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Rutting Prediction of Asphalt Mixtures Containing Treated and Untreated Recycled Concrete Aggregate

Nadheer Khaled Al-Bayati[1,*], Mohammed Q. Ismael[2]

Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq-Baghdad
Nazeer.Khaled2101m@coeng.uobaghdad.edu.iq[1], drmohammedismael@coeng.uobaghdad.edu.iq[2]

ABSTRACT

Rutting is a crucial element of the mechanical performance characteristics of asphalt mixtures, which was the primary target of this study. The task involved substituting various portions of virgin coarse aggregate with recycled concrete aggregate materials that had been treated or left untreated at rates ranging from 25 to 100%, with a constant increase of 25%. The treatment process of recycled concrete aggregate involved soaking in acetic acid, followed by a mechanical process for a short time inside a Los Angeles machine without the balls. This research utilized two primary tests: the standard Marshall test to identify the optimal asphalt contents and the volumetric characteristics of asphalt mixtures. The other one was the wheel tracking test, which involved manufacturing 11 slabs with a dimension of 30 x 40 × 5 cm and testing them under repeated wheel loads of 700 N at 55°C to investigate rutting resistance. The results demonstrate that using RCA had a negative impact on rutting resistance, where rut depth increased by 21.64% when using 100% pre-soaked treated RCA.

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

*Corresponding author
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تنبأ التخدد للخلطات الاسفلتية الحاوية على الركام الخرساني المعاد تدويره المعالج وغير المعالج

نظير خالد البياتي*، محمد قادر اسماعيل

قسم الهندسة المدنية، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

يعتبر التخدد عنصرا اساسيا في الاداءالميكانيكي للخلطات الاسفلتية وهو الهدف الاساسي لهذه الدراسة. تضمنت المهمة استبدال أجزاء مختلفة من الركام الخشن بمواد الركام الخرساني المعاد تدويره المعالجة بالتنقيع في حامض الخليك وغير المعالجة بمعدلات تتراوح من 25 إلى 100٪ مع زيادة ثابتة بنسبة 25٪.لإكمال هذه المهمة:تم اعتماد فحصين هما اختبار مارشال لتحديد المحتوى الأمثل للاسفلت. أما الآخر هو اختبار تتبع العجلة لتقييم عمق التخدد عن طريق تصنيع الواح بابعاد 30×40×5 سم وفحصها تحت حمل متكرر مقداره 700 نيوتن بدرجة حرارة 55 سيليزية. وقد اظهرت النتائج ان استخدام الركام المعاد تدويره له تأثير سلبي على مقاومة التخدد. حيث ازداد عمق التخدد بمقدار 21.64% عند استخدام 100 % من الركام الخرساني معالج.

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

1. INTRODUCTION

Most of Iraq's roads are made of asphaltic concrete due to the availability of raw materials and ease of manufacture **(Almuhmdi et al., 2021; Al-Saad and Ismael, 2022; Ayada and Al-Shafi'i, 2022; Taher and Ismael, 2023)**. It has suffered from harsh circumstances due to summer temperatures exceeding 50ºC for five to six months **(Raof and Ismael, 2019; Mawat and Ismael, 2020).** Asphalt pavements subjected to high temperatures and heavy traffic loads can exhibit rutting distress **(Abd and Qassim, 2017; Al-Saadi and Ismael, 2023)**. Rutting is a channelized depression that appears on asphalt pavements along wheel trucks **(Taher and Ismael, 2022; Ouyang et al., 2023; Peng and Unluer, 2023.).**Due to the vertical plastic deformation that causes the rutting, the road level varies, making navigation challenging and causing rainwater to accumulate in the channel **(Venudharan and Biligiri, 2020).** Many accidents are recorded due to rutting distress **(Henao-Pereira et al., 2020; Chen et al., 2022)**. They are seen as the causes of accidents that start to occur. Also, it raises the price of maintenance and rehabilitation in the impacted areas **(Ismael et al., 2021; Sapkota et al., 2023; Daquan et al., 2018)**.

Aggregate and asphalt cement make up asphalt mixes. The function of the aggregate skeleton is to resist traffic loads. At the same time, asphalt cement makes these aggregates contiguous to each other **(Albayati, 2017; Tahmoorian et al., 2022; Saleem and Ismael, 2020)**. These components have most significantly impacted rutting caused by shear failure. The resilience of asphalt cement to rutting is influenced by the binder properties of approximately 40% **(Du et al., 2018)**. While 80 % of the shear resistance derives from the aggregate internal friction angle **(Wang et al., 2008)**. Three major categories of variables essentially determine permanent deformity. The first set of variables involves how the asphalt mix is categorized, including its aggregate properties, gradation, type of cement, and compaction. The second major category of parameters includes pavement temperature, axle design load, and vehicle

frequency. These factors are unrelated to the qualities of the HMA mix. The third significant set of variables has to do with the characteristics of pavement substructures, which are layer thickness and material properties of the subbase and base layers **(Ngxongo and Allopi, 2017; Ali and Ismael, 2021).** On the other hand, the increase in demand for raw materials leads to a rise in their prices, which leads to an increase in the cost of asphalt concrete production and adverse effects on the environment **(Nazal and Ismael, 2019).** However, there is another critical and dangerous element affecting the environment: the accumulation of construction waste as a result of urban development, expansion, and population growth, which requires substantial land expanses for landfilling and disposal **(Ismael et al., 2023).** Construction waste contains various materials; one of the most important is concrete waste. Recycled concrete aggregate can be used instead of virgin natural aggregate in asphalt mixtures from an environmental point of view by reducing landfill areas and thus preserving soil and vegetation from damage **(Zuluaga et al., 2021; Poltue et al., 2020).** Generally, RCA is produced from the crushing of waste cement concrete, generating a universal challenge because RCA varies in quality based on the type of original concrete used. Therefore, it is essential to explore asphalt mixtures containing RCA **(Al-Bayati and Tighe, 2019).** The RCA composition is roughly 65-70 % natural aggregate, while mortar makes up 30–35% of the total material **(Ismail and Ramli, 2017).**
The current study aims to determine whether using treated or untreated recycled concrete aggregate instead of various amounts of coarse aggregate might increase the susceptibility of asphalt mixtures to permanent deformation.

2. MATERIALS AND METHODS

Asphalt cement (40–50) penetration grade, virgin aggregate (coarse and fine), recycled concrete aggregate, and ordinary Portland cement as filler were elements of the raw materials used in this study.

2.1 Asphalt Cement

A.C. (40–50) penetration grade asphalt is frequently used for road paving, provided by an asphalt plant located in the Salman Pak district on the exterior of Baghdad. The principal supplier of asphalt cement was the Dourah refinery in Baghdad. **Table 1.** exhibits the asphalt cement's physical properties according to the SCRB R/9 2003 standard.

Table 1. The physical properties of asphalt cement.

Test	Test Method	Result	SCRB Requirements
Penetration (25° C,100gm, 5sec).	AASHTO – T49	42	40-50
Ductility (25° C, 5cm/min)	AASHTO – T51	165	≥ 100
Flashpoint (Cleveland open cup).	AASHTO – T48	>232	232 Min
Specific gravity at 25° C	ASTM 70	1.03	-
Solubility in trichloro – ethylene %.	AASHTO – T44	99.2	>99
Residue from thin film oven test. -Retained penetration, % of original. -Ductility (25° C, 5cm/min)	AASHTO – T179	 77 98	 >55 >25

2.2 Aggregate

The Salman Pak asphalt plant supplied coarse and fine virgin crushed aggregate. These aggregates were primarily obtained from the Al-Nebaie quarry. **Tables 2 and 3** exhibit the fine and coarse aggregate physical properties according to the SCRB R/9 2003 standard.

Table 2. Physical properties of fine aggregate.

Test	Test Method	Result	SCRB Requirements
Bulk Specific Gravity.	ASTM C128	2.58	-
% Water Absorption.	ASTM C128	0.83	-
Clay Lumps and Friable Particles in Aggregate.	ASTM C142	0%	3% Max
Sand equivalent.	ASTM D2419	95%	45% MIN

Table 3. Physical properties of coarse aggregate.

Test	Test Method	Result	SCRB Requirements for Type IIIA
Bulk Specific Gravity	ASTM C-127	2.55	-
% Water Absorption.	ASTM C-127	0.45	-
Resistance to Degradation by Abrasion and Impact in the Los Angeles Machine.	ASTM C-131	13	30% Max
Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate. (Five cycles).	ASTM C-88	2% (Na_2SO_4)	18 % Max ($MgSO_4$) 12% Max (Na_2SO_4).
Degree of Crushing	ASTM D-5821	92%	90% of Min has one or more fractured faces.
Flat and Elongated pieces more than (5:1) between Max and Min Dimension.	ASTM D-4791	0%	10% Max.
Clay Lumps and Friable Particles in Aggregate.	ASTM C-142	0%	3% Max

Ordinary Portland cement was utilized as the filler in this experiment. It had been hauled from the main mixing plant in the Dourah neighborhood, south of Baghdad. **Table 4.** exhibits the physical properties of filler. Following SCRB R/9 2003, the Iraqi requirements for wearing course type IIIA, the middle range of aggregate gradation, were selected. The aggregate had a 19 mm maximum size. (12.5mm nominal size). **Fig. 1** shows the grain size distribution.

Table 4. Physical properties of mineral filler.

Test	Result	SCRB Requirement Percentage Passing by Weight
% passing (No 30)	100	100
% passing (No50)	100	95-100
% passing (No200)	98	70-100
Bulk Specific Gravity.	3.14	-

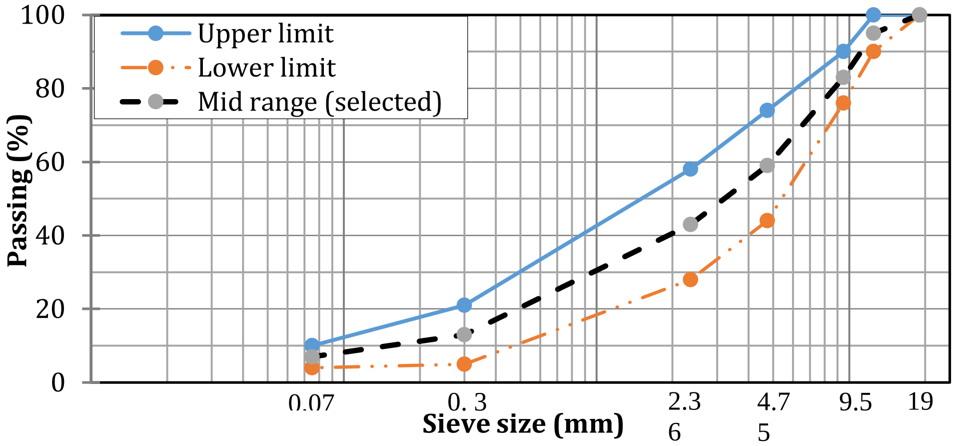

Figure 1. Grain size distribution.

2.3 Recycled Concrete Aggregate

It was gained by gathering and crushing the small pieces of a crumbling concrete curb stone. The RCA was then sieved and divided into the necessary coarse gradations following the wearing course type IIIA of the SCRB R/9 2003 Iraqi standard.RCA properties have been enhanced through treatment. The RCA was submerged in 0.1 M acetic acid for 24 hours as part of the procedure. The RCA was drained and submerged in distilled water for a whole day. The RCA was then dried and placed inside the Los Angeles device without the balls for 100 cycles to remediate the improperly bonded mortar that resulted from soaking. This procedure was known as pre-soaked treatment. **Fig. 2** shows the RCA particles. **Table 5** exhibits the physical properties of RCA.

3. METHODS

The Marshall and wheel tracking tests were both used in the testing approach to determine the ideal asphalt composition and rutting susceptibility.

Figure 2. Concrete waste and RCA particles.

Table 5. Physical properties of RCA.

Test	Test Method	Result	
		Untreated (U)	Pre-soaked (PT)
Bulk Specific Gravity.	ASTM C127	2.31	2.334
% Water absorption.	ASTM C127	2.88	2.82
Resistance to Degradation by Abrasion and Impact in the Los Angeles Machine.	ASTM C-131	23	21

3.1 Marshall Test

According to the ASTM D6926 standard, the Marshall design approach evaluated mixtures containing untreated and pre-soaked treated RCA (25, 50, 75, and 100%). Wearing course type IIIA of SCRB R/9 2003 was adopted for an asphalt cement content range of 4–6% with a 0.5% increment. Three (4×2.5-inch) cylindrical specimens weighing 1200 gm were produced for each percent of asphalt cement, and each face was compacted with 75 blows by a 4.535 kg free-dropped hummer. The bulk specific gravity and resistance to plastic flow were then determined following ASTM D2726 and ASTM D6927, respectively.

3.2 Wheel Tracking Test

The wheel-tracking device delivered consecutive loads through a travelling wheel across a specimen to imitate rutting resistance on asphalt mixtures. Using a Dyna compaction device that complied with EN 12697-33 requirements, 11 slabs that measured 30 x 40 x 5 cm were fabricated. The compactor can apply specific loads to compact loose asphalt mixtures to generate slabs with the desired density or thickness. This work obtained the desired density using various loads of 5 and 6 kN with 50 passes on a trial mix weighing 13.95 kg with virgin aggregate.

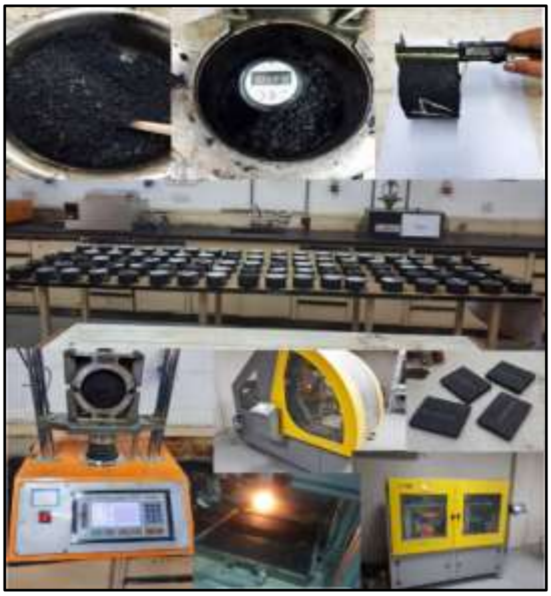

Figure 3. Marshall and wheel tracking test sequences.

The second trial load of 6 kN was sufficient for achieving the necessary density and thickness of 50±5 mm with 50 passes. Another combination was compacted using a 6 kN load, 50 passes, and varied weights based on their bulk density as measured by the Marshall test. An instrumental wheel tracker from Dyna-Track that complied with EN 12697-22 requirements. It was used to measure the depth of the ruts by applying a wheel load of 700 N (70 psi) for 10,000 cycles (or 20,000 passes) at a temperature of 55 °C. **Fig. 3** shows the Marshall and wheel tracking test sequences.

4. RESULTS AND DESCUSION

4.1 Results of the Marshall Test

Table 6 exhibits Marshall test results of mixtures containing several percentages of untreated and pre-soaked treated recycled concrete aggregate. It is obvious to notice an increase in optimum asphalt content when the proportion of RCA in asphalt mixtures increases. This is because the cement mortar adhering to the aggregate contains pores where more amounts of asphalt binder were absorbed. Asphalt mixtures made entirely of recycled concrete aggregate demonstrated the most significant increase in asphalt content, with growth rates of 10.97 and 9.95% over the control mixture for combinations of untreated and pre-soaked treated aggregate.

All mixtures demonstrated more excellent stability than the control mixture regarding Marshall's stability. The highest stability was recorded in 50% untreated and pre-soaked treated RCA mixtures. The increases were 13.67 and 10.23% over the control mixture, respectively. It might result from the recycled aggregate having more fractured faces than virgin aggregate, which increased the contact area. The recycled concrete aggregate impacted Marshall flow, and it was found that the flow increased when the amount of RCA increased. The maximum increase recorded for Mixtures containing 100% untreated and pre-soaked treated RCA were 15.10 and 17.22% over the control mixture.

Table 6. Marshall test results.

Treatment	RCA (%)	O.A.C (%)	Stability (kN)	Flow (mm)	Bulk density g/cm^3	VMA %	VFA %
C	0	4.92	11.04	3.31	2.326	14.98	74.45
U	25	5.02	11.95	3.42	2.299	15.11	73.94
U	50	5.13	12.55	3.46	2.278	15.16	74.09
U	75	5.25	12.31	3.63	2.261	15.10	73.39
U	100	5.46	11.96	3.81	2.245	15.07	73.93
PT	25	4.99	11.65	3.45	2.302	15.06	73.53
PT	50	5.08	12.17	3.59	2.281	15.09	73.57
PT	75	5.21	12.04	3.74	2.262	15.08	73.85
PT	100	5.41	11.78	3.88	2.247	15.04	73.47
SCRB Limit	-	4-6	8 Min	2-4	-	14 Min	-

C= Control, U= Untreated, PT= Pre-soaked treated

The bulk density of mixtures decreased when the amount of RCA increased. The maximum decrease was recorded for mixtures containing 100% untreated and pre-soaked treated

RCA, which were 3.48 and 3.39% lower than the control mixture. RCA also had a part to play in the VMA change. All combinations witnessed an increase in VMA content due to the rough surface of RCA. The gains were 1.2 and 0.73% over the control mixture when replacing 50% untreated and pre-soaked treated RCA, respectively. All results in **Table 6** met the SCRB R/9 2003 standard of wearing course type IIIA.

4.2 Results of the Wheel Tracking Test

Eleven slabs with a size of 30×40×5 cm were tested. The test conditions applied a 700 N repeated wheel load at 10000 cycles at a constant 55° C ambient temperature. The rutting behavior patterns of asphalt mixtures were examined using dynamic stability, which is defined by counting the cycles that cause 1mm of persistent deformation in the final quarter of a wheel tracking test that lasts one hour (total time) **(Zhang et al. 2022)**. Because the test time was longer, Eq. (1) was utilized to determine the dynamic stability **(Ismael et al., 2022)**.

$$DS\left(\frac{Cycle}{mm}\right)=\frac{10000-7500}{R_{10000}-R_{7500}} \quad (1)$$

where: R_{10000} = Rut depth in mm @ 10000 Cycles, and R_{7500} = Rut depth in mm @ 7500 Cycles. Dynamic stability (determined according to Eq. 1) is exhibited in **Fig. 4**. All these mixtures recorded lower dynamic stability than the control mixture. **Table 7 and Figs. 5 and 6** display the rutting depth at 10000 cycles. The rut depth in all combinations of recycled concrete aggregate was higher than in the control mix. The amount of asphalt could be the cause. Maximum rut depth was recorded for mixtures containing 100% untreated and pre-soaked treated RCA, which increased by 19.44 and 21.64% over the control mixture.

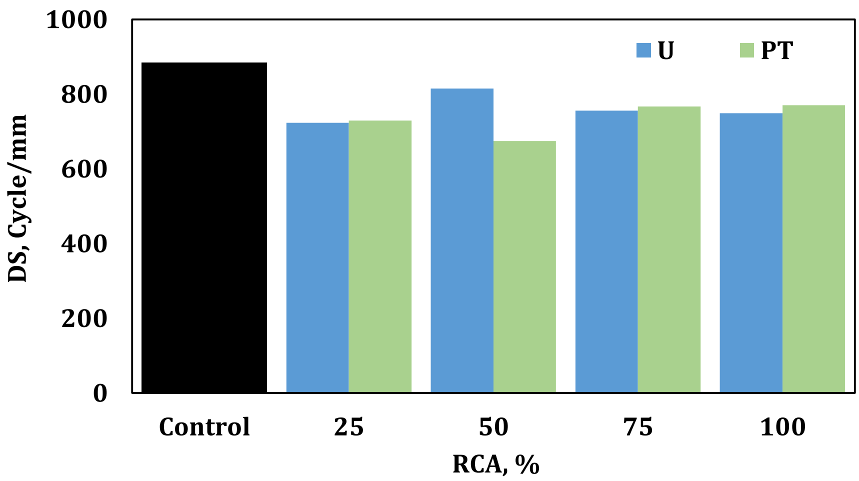

Figure 4. Dynamic stability.

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

% RCA								
Control	Untreated (U)				Pre-soaking treatment (PT)			
	25%	50%	75%	100%	25%	50%	75%	100%
12.29	13.31	13.63	14.05	14.68	13.27	13.79	14.26	14.95

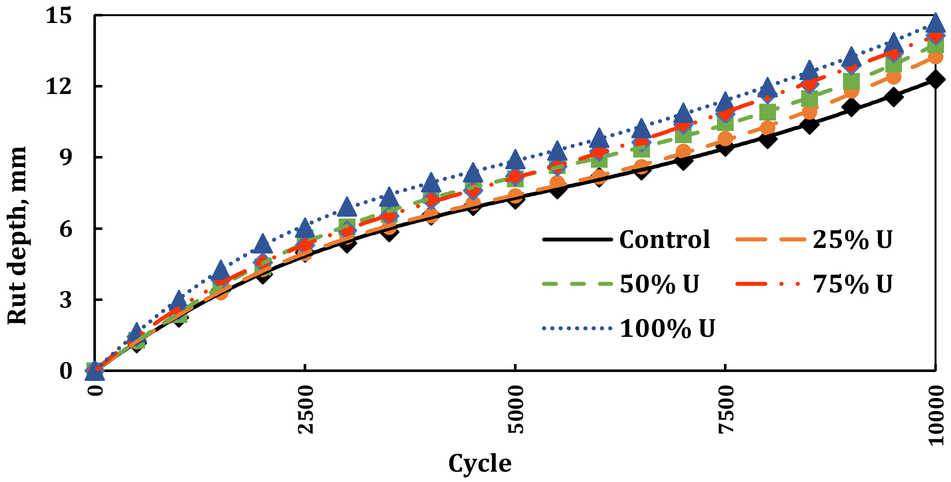

Figure 5. Rutting depth(mm) @ 10000 cycles for untreated recycled concrete aggregate (U) mixtures.

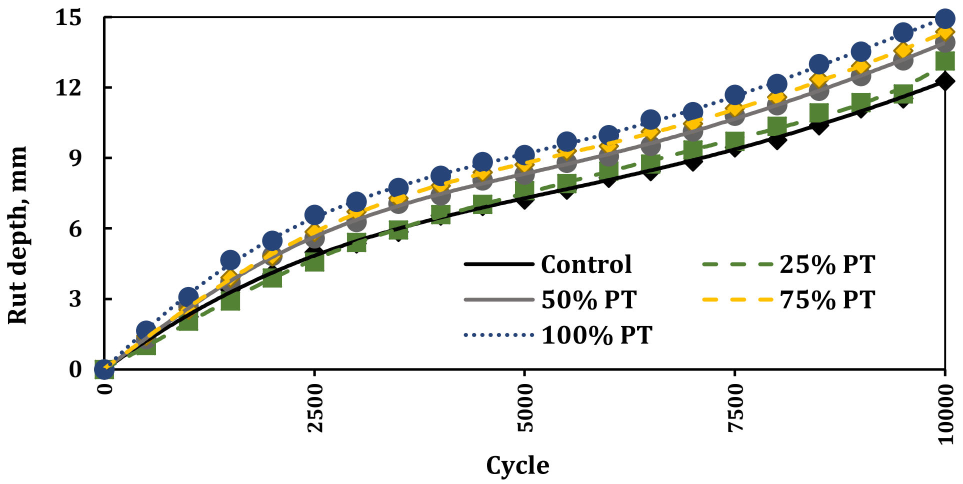

Figure 6. Rutting depth(mm) @ 10000 cycles containing pre-soaked treated recycled concrete aggregate (PT).

5. STATISTICAL ANALYSIS

Regression analysis is one of the most crucial statistical subfields used in the study of science and knowledge. It serves as a statistical model for estimating the functional relationship between two or more variables so that alterations in one of the variables can be known or expected based on how they will affect the other variables. In this study, cycle length, treatment, and % RCA were the three independent variables that impacted the rutting depth. Using SPSS software, rutting depth was predicted as a multiple linear equation, as shown in Eq. (2).

$$RD\ (mm) = 1.06 + 0.001 \times \text{Cycle length} + 0.015 \times \text{Treatment} + 0.017 \times \text{RCA} \quad (2)$$

where:
Cycle length (500-10000).

Treatment 0 for Untreated RCA, 1 for Treated RCA.
RCA (0, 25, 50, 75,100).
The coefficient of determination R^2 was 0.977, indicating a strong relationship with the predicted model.

6. CONCLUSIONS

The following relevant items can be added to the summary of this research based on the test results that were achieved and the characteristics of the materials used:

1- The optimal asphalt content rises when the replacement ratios of recycled concrete aggregate are increased because some of the asphalt binders are absorbed by the cement mortar that adheres to the aggregate.

2- The material made from recycled concrete had several fractured faces, acute corners, and potholes that increased the surface contact area and Marshall's stability compared with the control mixture.

3- A continued increase in replacement ratios for recycled concrete aggregate led to increased Marshall flow due to increased optimal asphalt content.

4- A continued increase in replacement ratios for recycled concrete aggregate led to decreased bulk density due to increased cement mortar that adhered to the aggregate.

5- A continued increase in replacement ratios for recycled concrete aggregate led to decreased permanent deformation resistance due to increased asphalt binder.

6- Treatment of recycled concrete aggregate did not lead to a significant difference in the volumetric characteristics or the rutting performance of asphalt mixtures due to the loss of some cement mortar adhering to the aggregate.

NOMENCLATURES

Symbol	Description	Symbol	Description
A.V	Air voids	SCRB	State Corporation for Roads and Bridges
AASHTO	American Association of State Highway and Transportation Officials	U	Untreated
O.A.C	Optimum asphalt content	VFA	Voids filled with asphalt
PT	Pre-soaking treatment	VMA	Voids in mineral aggregate
RCA	Recycled concrete aggregate		

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