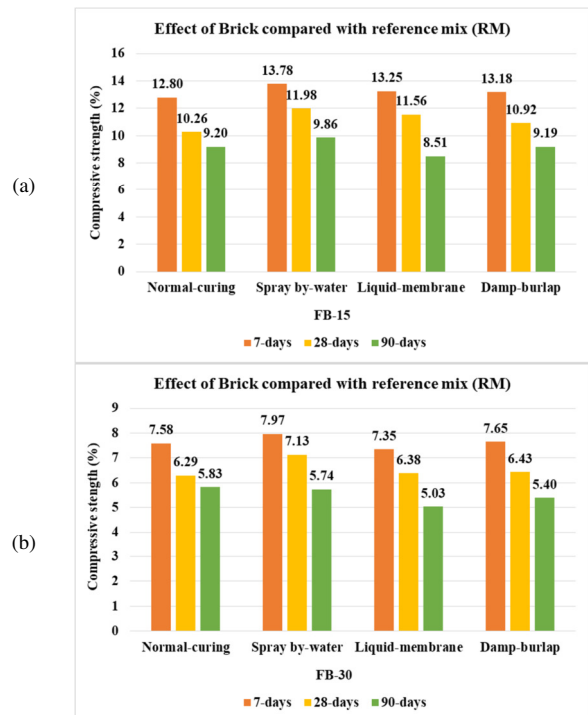


Fig. 9. Effect of brick compared with RM for: (a) compressive strength percentages of FB-15, (b) compressive strength percentages of FB-30.

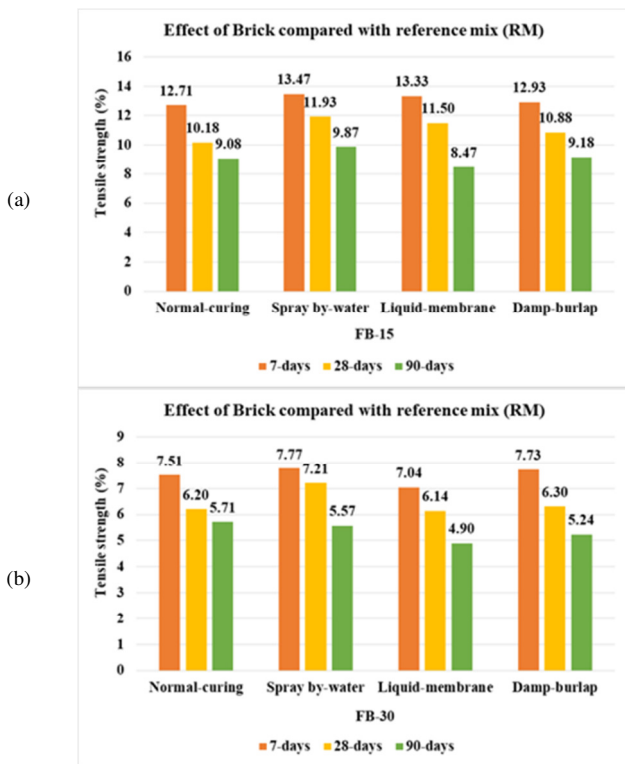


Fig. 10. Effect of brick compared with RM for: (a) tensile strength percentages of FB-15, (b) tensile strength percentages of FB-30.

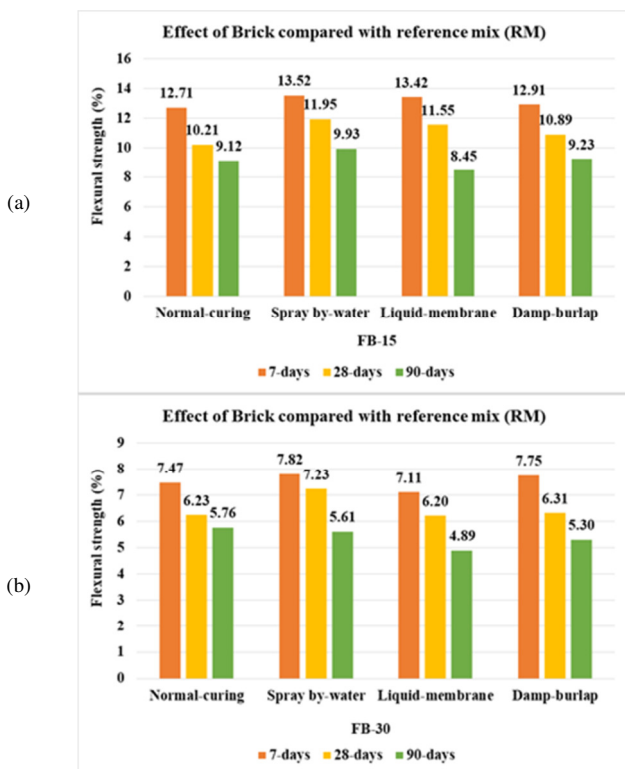


Fig. 11. Effect of brick compared with RM for: (a) flexural strength percentages of FB-15, (b) flexural strength percentages of FB-30.

Figures 9-11 display the percentages of strength increases and decreases. A key contribution of this study is the use of waste CB as a sustainable material, replacing FA by 15% and 30%, and limestone filler by 50%.

VII. CONCLUSIONS

At 28 days, under normal curing conditions, the FB-30 mixture showed increases in compressive, flexural, and splitting tensile strength of 6.29%, 5.42%, and 4.75%, respectively, compared to the RM. The FB-15 mixture performed even better, with strength improvements of 10.26% (compressive), 8.85% (flexural), and 7.75% (splitting tensile) under the same conditions. Among all tested combinations, FB-15 under normal curing delivered the highest mechanical performance. Regarding the curing methods:

- Spray-by-water resulted in the lowest mechanical strength across RM, FB-15, and FB-30 compared to other curing techniques.
- Damp burlap curing improved strength outcomes for all mixtures relative to both normal curing and spray-by-water.
- Liquid membrane-forming compound curing (Sika Antisol-WB) provided the highest mechanical strength overall among all curing methods.

Specifically, FB-15 combined with liquid membrane curing yielded the best strength results among all tested mixtures and curing techniques.

REFERENCES

- [1] A. A. Salih and Z. M. Abed, "Effect of Using Porcelanite as Partial Replacement of Fine Aggregate on Roller Compacted Concrete with Different Curing Methods," *Journal of Engineering*, vol. 22, no. 9, pp. 21–35, Sep. 2016, <https://doi.org/10.31026/j.eng.2016.09.02>.
- [2] Ö. F. Keleş and M. V. Akpınar, "Strength properties of roller compacted concrete pavement (RCCP) under different curing methods," *Construction and Building Materials*, vol. 324, Mar. 2022, Art. no. 126530, <https://doi.org/10.1016/j.conbuildmat.2022.126530>.
- [3] S. D. Tayabji and T. W. Sherman, *Report on Roller-Compacted Concrete Pavements*. USA: ACI, 2001.
- [4] S. I. Sarsam, "Correlating the Durability Properties of Roller Compacted Concrete," *Journal of Cement Based Composites*, vol. 1, no. 3, pp. 23–27, Jul. 2021, <https://doi.org/10.36937/cebacom.2020.003.005>.
- [5] P. Shafiq, Hashemi, Mohammad, Nam, Boo Hyun, and S. and Koting, "Optimum moisture content in roller-compacted concrete pavement," *International Journal of Pavement Engineering*, vol. 21, no. 14, pp. 1769–1779, Dec. 2020, <https://doi.org/10.1080/10298436.2019.1567919>.
- [6] *Engineering and Design Roller-Compacted Concrete*. US Army Corps of Engineers, 2000.
- [7] S. Q. A. Almajeed and Z. K. Abbas, "Fabrication of Sustainable Roller-compacted Concrete Pavement containing Plastic Waste as Fine and Coarse Aggregate," *Engineering, Technology & Applied Science Research*, vol. 14, no. 4, pp. 15547–15552, Aug. 2024, <https://doi.org/10.48084/etasr.7882>.
- [8] A. Aghaeipour and M. and Madhkan, "Mechanical properties and durability of roller compacted concrete pavement (RCCP) – a review," *Road Materials and Pavement Design*, vol. 21, no. 7, pp. 1775–1798, Oct. 2020, <https://doi.org/10.1080/14680629.2019.1579754>.
- [9] *Guide for roller-compacted concrete pavements*. National Concrete Pavement Technology Center, 2010.
- [10] K. H. Khayat, N. A. Libre, and Missouri University of Science and Technology. Center for Transportation Infrastructure and Safety, "Roller

- compacted concrete : field evaluation and mixture optimization.," NUTC R363, Aug. 2014.
- [11] A. Al-Mansour, C. L. Chow, L. Feo, R. Penna, and D. Lau, "Green Concrete: By-Products Utilization and Advanced Approaches," *Sustainability*, vol. 11, no. 19, Jan. 2019, Art. no. 5145, <https://doi.org/10.3390/su11195145>.
- [12] A. Sivakrishna, A. Adesina, P. O. Awoyera, and K. Rajesh Kumar, "Green concrete: A review of recent developments," *Materials Today: Proceedings*, vol. 27, pp. 54–58, Jan. 2020, <https://doi.org/10.1016/j.matpr.2019.08.202>.
- [13] B. Suhendro, "Toward Green Concrete for Better Sustainable Environment," *Procedia Engineering*, vol. 95, pp. 305–320, Jan. 2014, <https://doi.org/10.1016/j.proeng.2014.12.190>.
- [14] *327 - Roller-Compacted Concrete Pavements*. ACI, 2024.
- [15] S. W. Lee, Y.-H. Cho, and C. Park, "Mechanical performance and field application of low cement based concrete under compaction energy," *KSCCE Journal of Civil Engineering*, vol. 18, no. 4, pp. 1053–1062, May 2014, <https://doi.org/10.1007/s12205-014-0353-1>.
- [16] P. Gauthier, *Design and Construction of Roller Compacted Concrete Pavements in Quebec*. CANADA: CAC, ABQ, ACRGTQ, 2005.
- [17] R. S. Chhabra, G. D. R. N. Ransinchung, and S. S. Islam, "Performance analysis of cement-treated base layer by incorporating reclaimed asphalt pavement material and chemical stabilizer," *Construction and Building Materials*, vol. 298, Sep. 2021, Art. no. 123866, <https://doi.org/10.1016/j.conbuildmat.2021.123866>.
- [18] W. A. Yrjanson and R. G. Packard, "Econocrete Pavements: Current Practices," in *Transportation Research Record*, 1980, Art. no. 741, <https://trid.trb.org/View/159664>.
- [19] J. Greene, A. Nazef, and B. Choubane, "Thirty-Year Performance Evaluation of Two-Layer Concrete Pavement System," *Transportation Research Record*, vol. 2226, no. 1, pp. 21–29, Jan. 2011, <https://doi.org/10.3141/2226-03>.
- [20] S. R. Kasu, K. Manupati, and A. R. Muppireddy, "Investigations on design and durability characteristics of cement treated reclaimed asphalt for base and subbase layers," *Construction and Building Materials*, vol. 252, Aug. 2020, Art. no. 119102, <https://doi.org/10.1016/j.conbuildmat.2020.119102>.
- [21] S. Singh and G. D. R. N. Ransinchung, "Durability Properties of Pavement Quality Concrete Containing Fine RAP," *Advances in Civil Engineering Materials*, vol. 7, no. 1, pp. 271–290, Jun. 2018, <https://doi.org/10.1520/ACEM20180012>.
- [22] H. E. Fardin and A. G. dos Santos, "Roller Compacted Concrete with Recycled Concrete Aggregate for Paving Bases," *Sustainability*, vol. 12, no. 8, Jan. 2020, Art. no. 3154, <https://doi.org/10.3390/su12083154>.
- [23] A. S. Shamran and Z. K. Abbas, "Fabricating a Sustainable Roller Compacted Concrete Containing Recycled Waste Demolished Materials: A Literature Review," *Journal of Engineering*, vol. 30, no. 3, pp. 15–29, Mar. 2024, <https://doi.org/10.31026/j.eng.2024.03.02>.
- [24] K. Sobhan and M. Mashnad, "Roller-Compacted Fiber Concrete Pavement Foundation with Recycled Aggregate and Waste Plastics," *Transportation Research Record*, vol. 1775, no. 1, pp. 53–63, Jan. 2001, <https://doi.org/10.3141/1775-08>.
- [25] *211.3R-02: Guide for Selecting Proportions for No-Slump Concrete*. ACI, 2009.
- [26] *C150/C150M – 11 Standard Specification for Portland Cement*. ASTM International, 2011.
- [27] *C1602/C1602M – 12 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete*. ASTM International, 2012.
- [28] *C309 – 19 Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete*. ASTM International, 2019.
- [29] *C171 – 16 Standard Specification for Sheet Materials for Curing Concrete*. ASTM International, 2016.
- [30] *C128 – 15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*. ASTM International, 2015.
- [31] *ASTM C29/C29M-09 Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate*. ASTM International, 2009.
- [32] *D1557 – 12 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))*. ASTM International, 2021.
- [33] *C 1435 – 99 Standard Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer*. ASTM International, 1999.
- [34] M. S. Mohammed, H. ElKady, and H. A. Abdel- Gawwad, "Utilization of construction and demolition waste and synthetic aggregates," *Journal of Building Engineering*, vol. 43, Nov. 2021, Art. no. 103207, <https://doi.org/10.1016/j.jobbe.2021.103207>.
- [35] L. S. Rasheed and L. M. R. Mahmood, "Clay Brick Waste as Internal Curing Agent in Normal Weight Concrete," in *First International Conference on Engineering Sciences' Applications*, Kerbala, Iraq, 2014.
- [36] V. W. Y. Tam, X. F. Gao, and C. M. Tam, "Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach," *Cement and Concrete Research*, vol. 35, no. 6, pp. 1195–1203, Jun. 2005, <https://doi.org/10.1016/j.cemconres.2004.10.025>.
- [37] D. jabbar Abdullah, Z. K. Abbas, and S. K. Abd, "Study of Using of Recycled Brick Waste (RBW) to produce Environmental Friendly Concrete: A Review," *Journal of Engineering*, vol. 27, no. 11, pp. 1–14, Nov. 2021, <https://doi.org/10.31026/j.eng.2021.11.01>.