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Rutting performance of asphalt mixtures containing treated RCA and reinforced by carbon fibers

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Abstract— This study examined the rutting performance of hot asphalt mixtures containing treated RCA and reinforced by carbon fibers. The methodology involved substituting RCA instead of coarse virgin aggregates in the several percentages (20, 40, 60, 80, and 100%) that were treated by being submerged for 24 hours in an acetic acid solution with a concentration of 0.1M. Carbon fibers were added in several percentages of 0.15, 0.25, and 0.35% by the entire weight of the mix to produce cylindrical specimens (4×2.5 inches) for evaluating the Marshall and volumetric properties, and rectangular slabs (30×40×5 cm) for evaluating rutting resistance. The study finds, that incorporating RCA and carbon fibers did not substantially affect the volumetric characteristics of asphalt mixtures, but Marshall's stability increased. The combination containing 60% RCA and 0.35% carbon fibers showed the greatest increase in Marshall stability, which was 35.81% over the control mixture. The addition of RCA led to a reduction in the rutting performance, whereas the addition of carbon fibers increased it, as seen by a decrease in rutting depth. The combination incorporating 40% RCA and 0.35% carbon fibers exhibited a minimum rutting depth of 40.64% lower than the control mixture. The combination incorporating 20% RCA and 0.35% carbon fibers exhibited the maximum level of dynamic stability, which was 1.64 times greater than the control mixture.

Keywords: hot asphalt mixtures, carbon fibers, RCA, rutting, wheel tracking test.

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I. INTRODUCTION

Asphalt pavement materials experts have been concerned about distress issues since the commencement of asphalt use [1], [2]. Including all defined distresses detected in asphalt pavement, permanent deformation, represented by its most destructive variant of rutting, stands out as a significant challenge for construction experts [3]. In Iraq, rutting in asphalt pavement has expanded due to the high truck axle loads, tire pressure, and high-temperature summer [4]. The rutting results in a heterogeneity of road levels due to vertical plastic deformation, leading to difficulty maneuvering and rainwater collecting in the groove [5]. These are considered contributing factors to the emergence of accidents [6], [7]. It also increases maintenance and rehabilitation costs for affected areas [8]. Asphalt mixtures consist of aggregate and asphalt cement. The aggregate skeleton's function is to resist traffic loads, while asphalt cement is an adhesive material that keeps the aggregate skeleton together [9]. Asphalt cement behaves visco-elastic / visco-plastic in response to temperature and applied loads [10]. These components have the most significant impact on rutting that results from shear failure. The binder characteristics affect asphalt pavement resistance to rutting by about 40% [11]. An internal friction angle of aggregate contributes 80% of the shear resistance [12].

The demolition and reconstruction of old facilities lead to an increase in construction waste, which accumulates in large quantities and must be discarded in a large landfill since it can be recycled and disposed of [13], [14]. It is regarded as one of the most essential factors that are hazardous to environmental life [15], [16]. Construction waste incorporates a variety of components, but Portland cement concrete pieces are among the most important elements [17]. Recycling concrete aggregate would minimize landfill area and prevent soil and plants from deteriorating when used in asphaltic concrete mixtures instead of virgin aggregate [18], [19].

The use of construction waste in asphalt mixtures especially recycled concrete aggregate has received great attention from researchers applying the environmental sustainability approach [20]. The weak cement mortar's adhesion to the aggregate results in poor performance under stresses, particularly crushing and corrosion, as well as significant water absorption [21]. Because of this, the asphalt mixtures must be strengthened in order to survive and resist the applied load throughout the operational years [22].

Researchers and road material engineers have been particularly interested in sustainable asphalt mixtures. For a long time, and still ongoing, studies have been concerned with the use of recycled concrete aggregates in asphalt mixtures. Some researchers present the advantage of replacing parts of virgin coarse aggregates with recycled concrete aggregates.

Shaopeng et al. [23] evaluate two classes of asphalt mixtures, the first containing various portions of coarse recycled concrete aggregate and the other containing various portions of fine recycled concrete aggregate. They found that the addition of coarse recycled concrete aggregates enhanced rutting performance, while the mixtures containing fine recycled concrete aggregates behaved the opposite. Gul and Guler [24] evaluate the two grades of aggregate's standard limit (upper and lower limit grades). The portion of replacement was 25, 50, and 75% of total aggregates. They recorded a decrease in rutting depth for mixtures containing lower grades, while the opposite happened in upper grades, but the two grades demonstrated lower rutting resistance than the control mixture. Fatemi and Imaninasab [25] evaluate the asphalt mixtures containing 10, 20, 30, and 40% waste demolition aggregates replaced with total virgin aggregate. The result of the study was that there is a feasibility of using waste demolition aggregates in asphalt mixtures; all mixtures recorded a lower rutting depth than the control mixture, and the mixture containing 30% waste demolition aggregates recorded the lowest rutting depth. They provided an explanation for the increase caused by a rise in the aggregate's internal friction angle. Radević et al. [26] studied the possibility of utilizing recycled concrete aggregates in asphalt mixtures; various proportions of recycled concrete aggregate (15, 30, and 45%) were replaced with virgin aggregate in three mixture types. Coarse aggregates were replaced in the first type. Fine aggregates were replaced in the second type. Both fine and coarse were replaced in the last type. They showed an increase in rutting performance in mixtures containing coarse recycled concrete aggregates, with the mixtures containing 30% reaching the maximum. There were similarities in results between mixtures containing coarse recycled concrete aggregates and mixtures containing fine recycled concrete aggregates, while the mixtures containing both fine and coarse particles demonstrated little increase in rutting performance.

Asphalt mixture efficiency against rutting resistance was studied by Nwakaire et al. [27]. The study included replacing 20, 40, 60, 80, and 100% of virgin coarse with recycled concrete aggregates. This study summarized that the mixtures containing 20% recycled concrete aggregates demonstrate the highest permanent deformation resistance, while the mixtures containing 40 to 100% recycled concrete aggregates demonstrate a gradual decrease in permanent deformation resistance.

Other studies have also cautioned against the excessive use of recycled concrete aggregates in asphalt mixtures due to the harm done to the mixtures' performance and decreased durability. Mills -Beale and You [28] studied the asphalt mixtures for rutting responsiveness when replacing the coarse virgin aggregates with recycled concrete aggregates in various percentages of 25, 50, 65, and 75%. The study demonstrated that the addition of recycled concrete aggregates led to an increase in rutting depth over the control mixture, which was 8.1, 37, and 76% for mixtures containing 25- 50, 50-65, and 65-75% recycled concrete aggregates, respectively. Bhusal et al. [29] investigate the rutting performance of asphalt mixtures containing 20, 40, 60, 80, and 100% of coarse recycled concrete aggregates. The study summarized that the addition of recycled concrete aggregate led to a reduction in permanent deformation resistance due to the additional amounts of asphalt binder that had been absorbed by cement mortar pores, which played a negative role in high temperatures. Motter et al. [30] embedded 25, 50, 75, and 100% of coarse recycled concrete aggregates in asphalt mixtures. They recorded that the asphalt mixtures containing recycled concrete aggregates absorbed more asphalt binder than the control mixture, which led to weaker rutting resistance in these asphalt mixtures.

The cement mortar that attaches to the aggregates is what distinguishes it from virgin aggregate. The quality and characteristics of recycled concrete aggregate change with the amount of mortar present, resulting in poor resistance to load. Therefore, some researchers have applied some techniques to get rid of or reduce this mortar and improve the properties of recycled concrete aggregate. In order to improve the durability of recycled concrete aggregates, a new technique by a coating called double coating was developed by Kareem et al. [31]. The methodology of this technique included two coating layers: the first was to strengthen the weak particles by coating with cement slag paste, while the second layer was to improve absorbability by coating with Sika Tite-BE (reduce asphalt cement absorbed). The study's findings demonstrated that this technique was successful in enhancing the stiffness of asphalt mixtures and their moisture resistance. Al-Bayati and Tighe [32] explored two types of treatment, the first heated the recycled concrete aggregates at 300 C for one hour then treated them for 15 minutes in a Micro-Deval device. The second one immersed the recycled concrete aggregates in Acitic acid with 0.1 M for 24 hours. The two types of treatments applied to two types of recycled concrete aggregates where differ in the source. The heating method was effective with one type of recycled concrete aggregate, where the rutting depth was decreased, but did not produce any benefit with the other type. The method of pre-soaking in Acetic Acid reduced the rutting depth of the two types of recycled concrete aggregates.

Some researchers have found that recycled concrete aggregate treatment techniques have not succeeded in improving resistance to permanent deformation.

Abass and Albayati [33] used two types of treatment to improve recycled concrete aggregates. The first was to treat the recycled concrete aggregate with hydrated lime, the second one was treated with Hydrochloric Acid. The research concluded that with an increase in the amount of recycled concrete aggregate, the permanent deformation of all mixtures containing treated and untreated recycled concrete aggregates increases.

Azarhoosh et al. [34] used plastic bottle debris to coat the recycled aggregate in an effort to improve its properties. The rutting resistance of mixtures containing treated recycled concrete aggregates increased compared to their counterparts containing untreated recycled concrete aggregates, but when compared with a control mixture, this technique did not result in the desired outcome.

The reinforced or strengthened asphalt mixtures containing recycled concrete aggregates, for which the treatment methodology has not been successful in improving rutting performance, have not yet been studied. Therefore, this paper aims to fill this research gap and fix this problem by following the hypothesis: Recycled concrete aggregates have poor performance under repeated loads. In addition to absorbing additional amounts of asphalt cement, it is expected to weaken the asphalt mixture's ability to resist permanent deformation. Therefore, these asphalt mixtures need to be reinforced.

The scope of the study was to assess the rutting susceptibility of asphalt mixtures that substituted a portion of their coarse aggregates with treated recycled concrete aggregates and reinforced these mixtures with varying amounts of carbon fiber.

II. MATERIALS USED

The raw materials used in this work were obtained from various sources, including asphalt cement (40-50) penetration grade, recycled concrete aggregate, virgin aggregate, filler (O.P.C), and carbon fibers as additives.

a. Asphalt Cement

Road paving is often done with A.C. (40-50) penetration grade asphalt, which was supplied by an asphalt plant situated on the borders of Baghdad in the Salman Pak region. The Dourah refinery in Baghdad was the primary source of asphalt cement. Table 1 demonstrates the test results of asphalt cement utilized.

Table 1: Test Results of Asphalt Cement 40-50.

Test	Test Method	Result	SCRB Requirements
Penetration (25˚C ,100gm, 5sec).	AASHTO – T49	43	40-50
Ductility (25˚C, 5cm/min)	AASHTO – T51	167	≥ 100
Flashpoint (Cleveland Open Cup).	AASHTO – T48	>232	232 Min
Specific gravity at 25˚C	ASTM 70	1.02	-
Solubility in Trichloro – Ethylene %.	AASHTO – T44	99.4	>99
Residue From Thin Film Oven Test. -Retained Penetration, % of Original. -Ductility (25˚C, 5cm/min	AASHTO – T179	 77 98	 >55 >25

Source: Own elaboration.

b. Aggregates

The Salman Pak asphalt plant provided virgin crushed aggregate, both coarse and fine. Al-Nebaie quarry was the primary source of these aggregates.

The mid-range of aggregate gradation was adopted according to wearing course type IIIA of the SCRB R/9 2003 Iraqi standard. The maximum aggregate size was 19 mm (12.5 mm nominal size). Figure 1 displays the grain size distribution of total aggregates.

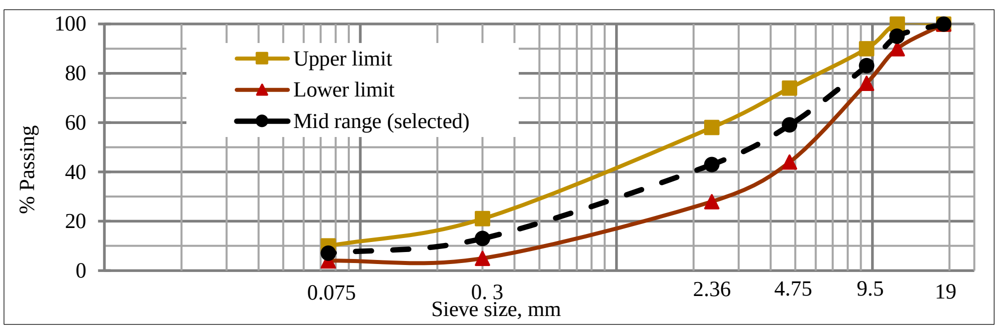

Figure 1: Grain size distribution.
Source: Own elaboration.

c. Recycled concrete aggregates

It was obtained by assembling and crushing the small pieces of a crumbling New Jersey barrier. Then RCA was sieved and separated into the required coarse gradation according to wearing course type IIIA of the SCRB R/9 2003 Iraqi standard. A treatment process was carried out to get rid of the adhered mortar that cracked and weakened during crushing. The process included immersing the recycled concrete aggregates for 24 hours in acetic acid at a concentration of 0.1 M. Then, it was drained and immersed in distilled water for 24 hours. After that, it was dried and placed inside the Los Angeles machine without the balls for 3 minutes (100 cycles) to remove the poorly adhered mortar that resulted from soaking. Table 2 displays the physical properties of virgin and recycled concrete aggregates.

Table 2: Physical properties of virgin and recycled concrete aggregates.

Test	Test Method	Result			SCRB Requirements
		Coarse RCA	Virgin Coarse Agg.	Virgin Fine Agg.	
Bulk Specific Gravity.	ASTM C127	2.333	2.55	2.58	-
Water Absorption. [%]	ASTM C127	2.89	0.45	0.83	-
Resistance to Abrasion by Los Angeles Machine. [%]	AASHTO T96	21	13	-	30

Source: Own elaboration.

d. Mineral filler

SCRB R9/ 2003 defined filler as non-plastic materials such as limestone, stone dust, hydrated lime, and Portland cement.

In this study, ordinary Portland cement was utilized. It was brought from the central mixing plant in Saydiah district, south of Baghdad. Table 3 displays the physical properties of mineral filler.

Table 3: Physical properties of mineral Filler.

Test	Result	SCRB Requirement
Sieve Analysis. % passing sieve (No 30). % passing sieve (No 50). % passing sieve (No 200).	 100 100 97	 100 95-100 70-100
Specific gravity	3.14	-

Source: Own elaboration.

e. Carbon fibers

The use of fibers is a common occurrence; fiber-reinforced bitumen was first used in 1950. Carbon fiber is now used as reinforcement in concrete structures in nearly all industrial cities. [35]. Because of their outstanding mechanical properties and high affinity for asphalt, carbon fibers have significant promise for asphalt or mixture modification. Unfortunately, because of a lack of understanding about optimizing carbon fiber length, diameter, and surface roughness, the influence of carbon fibers on mixture performance needs to be thoroughly known. Carbon fiber length is significant in determining performance when utilized in asphalt mixtures, as overly long fibers may create a lump when mixed. In addition, very short fibers have little strengthening effect [36], [37]. Combining carbon fiber with an asphalt mixture also significantly affects fiber distribution and mixing efficiency.

In this work, Wrap C-300, a medium-strength 4000 N/mm2 material with a dry density of 1.82 g/cm3 made of unidirectionally woven carbon fiber, was purchased from a local distributor and employed. It was cut with scissors into a constant length of 20 mm. The dry process (carbon fibers mixed with dry total aggregate) was selected for mixing.

III. EXPERIMENTAL METHODOLOGY

The testing program included the Marshall test for asphalt mix design to identify the optimal asphalt content, and a wheel tracking test was carried out to assess the rutting susceptibility.

a. Marshall test

The standard Marshall design method, according to ASTM D6926, was carried out for a mixture containing recycled concrete aggregates of (20, 40, 60, 80, and 100%). Asphalt contents of 4-6% with an increment of 0.5% were adopted according to wearing course type IIIA of SCRB R/9, 2003. For each percentage of asphalt cement, three (4×2.5-inch) cylindrical specimens weighing 1200 g were manufactured and compacted by 75 blows for each face. Following that, the bulk specific gravity was identified according to ASTM D2726. Resistance to plastic flow was determined according to ASTM D6927.

b. Wheel tracking test

The wheel-tracking apparatus simulated rutting resistance on asphalt mixes by delivering successive loads through a traveling wheel across a specimen. The loose asphalt mixture was compacted using a Dyna compactor that met EN 12697-33 specifications to produce a 30×40×5 cm slab size. The compactor can apply specific loads to compress asphalt slabs to a desired density or thickness. The proper compaction load must be determined through trial and error to achieve the desired thickness. Two trial mixtures weighing 13.95 kg were produced. It was compacted by repeating 50 passes with different loads of 5 and 6 kN, and it was established that the second trial load of 6 kN was adequate for obtaining the desired thickness of 5 cm with 50 passes. Each other combination was compacted using a 6 kN load, 50 passes, and varied weights based on their bulk density as measured by the Marshall test. A Dyna-Track single wheel tracker device that met EN 12697-22 specifications was utilized to assess rutting depth by applying 700±10 N (70 psi) wheel load at a temperature of 55 °C for 10000 cycles (20000 passes) or rut depth reaching 25 mm. Figure 2 displays the compaction and testing of Marshall and slab specimens.

Figure 2: Marshall and slabs compaction and testing.
Source: Own elaboration.

IV. RESULTS AND DISCUSSION

a. Optimum asphalt contents and other properties results

The optimum asphalt content was calculated by the average of three asphalt contents at maximum stability, maximum bulk density, and 4% air voids. Table 4 displays the Marshall test output for mixtures containing recycled concrete aggregates at various percentages. It should be observed that as the percentage of recycled concrete aggregate increased, the optimum asphalt content did too. This could be because cement mortar adheres to aggregates, which absorb some asphalt cement through their pores. The maximum increase occurred when added 100% of coarse recycled concrete aggregates, which was 9.53% over the control mixture.

Regarding Marshall's stability, all these mixes showed more stability than the control mixture. The increase began with a mixture containing 20% recycled concrete aggregates and culminated with 60% recycled concrete aggregates, which was 11.51% over the control mixture. It could be because the recycled aggregates had a more fractured face than virgin aggregate, resulting in a larger contact area. The rise decreased in mixtures containing 80 and 100% recycled concrete aggregates but remained greater than the control mixture. It may be due to the crushing and grinding of some mortar during compaction, which resulted in a loss or reduction of contact surface area.

It was noted that the flow increased when the quantity of recycled concrete aggregates grew.

Compared to the control mixture, the bulk density of all mixtures containing recycled concrete aggregates decreased. It was due to the cement mortar adhering to the aggregate.

Recycled concrete aggregates also played a role in the VMA alteration since all combinations saw an increase in VMA content. This was because recycled concrete aggregates have a rough surface.

It may be noted that all results in Table 4 meet the SCRB R/9 2003 requirements.

Table 4: Marshall test results.

Mixture	O.A.C, %	Stability, kN	Flow, mm	Bulk Density, gm/cm^3	VMA, %	VFA, %	VTM, %
Control	4.93	11.03	3.3	2.325	14.97	74.46	3.82
RCA20	4.98	11.52	3.43	2.307	15.04	73.64	3.97
RCA40	5.02	12.04	3.51	2.289	15.1	73.23	3.95
RCA60	5.13	12.3	3.63	2.274	15.09	73.9	3.94
RCA80	5.23	11.96	3.74	2.259	15.07	73.85	3.94
RCA100	5.4	11.79	3.89	2.246	15.05	73.46	3.99
SCRB 2003 requirements	4-6	8 Min	2-4	-	14 Min	-	3-5

Source: Own elaboration.

b. Reinforced mixture properties

In this work, a constant length of 20 mm was maintained, and several contents 0.15, 0.25, and 0.35% by total weight of mix were added to an entire aggregate containing recycled concrete aggregates with a percentage of 20, 40, 60, 80, and 100%. They were mixed in a dry process. For each percentage, three (4×2.5-inch) cylindrical specimens were manufactured and tested. The results, in Table 5 display Marshall test results.

Table 5: Marshall test results of reinforced mixtures.

Mixture	Carbon Fibers, %	Bulk Density, gm/cm^3	Stability, kN	Flow, mm	VTM, %	VMA, %	VFA, %
Control	-	2.325	11.03	3.3	3.82	14.97	74.46
RCA20	0.15	2.301	12.83	3.19	4.09	15.26	73.2
	0.25	2.298	13.21	3.17	4.22	15.37	72.55
	0.35	2.296	13.77	3.15	4.3	15.44	72.16
RCA40	0.15	2.284	13.79	3.28	4.04	15.3	73.6
	0.25	2.282	14.33	3.19	4.12	15.37	73.2
	0.35	2.279	14.51	3.14	4.25	15.48	72.55
RCA60	0.15	2.269	14.2	3.35	4.15	15.29	72.86
	0.25	2.267	14.7	3.31	4.23	15.36	72.47
	0.35	2.265	14.98	3.27	4.31	15.44	72.09
RCA80	0.15	2.256	13.37	3.37	3.96	15.23	74
	0.25	2.254	14.37	3.32	4.05	15.31	73.55
	0.35	2.253	14.54	3.28	4.09	15.34	73.34
RCA100	0.15	2.241	13.02	3.43	3.95	15.31	74.2
	0.25	2.238	14.1	3.39	4.08	15.42	73.55
	0.35	2.235	14.58	3.35	4.21	15.53	72.9
SCRB 2003 requirements	-	-	8 Min	2-4	3-5	14 Min	-

Source: Own elaboration.

It may be noted that all results in Table 5 meet the SCRB R/9 2003 requirements.

The stability increased for all mixtures containing carbon fibers for all percentages. The greatest increase happened when adding 0.35% carbon fiber to the mixtures containing 60% coarse recycled concrete aggregates, which was 35.81% greater than the control mixture.

The VMA and A.V. increased, possibly as a result of reducing bulk density. The maximum increase in VMA happened in mixtures containing 100% recycled concrete aggregate and 0.35% carbon fibers, which was 3.74% more than the control mixture. The maximum increase in A.V. happened in mixtures containing 60% recycled concrete aggregate and 0.35% carbon fibers, which was 12.82% more than the control mixture.

c. Wheel tracking test results

21 slabs (40×30×5 cm) were manufactured and tested at 55° C using a 700 N moving wheel load for 10000 cycles (20000 passes). Table 6 displays the final rut depth at 10,000 cycles, and Figures 3 to 7 display the rut depth of each mixture through 10,000 cycles length. It is very clear that the addition of recycled concrete aggregates impaired asphalt mixtures' ability to resist permanent deformation; however, carbon fibers strengthened these mixtures, as evidenced by reducing the rut depth. The mixtures containing 40% recycled concrete aggregate reinforced with 0.35% carbon fiber recorded the lowest rut depth, reaching 40.64% less than the control mixture.

Table 6: Rutting depth (mm) results @ 10000 cycles.

Carbon Fiber, %	Control	RCA20	RCA40	RCA60	RCA80	RCA100
0	12.28	13.14	13.64	13.93	14.38	14.94
0.15	-	10.03	10.23	10.17	10.65	11.21
0.25	-	8.81	8.87	8.92	9.35	9.87
0.35	-	7.76	7.29	7.95	8.06	8.37

Source: Own elaboration.

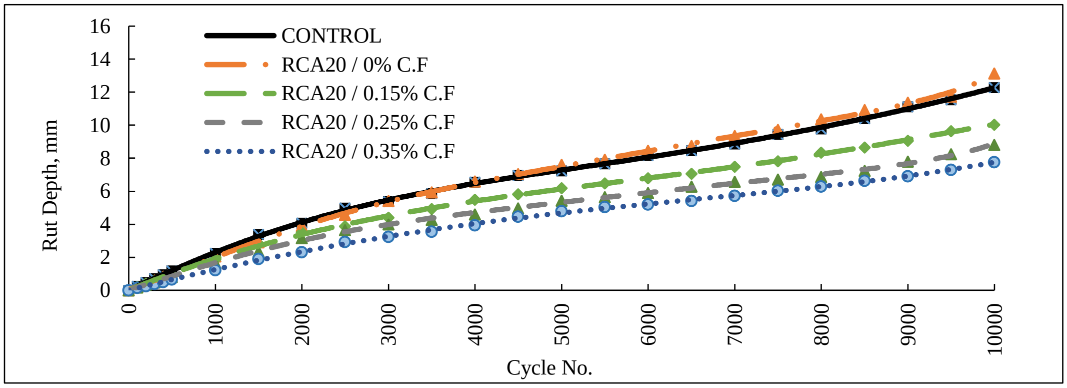

Figure 3: Rut depth of RCA20.
Source: Own elaboration.

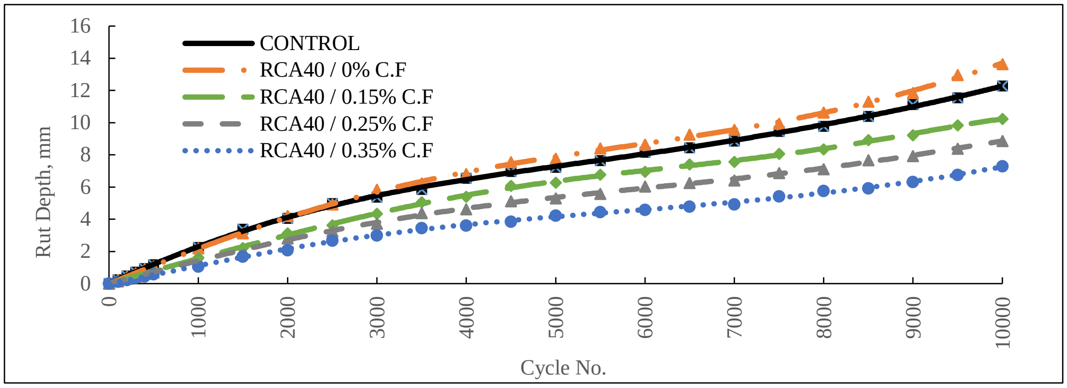

Figure 4: Rut depth of RCA40.
Source: Own elaboration.

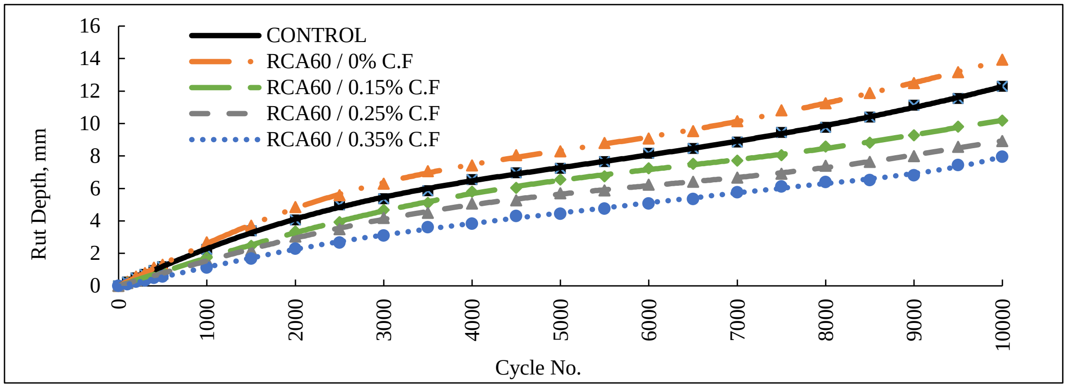

Figure 5: Rut depth of RCA60.
Source: Own elaboration.

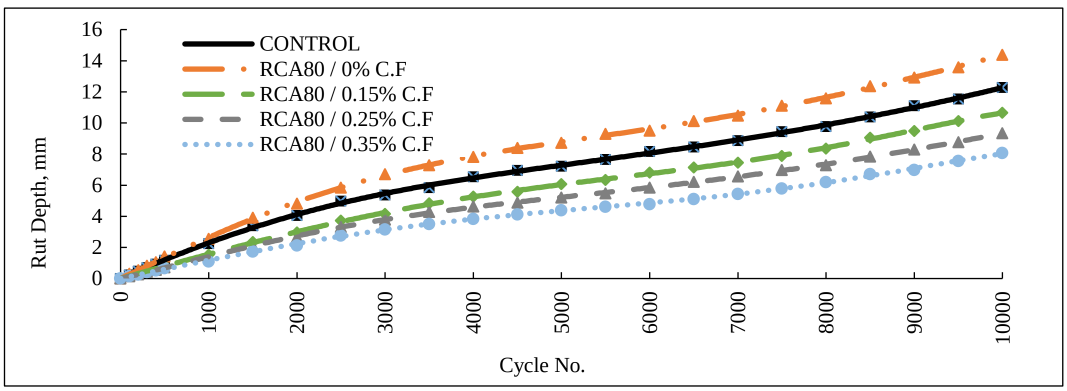

Figure 6: Rut Depth of RCA80.
Source: Own elaboration.

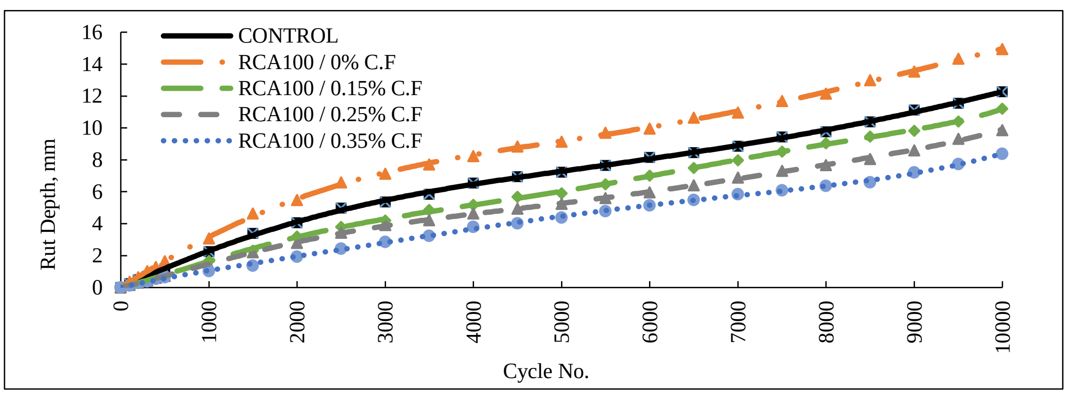

Figure 7: Rut depth of RCA100.
Source: Own elaboration.

d. Dynamic stability

Dynamic stability is a prevalent measure for determining how rutting-prone an asphalt mixture is. It is measured by the number of cycles that cause 1 mm of permanent deformation at the last 25% of the testing time, whose total duration is 1 hour. In this study, a long experiment period was conducted, hence Equation (1) was used to compute the dynamic stability [3].

$$DS = \frac{C_{10000} - C_{7500}}{RD_{10000} - RD_{7500}} \quad (1)$$

Where:
DS =Dynamic Stability (cycle/mm)
C10000 = Cycles 10000
C7500 = Cycles 7500
RD10000= Rut depth at the cycles 10000
RD 7500= Rut depth at the cycles 7500

Table 7, and Figures 8 to 12 demonstrate the dynamic stability of all combinations.

Table 7: Dynamic Stability (Cycle/mm) According to Equation (1).

Carbon Fibers, %	Control	RCA20	RCA40	RCA60	RCA80	RCA100
0.00%	884	729	674	799	767	770
0.15%	-	1127	1158	1180	903	926
0.25%	-	1191	1244	1238	1055	977
0.35%	-	1446	1330	1367	1147	1097

Source: Own elaboration.

It indicates the maximum value occurred in a mixture containing 20% recycled concrete aggregates and reinforced by 0.35% carbon fibers, which was 1.64 times greater than the control mixture.

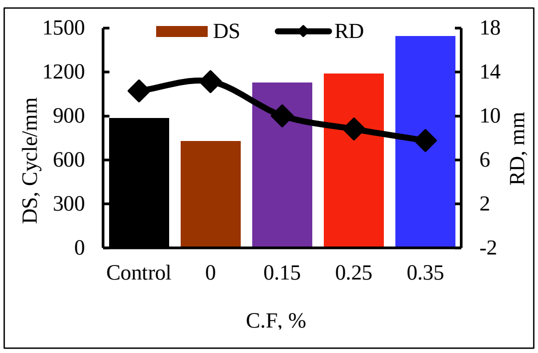

Figure 8: Dynamic stability of RCA20.
Source: Own elaboration.

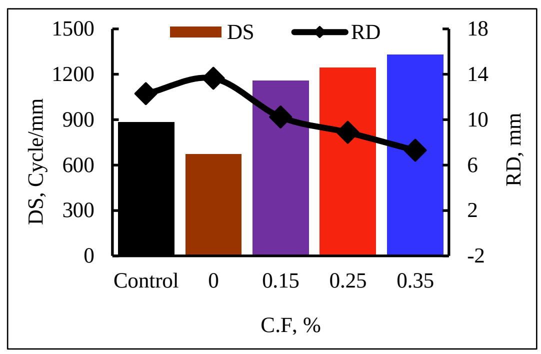

Figure 9: Dynamic stability of RCA40.
Source: Own elaboration.

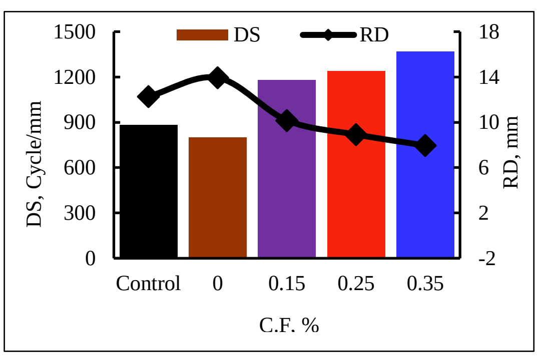

Figure 10: Dynamic stability of RCA60.
Source: Own elaboration.

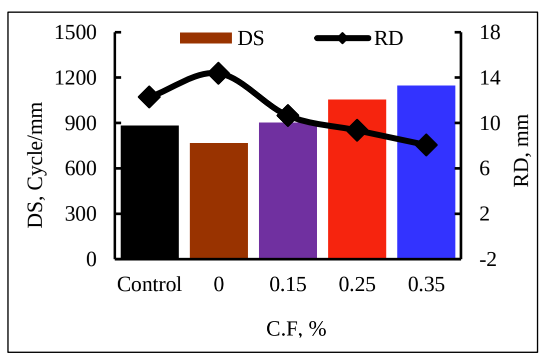

Figure 11: Dynamic stability of RCA80.
Source: Own elaboration.

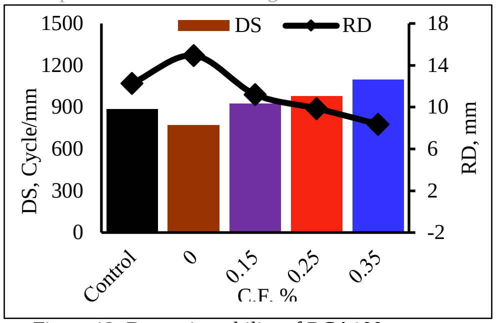

Figure 12: Dynamic stability of RCA100.
Source: Own elaboration.

V. CONCLUSIONS

The following crucial aspects can be added as a summary of this paper dependent on the tests carried out, as well as the properties of the materials utilized that have been highlighted.

1- The asphalt cement content rosed when recycled concrete aggregates were replaced with virgin aggregates. The increase was 9.53% when 100% replaced coarse recycled concrete aggregate instead of virgin material.

2- When the proportion of recycled concrete aggregate in the asphalt mixture increases, the bulk density decreases progressively; the lowest decrease was observed when replacing 100% of the recycled concrete aggregate, where the bulk density was 3.4% lower than the control mixture.

3- Adding recycled concrete aggregate to the asphalt mixtures led to a boost in Marshall stability. The greatest boost was 11.51% when 60% coarse recycled concrete aggregate was used.

4- The addition of recycled concrete aggregates, as well as carbon fiber, did not significantly alter the volumetric properties, as all mixtures met the requirements of the SCRB 2003 Iraqi standard.

5- All combinations with varying percentages of recycled concrete aggregate showed less permanent deformation resistance than the control mixture. The mixture containing 100% recycled concrete aggregates demonstrated the highest rutting depth, which was 21.66% over the control mixture.

6- Generally, the addition of carbon fiber increased Marshall's stability and permanent deformation resistance. The mixture having 60% recycled concrete aggregates and being reinforced with 0.35 % carbon fiber showed the highest increase in Marshall stability strength, which was 35.81% over the control mixture. However, the combinations containing 40% recycled concrete aggregates with the addition of 0.35 % carbon fiber exhibited the greatest increase in resistance to permanent deformation, which was 40.64% over the control mixture.

7- All combinations with varying percentages of recycled concrete aggregate showed less dynamic stability than the control mixture, while the mixtures containing recycled concrete aggregates and reinforced by carbon fiber recorded higher dynamic stability than the control mixtures. The mixture, which incorporates 20% recycled concrete aggregates and is reinforced by 0.35% carbon fiber, recorded the highest value of 1.64 times over the control mixture.

8- Carbon fibers often have a smooth surface, thus adding them to the asphalt mixture eliminates the need for additional asphalt binder.

VI. ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
A.C	Asphalt Cement
ASTM	American Society for Testing and Materials
A.V	Air Voids
C.F	Carbon Fibers
DS	Dynamic Stability
O.P.C	Ordinary Portland Cement
RCA	Recycled Concrete Aggregates
RCA20	Mixture Containing 20% Recycled Concrete Aggregates
RCA40	Mixture Containing 40% Recycled Concrete Aggregates
RCA60	Mixture Containing 60% Recycled Concrete Aggregates
RCA80	Mixture Containing 80% Recycled Concrete Aggregates
RCA100	Mixture Containing 100% Recycled Concrete Aggregates
RD	Rut Depth
SCRB	State Corporation for Roads and Bridges
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate
VTM	Voids in Total Mix

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