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# Evaluating the Rutting Resistance of Asphalt Mixtures Containing Waste Steel and Treated Recycled Concrete Aggregate

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**Abstract**

Using treated recycled concrete aggregate (RCA) in asphalt with waste steel reinforcement benefits the economy and the environment while delaying asphalt pavement deterioration. This study examined the impact of using RCA in several percentages reinforced by three dosages of waste steel: 0.3, 0.6, and 0.9 added as a proportion of mixture weight. The RCA was immersed in a 0.1M Hydrochloric acid solution for one day to treat the weak cement mortar in RCA and reduce the thickness of this layer. The assessment was carried out in a laboratory using the typical Marshall test to determine the optimum quantity of asphalt contents, the volumetric properties of asphalt mixtures, and the wheel tracking test; the study involved ten rectangular slabs measuring 30×40×5 cm, and they were repeatedly subjected to 700 N wheel loads at 55°C to test their rut resistance. According to the study, while Marshall's stability increased, adding waste steel and RCA did not significantly alter the volumetric properties of asphalt mixes. The greatest improvement in Marshall stability, 45.18% over the conventional mix, was seen in the mix, including 75% RCA and 0.9% waste steel. The rutting performance decreased with the addition of RCA and rose with the inclusion of waste steel. The results indicate that adding waste steel to asphalt mixtures effectively increases the rutting resistance. The mixture with 50% RCA and 0.9% waste steel showed less rutting depth of 25.01% than the conventional mix.

*Keywords:* HAM; RCA; Waste Steel; Rutting; Wheel Tracking Test; Dynamic Stability.

## 1. Introduction

Rutting is one of the most harmful distresses observed in asphalt pavements. The performance of asphalt pavement is greatly impacted by rutting, especially when the ruts retain water and lead to hydroplaning [1, 2], essentially in Iraq, which leads to many accidents. The reason is the progressive movement of materials under repeated high truck loads with high ambient temperatures; the most frequent cause is the application of excessive amounts of asphalt binder [3]. According to some recent research, the asphalt mixture's dilatation behavior may have contributed to the rutting depth. Specifically, the asphalt mixture in the disturbance zone showed greater air void content during this time [4, 5]. Moreover, it drives up the cost of upkeep and restoration in the affected areas [6-8]. The aggregate skeleton is vital in asphalt concrete's resistance to rutting since additional temperature increases and decreases bitumen viscosity and adhesion to aggregates [9]. Studying efficient techniques for mitigating rutting distress is essential for providing a safe and long-life route [10]. Additives of many kinds can be used to alter the asphalt pavement. Generally, the stiffness is improved, and the temperature susceptibility is increased with additions. An increase in stiffness makes the asphalt pavement more resistant to rutting in hot weather and enables the use of relatively flexible asphalt [11, 12].

Natural rocks are the source of aggregates, and mining for them depletes natural resources [13]. Countries with finite natural aggregate resources are considering conserving their natural resources for coming generations. Consequently,

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scientists are considering investing in the vast amount of firm waste generated by the manufacturing sector and dumped in waste disposal sites. They have thus investigated a range of recyclable materials that can be utilized as an aggregate. To increase the quality of pavement, a production technique that is both economical and environmentally friendly can be regarded as sustainable [14-16]. It is estimated that around 60% of the composition of concrete is made up of coarse aggregate. Because of this, trash recycling and reuse with efficient building techniques are now required due to rising costs, negative environmental effects, escalating energy usage, growing demand, depleting reserves, and heightened strain on natural resources [17].

To create a potential substitute for regular coarse aggregates, research on recycled aggregate concrete (RCA) has increased recently. The most common and widely accepted uses of RCA are in non-structural concrete and bedding materials in road construction [18]. When part of the natural aggregates in a pavement structure are replaced with recycled concrete aggregate (RCA), building costs are reduced, pollution levels are lowered, landfill capacity is preserved, and natural resources are preserved [19]. Replacing virgin aggregate led to economic feasibility, even when consuming a large amount of asphalt cement. It was due to the highest benefit value of $2 per ton of asphalt concrete when utilizing a 100% RCA mechanical processor [20]. Despite the benefits above, RCA has greater abrasion, porosity, and water absorption than natural aggregates. It also has a lower bulk specific gravity and stiffness [21]. Notably, as compared to traditional asphalt mixes, HMA with RCA causes a larger amount of asphalt to be used [22-24]. To mitigate the issue of excessive asphalt use and performance deterioration [22]. Proposed that coarse RCA should be used in HMA instead of fine RCA. In recent years, many studies have also experimented with various approaches to pretreat (RCA). These techniques include surface pretreatment [23] and calcination pretreatment [24]. The primary element influencing the quality of RCA is the substantial amount of cement mortar attached to the aggregate. Several researchers have devised ways to eliminate this mortar and improve RCA quality. Considerable studies have been done on applying various therapeutic methods and procedures to improve the low quality of RCA's mechanical and physical qualities [25], including (1) the process that involves clearing the aggregate surface of loose mortar particles and (2) the process that significantly modifies and enhances the adhering mortar's quality [26]. It is possible to remove the loose mortar particle attached to the surface using ultrasonic cleaning [27]. Rubbing and heating simultaneously, or ball milling [28] and (RCA) pre-soaking in an acidic setting [29].

Consequently, it is essential to enhance the asphalt mix's endurance to the imposed load during its operational lifespan [30]. An investigation was conducted into the properties and effectiveness of asphalt mixtures reinforced with carbon fiber. Several tests were used to see what carbon fiber did to asphalt mixes. These included the Marshall test, the creep test, the indirect tensile test, and the resistance to fatigue cracking by repeated load indirect tensile test [31]. Carbon fibers, comprising 0.16% of the total weight, improved the mechanical characteristics of asphalt mixes [32].

According to some studies, techniques for treating recycled concrete aggregates have not been able to increase resistance to permanent deformation. Albayati & Ismael (2024) used a procedure that involved submerging the RCA in $CH_3$ COOH at 0.1 M for 24 hours. After that, they were placed into the Los Angeles apparatus for 3 minutes without the ball [33]. Köfteci (2018) used different quantities of iron fiber to reach the ideal amount of fiber. The inquiry findings suggest that including inexpensive iron fiber enhances the efficiency of asphalt mixtures. [34]. Saleem & Ismael (2020) used other temperatures to conduct wheel tracking at a temperature of 45 ˚C. The inclusion of 0.5%, 1%, and 1.5% steel fibers resulted in reductions in rut depth of 31.15%, 65.57%, and 49.18%, respectively, at a temperature of 45 ˚C. Similarly, adding 0.5%, 1%, and 1.5% steel fibers at 45 ˚C resulted in reductions in rut depth of 16.44%, 60.27%, and 34.25%, respectively [10].

Al-Saad & Ismael used two types of temperatures where the depth of the rut decreased. Rose, as the content of CF increased. Even when the temperature varied at 50°C, the asphalt combination achieved optimal high-temperature performance while mixed with CF contents of 0.75%, 1.5%, and 2.25%. As a result, the rutting depth decreased by 11.76%, 22.05%, and 33.82%, respectively, at a temperature of 60 °C [30]. Previous research has not examined asphalt mixtures strengthened with waste steel and processed recycled concrete aggregate; the treatment process has not been shown to improve their resistance to rutting. The purpose of this study was to prove that RCA weakens the asphalt mixture, so it must be reinforced.

The study will examine reinforced asphalt mixtures enhanced using recycled concrete aggregates. The study aimed to evaluate the vulnerability of rutting to the mixture that included different quantities of waste steel as reinforcement and treated RCA in place of some coarse aggregate particles.

## 2. Materials

### 2.1. Asphalt

Neat asphalt cement, with a 40-50 penetration grade, is used to construct pavements in Iraq. The Durrah refinery supplied it. Table 1 lists the physical characteristics of AC [35].

**Table 1. Asphalt physical characteristics**

| Testing | Units | Result | Specification Limits for SCRB 2003 | ASTM Specification No |
|---|---|---|---|---|
| Penetration (25℃ ,100 gm, 5 Sec) | 1/10 mm | 46 | 40-50 | D5 |
| Ductility (25 °C, 5 cm/min) | cm | 156 | ≥ 100 | D113 |
| Kinematic Viscosity at 135 °C | cSt | 405 | – | D2170 |
| Softening point (Ring & Ball) | °C | 52 | – | D36 |
| Flashpoint (Cleveland Open Cup) | °C | 233 | 232 Min | D92 |
| Specific gravity at 25 °C | °C | 1.02 | – | D70 |
| **After Thin-Film Oven Test ASTM, D1754** | | | | |
| Retained penetration of original | % | 77 | 55 (Min) | D5 |
| Ductility, [25℃, 5 cm/min] | cm | 85 | >25 | D113 |

## 2.2. Aggregates

Crushed fine and coarse aggregates came from the quarry in Al-Obaidi. The laboratory assessment determined the essential characteristics of the aggregate. The results of the trials were obtained based on SCRB 2003 specifications. Table 2 exhibits the coarse and fine aggregate's physical attributes. Figure 1 displays aggregate gradation.

**Table 2. Physical characteristics of the fine and coarse aggregate**

| Testing | ASTM Specification No. | Result | SCRB Specification Limits |
|---|---|---|---|
| **Virgin Coarse** | | | |
| Bulk Specific Gravity, | C -127 | 2.579 | – |
| Apparent Specific Gravity, | C -127 | 2.601 | – |
| Percent of Water Absorption, | C -127 | 0.54 | – |
| (Loss Angeles' abrasion), | C -131 | 15.79 | 30 |
| **Virgin Fine** | | | |
| Bulk Specific Gravity | C -128 | 2.61 | – |
| Apparent Specific Gravity | C -128 | 2.632 | – |
| % Water Absorption | C -128 | 0.952 | – |

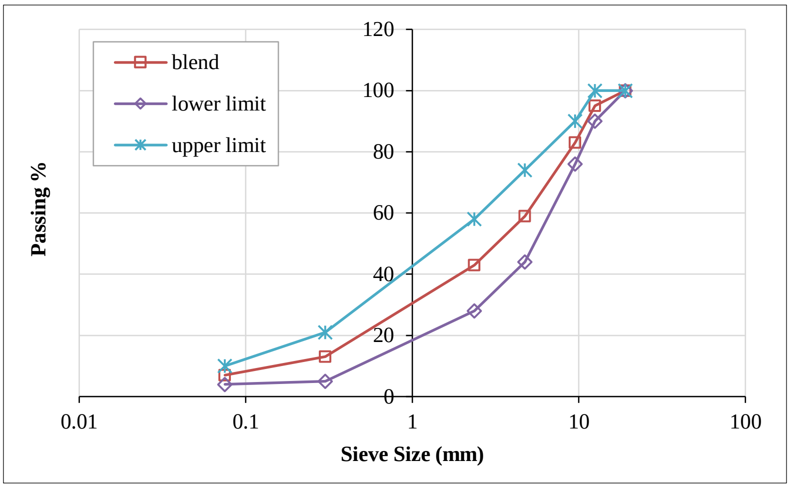



**Figure 1. Design aggregate gradation**

## 2.3. Filler

In this study, the mixtures were prepared using ordinary Portland cement. The filler was from a lime plant in the Saydih area - Iraq. Table 3 displays the physical characteristics of the filler.

**Table 3. Filler physical characteristics**

| Test | The result | SCRB 2003 Limits |
|---|---|---|
| % passing (No 30) | 100 | 10 |
| % passing (No 50) | 100 | 95-100 |
| % passing (No. 200) | 96 | 70-100 |
| Bulk Specific Gravity | 3.14 | --- |

## 2.4. Recycled Concrete Aggregates

Crushed Building debris was crushed to obtain aggregate size diverse from 19 to 4.75 mm to achieve sustainability. The RCA was, after that, subjected to sieving and partitioned into the desired coarse gradation by SCRB 2003 Iraqi specifications wearing coarse. The end product was immersed in a diluted HCL solution (37%) with a concentration of 0.1 moles for 24 hours. It was done to treat the weak cement mortar in RCA and make this layer thinner. Then, filtered water was used to submerge the RCA for a full day. After that, it had a full day-24 hours to dry. The samples were left to dry for a full day (24 h.). Next, treatments followed the customary mixing and compacting procedure. Adhered mortar affects RCA's properties, so the aggregate source (asphalt concrete plant) must be known. The aggregate is subjected to drying, stirring, and heating, which removes a substantial quantity of attached mortar and modifies its characteristics. Also, fine sand mixed with cracked cement mortar makes the mix less strong, so removing it through mechanical treatment is necessary. Figure 2 displays the experimental test combination and research organization needed to accomplish the study's stated goal in a flow chart.

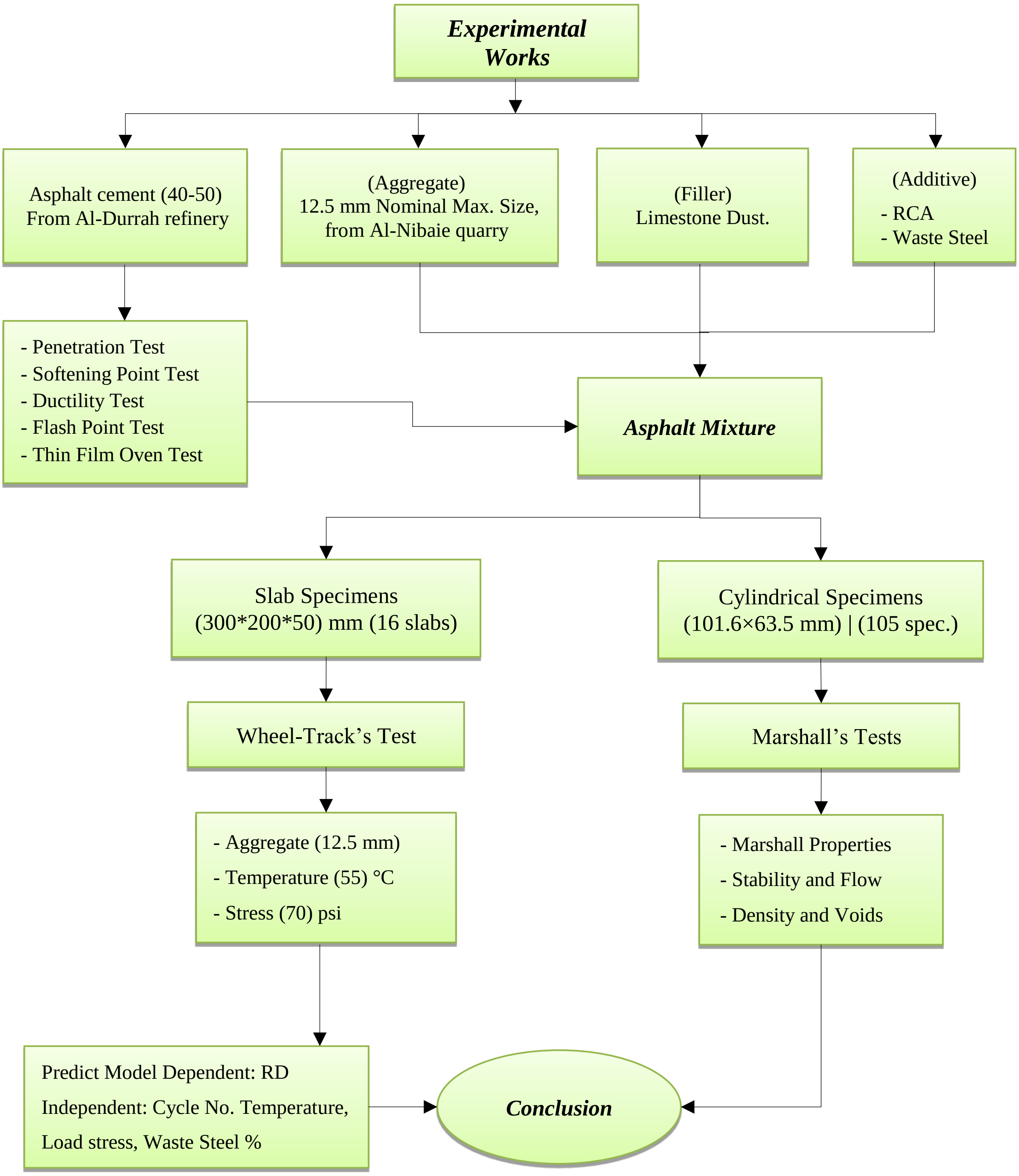
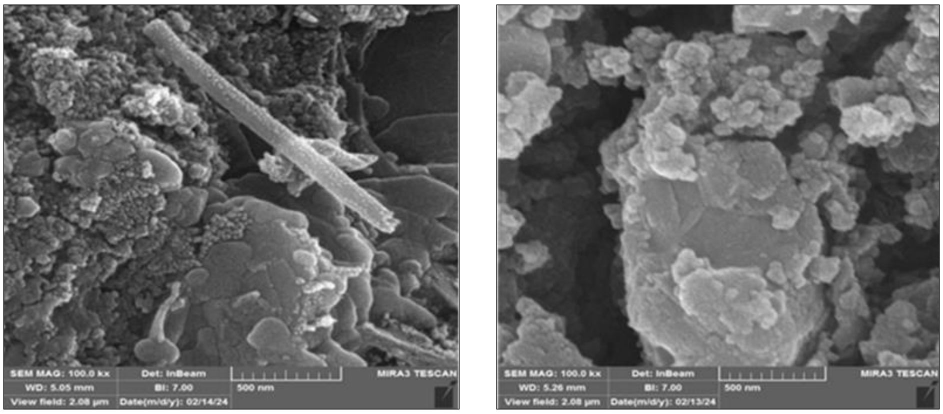



**Figure 2. Research methodology flowchart**

## 2.5. A Microscopic-Level Analysis

Scanning electron microscopy (SEM) technology was used to ascertain the influence of treatment on RCA. Figure 3 displays SEM images for treated and untreated RCA. As seen in Figure 4, the acid treatment action caused roughness to be extensively removed from the RCA surface. To increase the mixture's resilience against rutting. The acetic acid solution visibly eroded the surface and dissolved the attached mortar, decreasing the surface angle. The interior pores of the RCA are more evident after cleaning the surface with an acidic solution and removing all loose cementitious materials. Table 4 demonstrates the physical properties of RCA.



(a) Untreated (b)Treated

**Figure 3. Morphological features of RCA**

**Figure 4. Waste Concrete and RCA particles**

**Table 4. The RCA Physical properties**

| Test | Method of test | Result treated RCA |
|---|---|---|
| Bulk Specific Gravity, | ASTM, C127 | 2.41 |
| (%) Water Absorption | ASTM, C127 | 3.84 |

## 2.6. Waste Steel

Using waste steel improves the asphalt mixture's resistance to permanent deformation. Guo [36] used steel fiber to enhance asphalt concrete's mechanical qualities. The iron lathe was visited to pursue this objective, and waste steel was taken as piles. It was precisely trimmed using scissors to a length of around 1 cm (nearly) without processing. The dry process (waste steel combined with dry total aggregate) was chosen for blending. Figure 5 shows the place and form of waste steel used in this work.

**Figure 5. The source and form of waste steel**

## 3. Procedure for Experiments

The exploratory study utilized the Marshall mix design methodology for the wearing course Type IIIA to find the ideal asphalt content [9, 37]. Also, wheel-tracking testing was conducted to evaluate the vulnerability to rutting.

### 3.1. Marshall Test

As per ASTM D6927, the Marshall mix design approach involved experimenting with a mixture containing treated RCA at different proportions: 0, 25, 50, and 75%. The SCRB R/9 2003 Iraqi standard specifies using asphalt with a content ranging from 4% to 6%, up by 0.5%. Three cylindrical samples with a diameter of (101.6) mm and a height of (63.5) mm were formed, and the asphalt cement was compressed to 75 blows on each face for every percentage. The specimens weighed 1200 gm. Next, bulk-specific gravity (ASTM D2726) and resistance to plastic flow (ASTM D6927) were found. Figure 6 displays the Marshall specimens and test runs.

**Figure 6. Marshall specimens and test runs**

### 3.2. The Wheel Tracking Test

Thirteen slabs, 30×40×5 cm, using a device for compacting that met EN 12697-33 specifications, are prepared. This device predicts the field's depth of ruts and (DS) for certain ventures. It involves the application of consecutive weights over a specimen via a moving wheel. The compactor is capable of precise loads to lose asphalt mixes to manufacture slabs with the desired thickness or density. This test quantifies the rut depth of rectangular slabs under a stress of 70 psi. The test is conducted at 55˚C for 10,000 cycles (the equivalent to 20,000 passes); Figures 7 and 8 depict the wheel-tracking machine utilized in this research, while Figure 9 displays some of the wheel-tracking specimens.

**Figure 7. Wheel tracking device [38]**

**Figure 8. Wheel tracking test**

**Figure 9. Some of the wheel-tracking specimens**

## 4. Results and Discussion

### 4.1. Volumetric Properties and Optimum Asphalt Contents

Table 5 summarizes the Marshall test results obtained for mixtures incorporating varying percentages of RCA in addition to the control mix. The optimal binder content was selected for compacted specimens with 4% air voids, as specified in the Asphalt Institute MS-2 (2014). The increase in binder concentration is mostly due to the frail cement mortar on the RCA surface absorbing asphalt through its pores. The highest increase was observed when 75% of coarse RCA was added, which was 7.74% on the control mixture.

**Table 5. The results of the Marshall test**

| Treatment | RCA (%) | O.A.C (%) | Stability (kN) | Flow (mm) | Bulk density (gm/cm$^3$) | VMA (%) | VFA (%) | VTM (%) |
|---|---|---|---|---|---|---|---|---|
| C | 0 | 4.91 | 9.34 | 2.63 | 2.332 | 15.10 | 73.51 | 4.0 |
| PTRCA | 25 | 5.00 | 10.03 | 2.85 | 2.322 | 14.17 | 71.77 | 4.0 |
| PTRCA | 50 | 5.21 | 10.49 | 3.38 | 2.316 | 13.91 | 71.24 | 4.0 |
| PTRCA | 75 | 5.29 | 11.70 | 3.74 | 2.314 | 13.72 | 70.85 | 4.0 |
| SCRB Limits | | (4-6) | (8) Min | (2-4) | – | (14) Min | – | (3-5) |

All RCA samples treated met the lower stability limit required by the SCRB. According to earlier research [33, 39]. The specimen was more stable because the recycled aggregate's uneven outer layer improved the adhesion and bond between the aggregates and binder.

Compared to the control mixture, these mixtures showed more stability. The largest increase in strength was observed at 75% RCA, which was 25.27% over the control mixture. The reason could be that the irregular faces of the RCA increased the bonding between the binder and the aggregate. We also note that treatment with HCL increased the stability of the mixture containing RCA. All plastic flow values rise when RCA increases, but they satisfy the SCRB's requirement. It increased to the highest value in the mixture containing treated RCA by 75%, where the percentage of increase reached 42.21%. All mixtures that contained recycled concrete aggregate saw a decrease in bulk density. The decrease reached 0.77% in the 75% ratio of treated RCA. It resulted from the cement mortar's adherence to the aggregate. It was compared to the control mixtures; the proportion of V.F.A was reduced in the RCA combinations. The specimens with 75% RCA by coarse aggregate weight had a reduced V.F.A. than the control mixture by 3.62%. The rough surface of the RCA particulates is the cause of it.

### 4.2. The Reinforced Mixture Properties

Roughly the same length of 1 cm was kept up, and different proportions of waste steel (0, 0.3, 0.6, and 0.9% of all of the weight of the mixture) were added to aggregate containing RCA with a proportion of 0, 25, 50, and 75%. They were combined using a dry method. Three cylindrical samples were made and tested for each proportion of 101.6×63.5 mm. The test result in Table 6 demonstrates Marshall's test outcomes and displays that the results comply with the SCRB.

Regarding Marshall's stability, all mixtures exhibited superior strength over the control mixture. The most significant increase occurred when 0.9% waste steel was added to the mixes comprising 75% coarse recycled concrete aggregates, resulting in a 45.18% higher value than the control mixture. Marshall's flow values also decreased due to recycled concrete aggregate, and the maximum decrease was in mixtures containing RCA by 75% and 0.3% waste steel, with a percentage of 8.75%. The VMA decreased, perhaps due to a decrease in bulk density. The mixture that contained 75% RCA and 0.9% waste steel demonstrated the greatest decrease in VMA, with a 4.64% improvement compared to the control mix.

**Table 6. Results of the Marshall test reinforced mixes**

| Mixture | Waste Steel% | Bulk density gm/cm$^3$ | Stability/kN | Flow/ mm | VTM % | VMA % | VFA % |
|---|---|---|---|---|---|---|---|
| Conventional | ------ | 2.332 | 9.34 | 2.63 | 4.0 | 15.10 | 73.51 |
| RCA25 | 0.3 | 2.291 | 10.64 | 2.60 | 4.0 | 14.61 | 72.62 |
| | 0.6 | 2.310 | 12.22 | 2.56 | 4.0 | 14.60 | 72.60 |
| | 0.9 | 2.322 | 13.19 | 2.59 | 4.0 | 14.56 | 72.53 |
| RCA50 | 0.3 | 2.318 | 11.34 | 2.54 | 4.0 | 14.55 | 72.52 |
| | 0.6 | 2.298 | 12.48 | 2.53 | 4.0 | 14.57 | 72.55 |
| | 0.9 | 2.309 | 13.31 | 2.57 | 4.0 | 14.43 | 72.27 |
| RCA75 | 0.3 | 2.316 | 11.74 | 2.40 | 4.0 | 14.53 | 72.47 |
| | 0.6 | 2.289 | 12.86 | 2.49 | 4.0 | 14.52 | 72.45 |
| | 0.9 | 2.295 | 13.56 | 2.44 | 4.0 | 14.40 | 72.22 |
| SCRB Limits | – | – | (8) Min | (2-4) | (3-5) | (14) Min | – |

## 4.3. The Results of the Wheel Tracking Test

13 slabs, 30×40×5 cm at 55°C, were made and tested by applying a force of 700 N to a moving wheel for 10,000 revolutions. Figures 10 to 12 showcase the extent of rut depth for each mixture via 10,000 cycles. All recycled concrete aggregate combinations had deeper ruts than the control mix. The substantial quantity of mortar applied to the RCA's surface explains this. This mortar is more prone to brittleness when subjected to various treatments and the compaction caused by wheel loads. So, the RCA particles and the asphalt binder do not stick together as well, and they do not work well together, so the resistance to rutting goes down. However, waste steel reinforced these mixes, as reduced rut depth shows. The result of the rutting depth for the mixture contains different percentages of treated RCA and waste steel. The decrease was 6.95, 16.22, and 22.86% for mixtures containing treated RCA 25% with waste steel contents of 0.3, 0.6, and 0.9%, respectively. The decrease was 8.07, 14.94, and 25.01% for mixtures containing treated RCA 50% with waste steel contents of 0.3, 0.6, and 0.9%, respectively. The decrease was 8.39, 13.50, and 20.01% for mixtures containing treated RCA 75% with waste steel contents of 0.3, 0.6, and 0.9%, respectively. Noted the minimum rut depth in combination that included 50% RCA reinforced with 0.9% waste steel, which decreased by 25.01% over the conventional mix (Table 7).

**Table 7. Rutting depth results (mm)**

| Waste Steel | conventional | RCA25 | RCA50 | RCA75 |
|---|---|---|---|---|
| 0 | 12.51 | 12.99 | 13.71 | 13.96 |
| 0.3 | – | 11.64 | 11.5 | 11.46 |
| 0.6 | – | 10.48 | 10.64 | 10.82 |
| 0.9 | – | 9.65 | 9.38 | 9.93 |

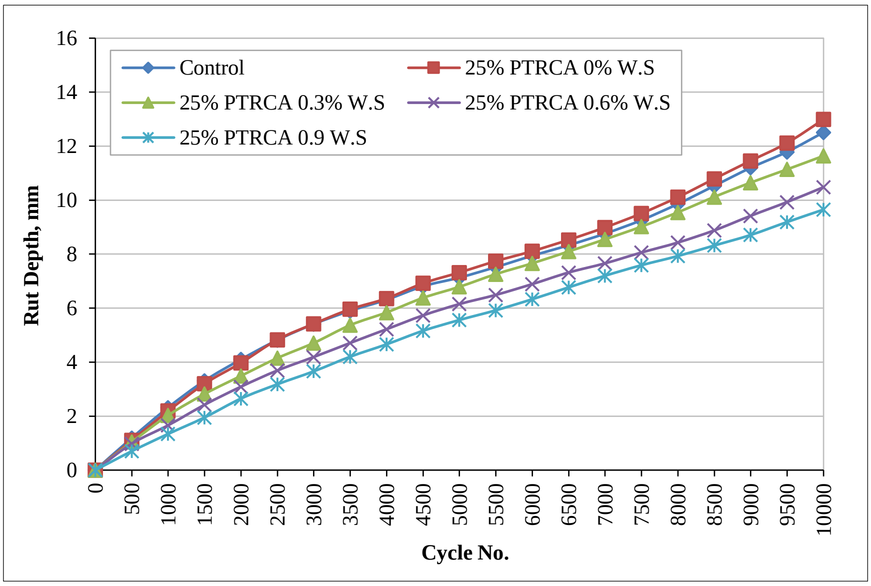



**Figure 10. Rut depth of RCA25**

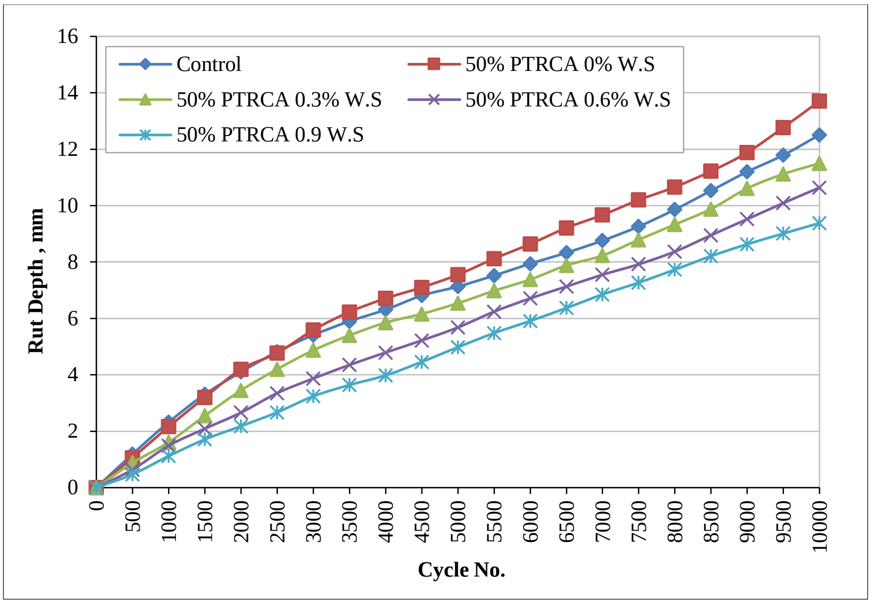



**Figure 11. Rut depth of RCA50**

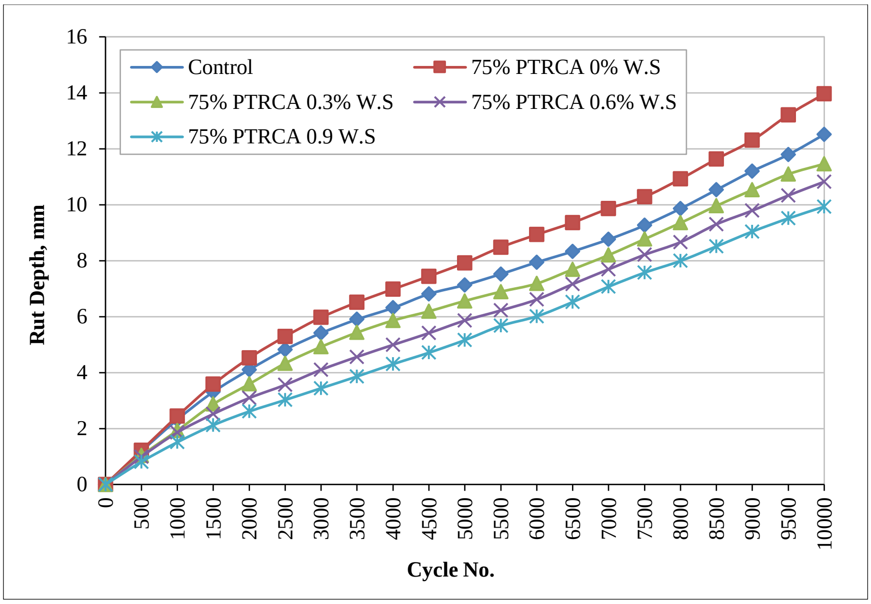



**Figure 12. Rut depth of RCA75**

## 4.4. Dynamic Stability

***Dynamic Stability (DS):*** The rutting behavior patterns of asphalt mixes were analyzed by quantifying the number of cycles that lead to a 1mm permanent deformation during the last 15 minutes of a one-hour wheel tracking test [40, 41]. This paper carried out a long trial phase; therefore, it Used Equation 1 to compute the dynamic stability [42, 43].

$$Dynamic\ Stability(cycle/mm) = (10000 - 7500)/(R10000 - R7500) \tag{1}$$

where R10000 is Rut depth at 10000 Cyc. (mm), R7500 is Rut depth at 7500 Cyc. (mm).

Table 8 and Figures 13 to 15 show the dynamic stability of all mixtures. Each reinforced mixture documented greater (DS) than the conventional mix. The mixtures have a treated RCA of 25% and waste steel reinforcement of 0.3, 0.6, and 0.9%; the increases were 1.24, 1.34, and 1.57 times, respectively. The mixtures have a treated RCA of 50% and waste steel reinforcement of 0.3, 0.6, and 0.9%; the increases were 1.19, 1.19, and 1.53 times, respectively. The mixtures have a treated RCA of 75% and waste steel reinforcement of 0.3, 0.6, and 0.9%; the increases were 1.20, 1.24, and 1.37 times, respectively. From the above, it was found that the highest dynamic stability was in the mixture containing treated RCA 25% and reinforced with 0.9% waste steel; this was 1.57 times larger than the conventional mixture.

**Table 8. The Dynamic Stability**

| Waste Steel | Conventional | 25% RCA | 50% RCA | 75% RCA |
|---|---|---|---|---|
| 0.00% | 770 | 719 | 713 | 680 |
| 0.3% | - | 955 | 923 | 930 |
| 0.6% | - | 1034 | 920 | 958 |
| 0.9% | - | 1214 | 1185 | 1060 |

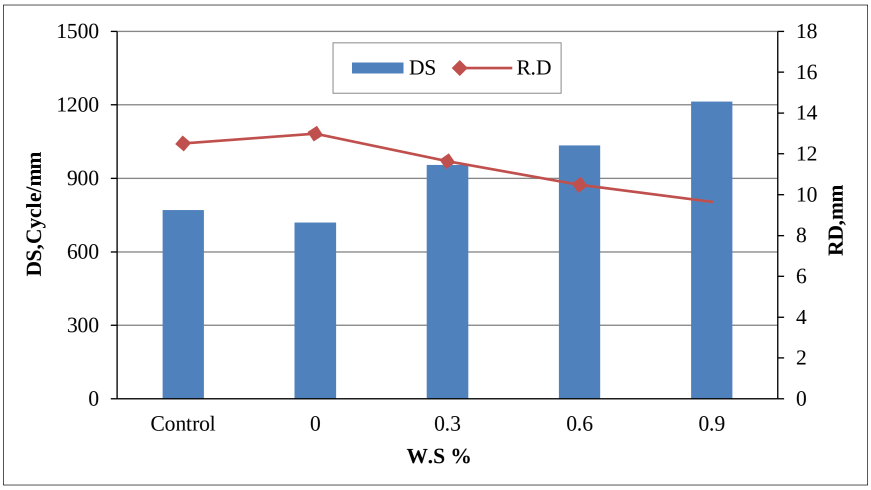



**Figure 13. Dynamic stability of RCA 25%**

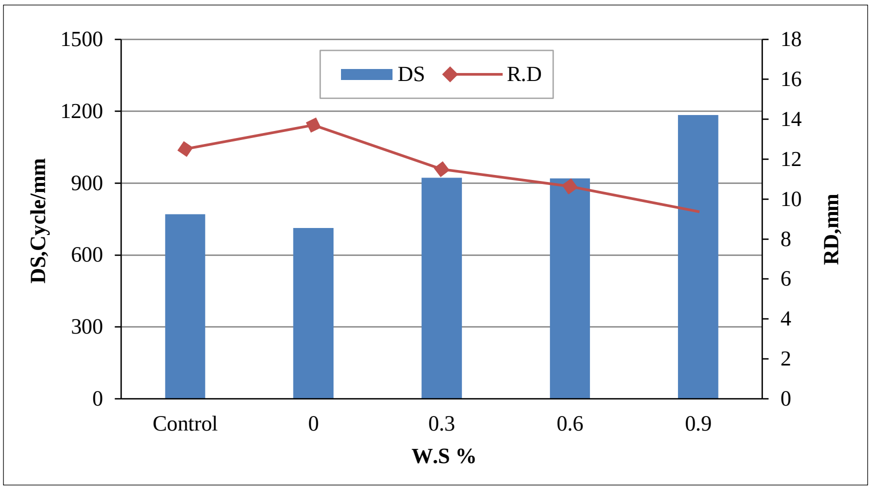



**Figure 14. Dynamic stability of RCA 50%**

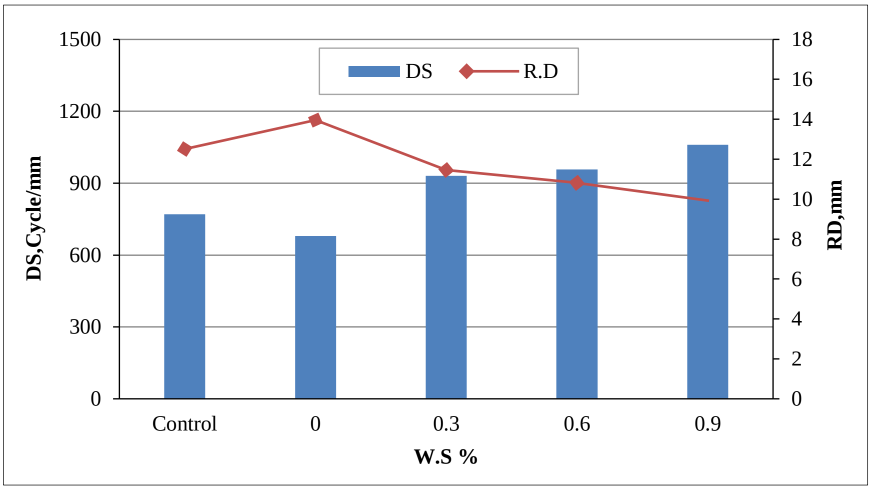



**Figure 15. Dynamic stability of RCA 75%**

### 4.5. Statistical Analysis

An assemblage of statistical methods for estimating the functional relations between two or more different factors for changes to one of the variables to be anticipated or known According to how it would impact the other variables is Regression analysis. The SPSS program is among the most widely used computer applications in statistical analysis. The computer program was used to create the model in V26 of the statistical package for the Social Sciences (SPSS). This study's three independent variables influenced the rutting depth: cycle length, waste steel, and % RCA. Applying SPSS software, a multiple linear equation, represented by Equation 2, forecasted the rutting depth.

$$RD = 1.894 + 0.001 \times Cycle\ length - 227.101 \times WS + 0.114 \times RCA \tag{2}$$

where Cycle length is 500 to 10000, RCA is (0, 25, 50, and 75), WS is (0, 0.3, 0.6, and 0.9).

The $R^2$ coefficient of determination, which was 0.980, demonstrated a strong association with the expected model

## 5. Conclusions

- The optimal asphalt content increased when RCA was substituted with virgin aggregates. The mixture experienced a 7.74% rise when 75% of the coarse recycled concrete aggregates were used instead of virgin material because the cement mortar adheres to the aggregates and absorbs a portion of the asphalt binders.
- Marshall's stability increased by 25.27% when adding 75% coarse RCA rather than virgin aggregates.
- The bulk density decreases progressively when the percentage of recycled concrete aggregates in the asphalt mixture increases. The smallest bulk density value was observed when RCA formed 75% of the asphalt mix; this time, the bulk density was 0.77% lower than the reference mixture.
- Including recycled concrete aggregates and waste steel did not substantially impact the volumetric properties since every various mixture complied with the SCRB 2003 requirements. The mixture has 75% RCA and is reinforced with 0.9% waste steel, which had the greatest improvement in Marshall stability, which was 45.18% over the conventional mix. A mixture of 50% RCA and 0.9% waste steel showed the maximum progress in resistance to permanent deformation, with a 25.01% increase compared to the conventional mix.
- Compared to the conventional mixture, all mixtures, including different percentages of RCA, displayed worse dynamic stability. However, the wheel tracking test findings indicated that the reinforced asphalt mixtures incorporating waste steel and recycled concrete particles exhibited greater dynamic stability than the traditional mix. The maximum increase happened when 25% of coarse RCA was reinforced by 0.9% waste steel, 1.57% over the control mixture.
- Considering these outcomes collectively, it can be concluded that the greatest results were obtained at a 0.9% additive rate when using waste steel and 50% RCA to enhance asphalt concrete against permanent deformation.

## 6. Declarations

### 6.1. Author Contributions

G.M.H. and M.Q.I. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

### 6.2. Data Availability Statement

The data presented in this study are available in the article.

### 6.3. Funding

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### 6.4. Acknowledgements

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### 6.5. Conflicts of Interest

The authors declare no conflict of interest.

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