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Assessment of Rutting Resistance of Asphalt Mixtures Incorporating Recycled Concrete Aggregate After Treatment

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ABSTRACT

Perpetual research endeavors have been created within the existing research to improve the sustainability elements concerning the road structure sector, i.e., minimize possible pollutants and improve monetary profitability. This study aims to determine how recycled concrete aggregates (RCA), which come from tearing down buildings, affect rutting performance using specimens prepared in a laboratory. Four replacement proportions (0, 25, 50, 75)% were studied for the coarse portion of natural aggregate. RCA was treated by immersing it in hydrochloric acid (HCL). The surface morphology of treated RCA was investigated using a scanning electron microscopy (SEM) test. This study employed two preliminary assessments: the typical Marshall test to find the ideal asphalt content and explore the volumetric properties of asphalt mixes. The other exam was the wheel-tracking assessment. A four asphalt concrete slab sample was placed under repeated wheel loads of 700 N at 55°C to determine its resistance to cracking and rutting. An investigation revealed that mixed with RCA content of 75%, rut depth is higher at 11.83%.

Keywords: RCA, Rutting, Wheel-tracking, Dynamic stability.

1. INTRODUCTION

Rutting is the main form of deterioration seen in flexible asphalt pavements. It arises when the shear force applied to the pavement surpasses the anti-shear strength of the mix under repeated loading **(Yang et al., 2009)**. Every pavement ages and deteriorates with time owing to the repetitive application of vehicle loads and the impact of climatic variables **(Llopis-Castelló et al., 2020)**. Deeper pavement ruts might increase repair and maintenance expenditures and cause severe traffic safety issues **(Al-Bayati, 2024; Ali, 2024**). It significantly impacts asphalt pavements' performance, storing water and making the road uneven **(Anon, 2020).** It also raises the possibility of traffic accidents by decreasing tire-pavement friction and hydroplaning **(Anon, 2012)**.

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About 95% of aggregate particles are bound together by a viscoelastic to visco-plastic cement that alternates in consistency according to temperature and load. High binder content and poor aggregate graduation conditions are typically the causes of rutting **(Brown, 1993)**. The primary purpose of the overall bony structure is to oppose traffic loads. Simultaneously, asphalt cement necessitates the adjacency of these particles **(Albayati, 2017; Saleem, 2020; Tahmoorian, 2022)**. Three primary groups of variables fundamentally determine persistent malformation. The initial set of factors categorizes the asphalt mixture, encompassing its aggregate characteristics, gradation, cement type, and compaction state. The second overarching classification of factors comprises pavement temperature, axle design load, and vehicle frequency. Another significant group of factors pertains to the attributes of pavement substructures, namely the layers' thickness and the substance characteristics of the subbase and base layers **(Ngxongo, 2017; Ali, 2021)**.

In contrast, population growth, urbanization, and urban development necessitated the construction of numerous structures and roads. The heightened demand for basic materials adversely affected the environment **(Nazal, 2019; Albayati, 2023)**. Another pressing and hazardous environmental concern is accumulating construction objects' waste, which requires a lot of landfill space and disposal **(Mercante, 2012; Bhusal, 2013; Ismael, 2023).** Demolishing reinforced or non-inforced concrete structures yields reclaimed concrete aggregate RCA. The RCA is extensively used in numerous transit infrastructure projects, like base aggregate, Portland cement concrete (PCC) aggregate, and unbound and bound pavement layers throughout the United States. However, RCA has not been used much in HMA because there has not been enough research on whether it is appropriate. Because of the elevated expense of disposal, the lack of virgin aggregate sources, and the limited availability of landfills. Globally, research is underway to assess the suitability of RCA in asphalt pavements **(Mills-Beale, 2010)**. **(Tam, 2007)** examined what happened to RCA when it was soaked in three robust acid solutions: sulphuric acid, hydrochloric acid, and phosphoric acid at 0.1 M for a whole day at 20 °C. The results demonstrated a notable lowering in water absorption, enhanced mechanical attributes, and no negative impact from chloride and sulfate ions on the RCA. Research has shown that the treatment methods for recycled concrete aggregate have not effectively enhanced opposition to permanent deformation attributable to the detachment of some cement mortar from the aggregate. **(Albayati, 2024)**. **(Abass, 2020)** used therapeutic methodologies to improve the quality of RCA. The initial involved treating the RCA with hydrated lime, while the second employed hydrochloric acid. The study determined that when the quantity of RCA grows, the permanent deformation of all mixes, including treated and untreated RCA, also rises. **(Kareem, 2018)** employed a novel approach: a two-layered addressing RCA integrated inside HMA. A first coat of cement slag pastes and a second coat of sika Tite-BE were applied. An investigation concluded that this treatment reduced absorption and increased communication with the aggregate and the asphalt binder. Therefore, this study examined how vulnerable asphalt mixtures are to rut using different amounts of treated RCA instead of coarse aggregate.

2. MATERIALS AND METHODS

The asphalt cement, aggregate, mineral filler, and recycled concrete aggregate used are locally sourced and have undergone testing to ensure compliance with the Standards Roads and Bridges of Iraq (SCRB) criteria **(SCRB R/9, 2003)**.

2.1 Asphalt Cement

The asphalt utilized in this study had a penetration of (40–50), the most often utilized material in pavement building. Al-Daurh refinery supplied it results of asphalt binder checks conducted **(SCRB R/9, 2003). Table 1**. displays asphalt cement's physical characteristics.

Table 1. Physical characteristics of Asphalt cement

Test	ASTM Test	Measured Parameters	SCRB Limits
Penetration@ (25 °C,,0.1mm,5sec)	**(ASTM D5, 2013)**	44	40-50
Softening Point °C	**(ASTM D36, 2014)**	54	-
Ductility@ (25° C, cm)	**(ASTM D113, 2007)**	166	>100
Kinematic Viscosity @ 135 °C, cSt	**(ASTM D2170, 2007)**	404	-
After the Film Oven Test: - Penetration @ 25 °C, % - Ductility (25°C,5 cm/min)	**(ASTM D1754, 1997; ASTM D5, 2013; ASTM D113, 2017)**	77 85	>55 >25

2.2 Aggregates

Coarse and fine aggregate was obtained from the Al-Obaidi Mix Plant. The size range of coarse aggregates for the wearing course is within 12.5 mm and the No. 4 sieve (4.75 mm). Fine aggregate had particle sizes between No.4 and No. 200. Laboratory evaluation articulated the fundamental characteristics of the aggregate. The outcomes are exhibited in **Tables 2 and 3** based on the specification limit **(SCRB R/9, 2003). Fig. 1** displays the grain size distribution.

Table 2. The coarse aggregate physical characteristics.

Property	ASTM Test	Measured Parameters	SCRB Limits
Bulk Specific Gravity.	**(ASTM C127, 2015)**	2.58	-
Apparent Specific Gravity	**(ASTM C127, 2015)**	2.61	-
(%), Water Absorption.	**(ASTM C127, 2015)**	0.55	-
(%) Los Angeles Machine, Abrasion	**(ASTM C131, 2014)**	16	(%)30-Max

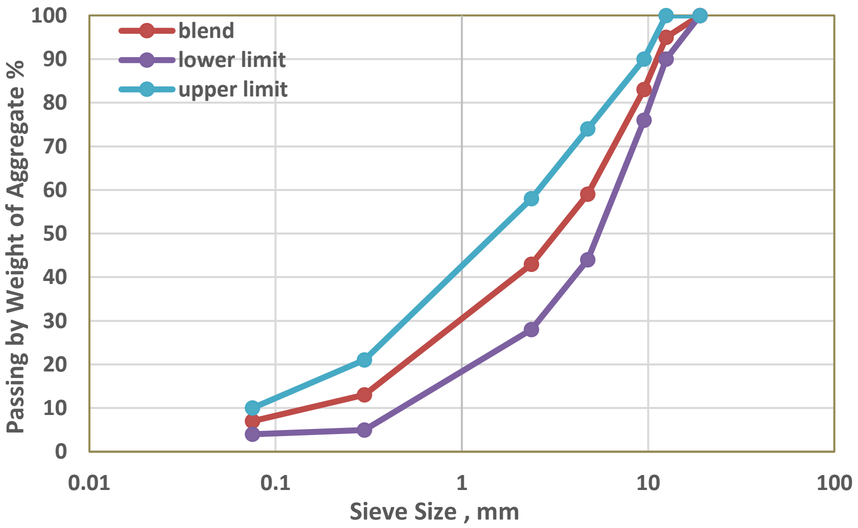


Figure 1. Aggregate gradation by **(SCRB R/9, 2003).**

Table 3. The fine aggregate Physical characteristics.

Property	ASTM Test	Measured Parameters	SCRB Limits
Bulk Specific Gravity	**(ASTM C128, 2015)**	2.60	-
(%)Water Absorption	**(ASTM C128, 2015)**	0.94	-

2.3 Mineral Filler

The Iraqi specification mandates that the filler consist of limestone dust or Portland cement. This search used limestone dust. **Table 4** shows the filler's physical properties.

Table 4. Mineral filler physical characteristics.

Property	Measured Parameters	ASTM Test	SCRB Limits
(%) passing,(No.200)	97	-	%70 Min
Specific Gravity	2.71	**(ASTM C-188, 2017)**	-

2.4 Recycled Concrete Aggregates

The coarse aggregate size was acquired by demolishing a building, resulting in a range of diameters from 19 mm to 4.75 mm, guaranteeing sustainability. The collected RCA (all sizes) substance was socked in a diluted HCL solution with a concentration of 0.1 mole. A full day is required to address the inadequate cement mortar of the RCA and thin down this layer. The RCA was then re-sank in clean water for a whole day to remove the acidic solution's residue **(Ibraheem, 2021; Al-Bayati, 2023)**. RCA was desiccated in the oven at 100 °C for three hours. Then, It was sifted and categorized into the necessary coarse gradations accordingly. **Fig. 2** displays the RCA, and **Table 5** illustrates their physical characteristics. For a better look, **Fig. 3** shows an SEM examination that shows how the treatment affected the RCA. The acid treatment smooths out the surface, but some mortar is still stuck to the RCA, and much of the cement slurry stuck to the RCA particles washed away.

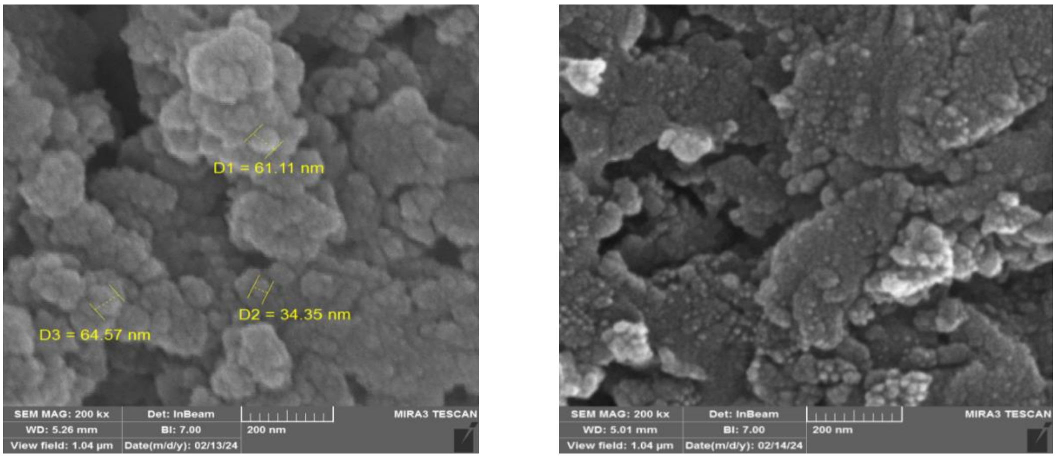
3. PROCEDURE FOR EXPERIMENTS

The testing methodology incorporated the Marshall and wheel tracking experiments to ascertain the optimum asphalt composition and susceptibility to rutting.

Figure 2. Concrete waste and RCA particles.

Table 5. Physical properties of coarse (RCA).

Test	ASTM Test	Measured Parameters
Bulk Specific Gravity.	**(ASTM C127, 2015)**	2.40
% Water absorption.	**(ASTM C127, 2015)**	2.84
Abrasion by Los Angeles Machine, [%].	**(ASTM C131, 2015)**	20



(a) Untreated. (b) Treated.

Figure 3. Morphological features of RCA.

3.1 Marshall Test

The Marshall method was utilized by **(ASTM D6927, 2015)** to find the optimum asphalt content, as seen in **Fig. 4**. Three (101.6 × 63.5) mm cylindrical samples weighing 1200 gm were manufactured. The mixes were pressed down 75 times on both sides, and asphalt contents (from 4 to 6%) were adopted with an increment of 0.5%. The Asphalt Institute's recommendations have identified 4% of air voids as the primary factor when selecting the optimum asphalt content (OAC) in this design. Also, all the properties were examined to find the exact requirements for control mixes stability, flow, voids, and bulk density **(Jasim, 2021; Badr, 2024).** To calculate the Marshall stability and flow on the control mix with treated RCA, 25%, 50%, and 75% were used.

3.2 Wheel Tracking

A wheel-tracking device replicates the resistance of combination asphalt to rutting depth by subjecting the samples to loads exerted by a wheel that moves continuously across them. The compactor can apply suitable loads by implementing a Dyne compaction device that adheres to **(EN 12697-33, 2019)** specifications to achieve the desired density or thickness of asphalt slabs. Standards were used to evaluate dynamic stability (DS) and the rut depth at a 70 PSI stress level applied to rectangular samples at 55 ˚C over 5000 cycles. Compressed asphaltic slabs are manufactured at AV equal to 4% utilizing a roller compactor device. This project used compact slabs of (400×300×50) mm. They weighed around 13,500 g. At the contact area, the loaded wheel applies 700 N. **Fig. 5** shows the wheel-tracking device at the University of Baghdad, and **Fig. 6** displays the wheel-tracking test sequences.

Figure 4. Marshall specimens prepared and tested sequences.

Figure 5. Wheel-tracking device at the University of Baghdad.

(a) Dyna-Compact Roller Machine.

(b). Prepared mixture.

(c). Casting the loose mixture.

(d). some of the tested slabs.

Figure 6. Sequences of wheel tracking test.

4. RESULTS AND DISCUSSION

4.1 Marshall Test Results

Table 6 lists the Marshall test findings for the treated RCA and the control mixture. Notice that when the quantity of RCA in asphalt mixes increases, the OAC also increases. Due to the porousness of the cement mortar, adhering to the aggregate allows for increased absorption of bitumen binder. The asphalt content of mixtures made with 75% treated RCA increased by 7.73% over the conventional mix, shown in **Fig. 7.** According to the test findings, the RCA mixes outperform the control mixtures regarding stability and flow values. It comes from pores in the cement mortar that cling to the aggregate, permitting increased absorption of asphalt binder. When the highest stability values of treated RCA samples were examined, acid treatment made the 75% RCA combination 25.26% more stable. Also, the uneven outer layer of the recycled aggregate helped the specimen be more stable, improving the adhesion and bonding between the binder and aggregate. All flow values increase and fulfill the **(SCRB R/9, 2003)** requirements. The maximum Marshall flow increase recorded for mixes containing 75% treated RCA was 46.01% over the control mixture.

Table 6. The Marshall results.

Treatment	RCA, %	O.A.C, %	Stability, kN	Flow, mm	Bulk density, g/cm^3	VTM, %	VMA, %	VFA, %
C	0	4.91	9.34	2.63	2.332	4.0	14.71	72.80
TRCA	25	5.00	10.03	3.50	2.322	4.0	14.17	71.77
TRCA	50	5.21	10.49	3.68	2.316	4.0	13.91	71.24
TRCA	75	5.29	11.70	3.84	2.314	4.0	13.72	70.85

C= Control, TRCA= Treated RCA

The bulk density of treated RCA was inferior to that of the control combination. The combination in which 75% treated RCA was included exhibited the most significant reduction, 0.77% lower than the control mixture. More research by (**Pourtahmasb and Karim, 2014; Hou et al., 2018**; **Daquan et al., 2018)** has also shown that adding more RCA to asphalt mixes makes them less dense overall. The treated RCA also changed the VMA values. Due to the RCA's uneven and rough surface, all groups decreased. The mixtures containing treated RCA by 75% showed the most significant decrease of 6.73%. **Fig. 8 (a, b, c, and d)** demonstrates the impact of RCA on Marshall results.

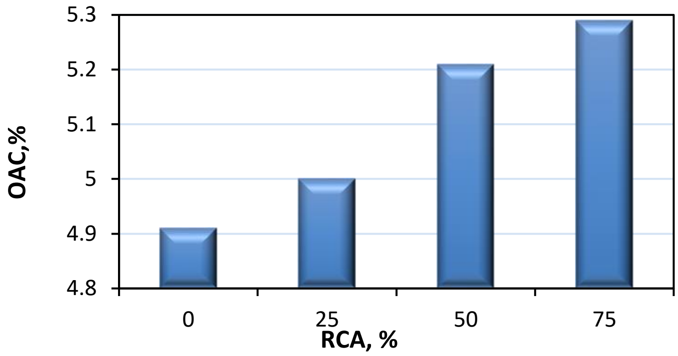
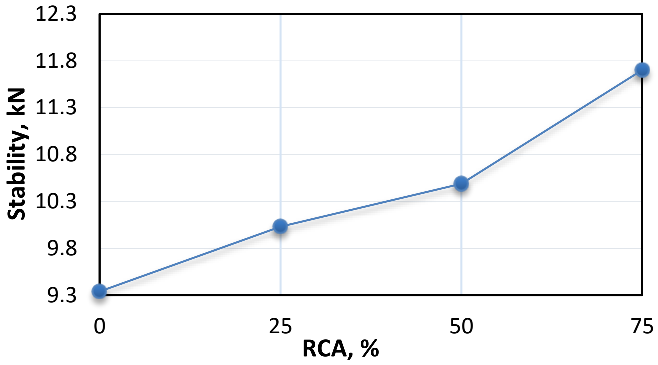
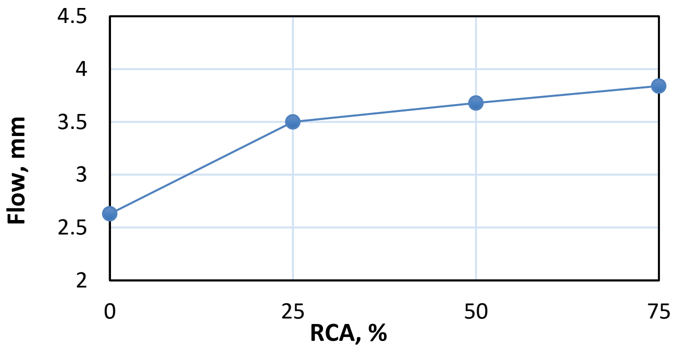


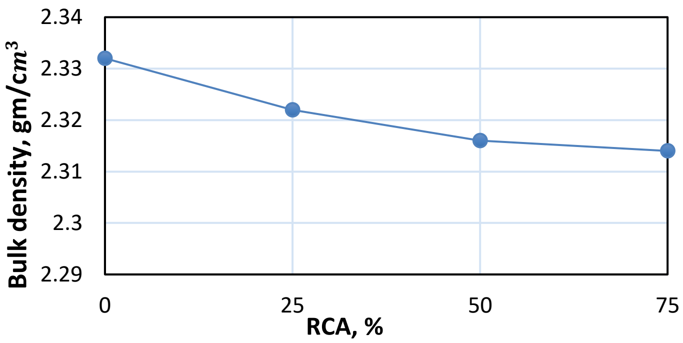
Figure 7. The Impact of RCA ON O.A.C.



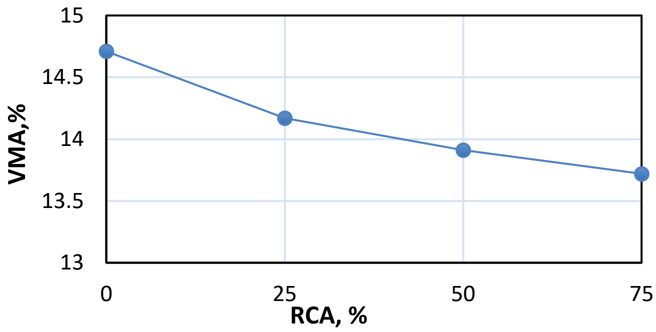
(a) Stability and RCA.



(b) Flow and RCA.



(c) Bulk density and RCA.



(d) VAM and RCA.

Figure 8. The influence of RCA on Marshall's results: Stability, (b) flow, (c) density, (d) VMA.

4.2 The Wheel Tracking

Four slabs measuring 300×200×50 mm were tested under a moving wheel load of 700 N for 10,000 cycles at 55°C. The rutting patterns in asphalt mixes were studied using dynamic stability (DS), the number of cycles that cause a 1 mm change in shape in the final quarter of a wheel tracking test, which lasts an hour **(Zhang, 2022).** Given the extended duration of the test, **Eq. (1)** was employed to ascertain the dynamic stability **(Phan, 2022)**.

$$\text{Dynamic Stability } \left(\frac{\text{Cycle}}{\text{mm}}\right) = \frac{10000-7500}{RD_{10000}-RD_{7500}} \quad (1)$$

Where:

RD_{10000}= Rut depth at 10000 cycles, RD_{7500} = Rut depth at 7500 cycles.

Table 7 and **Fig. 9** show the rutting of each mixture over 10,000 cycles. All treated RCA combinations had deeper ruts than the reference mixture. An explanation could be the amount of asphalt. The recorded maximum rut depth was in combinations that included 75% pre-soaked RCA, which increased by 11.83% over the reference mixture. In **Table 8** and **Fig. 10,** the DS of each mix was inferior to that of the initial blend.

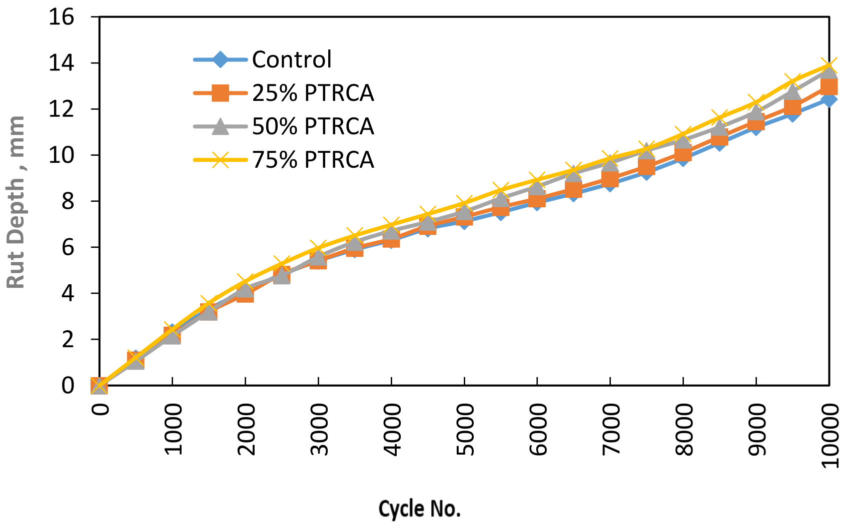


Figure 9. Rutting depth(mm) at 10000 cycles.

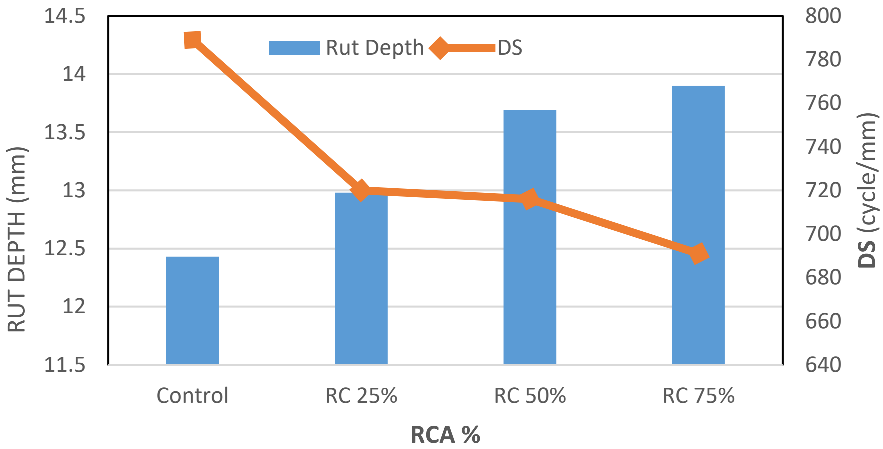


Figure 10. Relation between dynamic stability and rut depth and RCA.

Table 7. Rutting depth (mm) at 10000 cycles.

Control	TRCA25	TRCA50	TRCA75
12.43	12.98	13.69	13.90

Table 8. Dynamic Stability (Cycle/mm) per Equation (1).

Control	% RCA		
	25%	50%	75%
789	720	716	691

6. CONCLUSIONS

The experiment for this study used ten different asphalt mixes with varying amounts of coarse and natural aggregate replaced by RCA (25%, 50%, and 75%, respectively). The experiments carried out allow for the following conclusions:

1. The optimum asphalt cement percentage rose when treated RCA was replaced with virgin aggregates. Upon replacing 75% of the coarse RCA with virgin material, there was a 7.73% increase.
2. Marshall stability increased by adding recycled concrete aggregate to the asphalt mixes. When using 75% coarse RCA, the observed increase was 25.26%. It is because the recycled concrete exhibited several broken faces, sharp edges, and potholes, which enhanced the surface contact area.
3. The Marshall flow rose due to the increasing ideal asphalt content with a continuous rise in replacement ratios for recycled concrete aggregate. The most considerable increase was 46.01% when using 75% coarse RCA.
4. The volumetric characteristics were mainly unchanged with incorporating RCA, as all combinations complied with the SCRB 2003 Iraqi standard.
5. As the amount of RCA in the asphalt blend rises, the bulk density falls because the cement mortar enhances its adhesion to the aggregate. The combination in which 75% treated RCA was included exhibited the most significant reduction, 0.77% lower than the control mixture.

6. Mixes with variously proportioned treated RCA types show higher rutting resistance and a greater rutting depth than the control mixture. Indications suggest that treating RCA does not effectively enhance opposition to permanent deformation.
7. Because cement mortar was removed during RCA treatment, the asphalt mixture's volumetric properties and groove depth changed in small to significant ways.
8. Incorporating RCA resulted in an extended duration of mixing, and it is necessary to maintain a high temperature throughout the mixing procedure, not below 160 °C, and with a higher asphalt concentration.

NOMENCLATURE

Symbol	Description	Symbol	Description
A.V	Air voids, %	SCRB	State Corporation for Roads and Bridges,
AASHTO	American Association of State Highway and Transportation Officials	VFA	Voids filled by asphalt
O.A.C	Optimal Asphalt Content	VMA	Voids mineral aggregate
TRCA	Treated Recycled Concrete Aggregate	DS	Dynamic Stability
RCA	Recycled Concrete Aggregate	RD	Rutting depth

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Credit Authorship Contribution Statement

Ghufran Abd AL–Muhson Hussen: Writing – review & editing, Writing – original draft, Validation, Software, Methodology. Mohammed Qadir Ismael: Writing – review & editing, Software.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تقييم مقاومة التخدد في الخلطات الإسفلتية التي تحتوي على الركام الخرساني المعاد تدويره بعد المعالجة

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الخلاصة

تم إنشاء جهود بحثية مستمرة ضمن الأدبيات المتاحة لرفع عناصر الاستدامة المتعلقة بصناعة البنية التحتية للطرق، أي تقليل الملوثات المحتملة وتعزيز الربحية المالية. يهدف هذا العمل إلى تقييم تأثير الكتل الخرسانية المعاد تدويرها (RCA) المشتقة من المباني المهدمة على أداء التخدد باستخدام عينات تم إعدادها في المختبر. تمت دراسة أربع نسب استبدال (0، 25، 50، 75) ٪ للجزء الخشن من الكتل الخام. تمت معالجة RCA عن طريق غمرها في حمض الهيدروكلوريك (HCl). تم التحقيق في مورفولوجيا سطح RCA المعالج باستخدام تحليل المجهر الإلكتروني الماسح (SEM). استخدمت هذه الدراسة اختبارين أوليين: اختبار مارشال النموذجي لتحديد محتوى الإسمنت الأسفلتي الأمثل واستكشاف الخصائص الحجمية لمخاليط الأسفلت. اختبار آخر تم إجراؤه هو اختبار تتبع العجلة. تم تصنيع عينة (4) من بلاطة خرسانية أسفلتية بقياس 30 × 40 × 5 سم وتعرضت لأحمال عجلات متكررة بقوة 700 نيوتن عند 55 درجة مئوية لفحص مقاومتها للتخدد الناتج عن التآكل. وقد كشف التحقيق أن عمق التخدد الناتج عن التآكل يكون أعلى عند 11.59% عند خلطها بمحتوى RCA بنسبة 75.%.

الكلمات المفتاحية: الركام الخرساني المعاد تدويره، التخدد، فحص تتبع العجلة، الاستقرار الديناميكي.