American Journal of Engineering Research (AJER) ***2023***
American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-12, Issue-9, pp: 163-174
www.ajer.org
Research Paper Open Access

Investigating the Effect of Using Recycled Concrete Aggregate on the Performance of the Developed Asphalt Pavement Mixtures

Eslam Rafat Saad (1) ,Zeinab Salah Eldeen(2), Abdelzaher E. A. Mostafa(3)
(1)Master Of Engineering Student,, Civil Enginer at Housing, Building National Research Center , Cairo, Egypt.
(2)Prof. of Highways and Airports Engineering at Housing, Building National Research Center, Cairo, Egypt
(3)Prof. of Highways and Airports Engineering, Civil Engineering Department, Faculty of Engineering at Mataria, Helwan University, Cairo, Egypt
Corresponding Author: Eslam Rafat Saad

A B S T R A C T
In hot mix asphalt (HMA), recycled concrete aggregates (RCA) are employed as environmentally friendly substitutes for natural aggregates. Evaluation of utilization of RCA from construction & demolition waste (CDW) in HMA for base courses in pavements had been done in a lab setting. Marshall's mix design process was used in research to create HMA mixes with twenty percent, thirty percent, forty percent, & fifty percent RCA. Mixes' mechanical characteristics, such as stability, resistance to fatigue, permanent deformation, & loss of stability, had been investigated. By EN 12697-12 standards, an indirect tensile strength test was used to assess asphalt mixtures' resilience & durability before & after exposure to water. Experiment's findings demonstrated that stability & percentage of indirect tensile strength ratio (percent) of produced HMA, which uses forty percent recycled concrete aggregates in place of natural aggregate, have been improved.
KEYWORDS: *Recycled concrete aggregates; Construction & demolition waste; Asphalt mix design; Hot mix asphalt; Crushed aggregates; Alternative road construction materials; Modified binder; Modified Control Mix, Mechanical properties; Developed asphalt pavement Mixture, Permenant deformation , Fatigue, Loss of stability.*

Date of Submission: 09-09-2023 Date of acceptance: 22-09-2023

I. INTRODUCTION

The need for natural mineral aggregates in civil engineering has grown significantly, resulting in environmental problems such as resource depletion & landscape deterioration. use of alternative road construction materials, particularly recycled concrete aggregates, has been gaining popularity all over the world as a solution to these issues [1]. Construction debris is used to create RCA, which is then divided into coarse RCA (>4.75 mm) & fine RCA (>4.75mm) [2]. It has the potential to replace natural aggregates in asphalt mixtures, freeing up landfill space & lowering emissions from the processing of natural materials [3]. Because of the inclusion of mortar, cement paste, & contaminating materials like glass, rubber, asphalt, & bricks, RCA differs from typical aggregates. In several nations, the usage of RCA on pavements has become more practicable & well-liked [4]. This study examines the impact of employing recycled concrete aggregate in 4 different percentages (twenty percent, thirty percent, forty percent, and fifty percent) by weight of total aggregate added to asphalt throughout mixing) on the behavior of asphalt mixture.

Varied laboratory tests are available for the prediction & comparison of mechanical & engineering properties of asphalt mixes under varied loadings & environmental conditions [1]. Four mechanical properties—stability, fatigue resistance, permanent deformation, & resilient modulus—were looked at to anticipate & assess the long-term performance of asphalt mixes. samples had been put through Marshall stability & flow tests to gauge how well they performed.

II. RESEARCH PROBLEM

The research problem of this study were as follows:
1. In the construction sectors of the United States & Europe, recycled concrete has been commonly used, although it has been still uncommon in several developing nations, involving Egypt.
2. The quantity of waste generated from building materials in Egypt has been estimated to be 10,000tons each day or 4.5million tons every year. One-third of Egypt's daily solid trash production is represented by this figure. Costs attributed to waste treatment for a typical building project in Egypt range from 0.5 percent to 7.5 percent of total project cost.
3. Regarding the use of RCA, there are some efforts & practices on a global scale. Yet, there is still little RCA use in Egypt's construction sector.
4. Why aren't Egyptian contractors & consultants urged to employ RCA even for small construction projects?
5. Absence of field experiences, recognized rules of practice, & RCA knowledge in Egypt.
6. Utilizing RCA has not yet been thoroughly studied or shown to have clear environmental & financial advantages.
7. HMA uses expensive materials.
8. Fissures that have developed in Egypt's flexible asphalt are to blame for its poor quality & short lifespan.
9. Negative effects of hot mix asphalt on the environment.
10. Because of cracks & other problems that develop soon after construction, the cost of rebuilding roads in Egypt has increased significantly. These flaws impair the functionality of the road & raise the possibility of accidents, necessitating substantial government funding & resources for road repairs.

III. RESEARCH OBJECTIVES

Major goals of this research's evaluation of the potential use of recycled concrete aggregate to create hot mix asphalt had been to:
1- Utilize recycled concrete aggregate to create hot-mix asphalt.
2- lowering the price of components used in HMA.
3- lowering the expense of asphalt upkeep.
4- extending the lifespan of asphalt.
5- Reducing negative effects of hot mix asphalt on the environment.
6- Emphasize the idea of employing HMA in underdeveloped nations with recycled concrete aggregate.
7- Encourage Egyptian consultants & contractors to create Hot Mix Asphalt using RCA, especially for modest building projects.

IV. MATERIALS, TEST EQUIPMENT, & METHOD

4.1 Materials

4.1.1 Bitumen

All of the specimens utilized in this research's testing were made with bitumen that had been 60/70penetration grade & came from Suez. used bitumen in figure (I) underwent laboratory tests to assess its physical characteristics. Table (I) shows a summary of all these findings with associated restrictions.

Table I: Physical Properties of Used Bitumen

Properties	Values	Specifications
Penetration at25 °C (0.1mm)	66	60/70
Kinematic Viscosity at135 °C	365	+320
Softening Point	53	45/55

Figure (I) : The Used Bitumen (60/70 penetration grade)

4.1.2 Aggregate

A common crushed aggregate used in this investigation had been obtained from Atta'a Mountain. Physical characteristics of aggregate are determined through experiments & tests, & distribution of aggregate sizes has been determined by gradation tests. Testing was done to determine the aggregate's physical characteristics, & outcomes are fully summarized in Table (II).

Table II: Physical Properties of Used Aggregate

Properties	Aggregate Size		
	(6 - 9) mm	(9 – 13) mm	(13 - 25) mm
specific weight	2.40	2.70	2.60
saturated-dry surface	2.45	2.58	2.61
Apparent specific weight	2.68	2.72	2.73
water absorption%	1.3	2.87	2.57
Bulk density (t/m³)	2.31	2.53	2.54
Abrasion	0.85	0.65	0.69

4.1.3 Recycled Concrete Aggregate

Granular materials typically generated during the construction & demolition of buildings & structures were used to make recycled concrete aggregate [5]. recycled concrete aggregate utilized in this research was recovered after the demolition of a strip beam at the Housing & Building National Research Centre (HBRC). Since ninety-eight percent of the material had a nominal size higher than 4.75mm, it was classed as RCA. Testing was done to assess RCA's physical characteristics, & outcomes are fully summarized in Table (III).

Table III: Physical Properties of Used RCA

Test	Method	Value
Specific gravity – coarse aggregate	AASHTO T 84-00	2.200
Absorption – coarse aggregate	AASHTO T 84-00	3.670
Specific gravity – fine aggregate	AASHTO T 85-91	2.420
Absorption – fine aggregate	AASHTO T 85-91	3.690
Abrasion in Los Angeles machine	AASHTO T 96-02	22.28
Shape index	DNER-ME 086/94	0.70

V. METHODOLOGY

Aggregates have been banded together following EGYPTIAN CODE standards to achieve the right gradation. Each sort of aggregate's percentage is calculated, & results have been contrasted with specified limitations.

5.1 Marshall Stability & flow (T245)

This test (AASHTO T 245) is performed by AASHTO standard T245 [6]. To prepare Marshall specimens, bitumen had been heated for the same amount of time & at the same temperature as aggregates & RCA to reduce moisture content. The weight of the specimens is 1.2 kg. Specimens had been made by table (4)'s mix components. The mixture is then heated to 150°C over a fire flame. As a result, bitumen was poured last after fine aggregate & filler (stone dust) & coarse aggregate had been placed in a metallic bowl.

Table IV: Mix Components in Marshall Test

Mix Components	Percentage of Components (percent)	Mix Components (gm)
BIN (13 -25mm)	20%	240
BIN (9 -13mm)	30%	360
Sand (0 -6mm)	20%	240
C. Sand (0-6 mm)	10%	120
BIN (6 -9mm)	20%	240
Bitumen60/70	5%	60
Total weight of specimen		1200

All ingredients had been combined in a bowl by a mixer at a steady speed of one hundred rpm for about 3.5 minutes. After mixing, the mixture was manually poured into a metal bowl & returned to the oven at the same temperature with Marshall molds for an additional hour. After the mixture had been mixed for an hour, it had been poured into a Marshall mold & compacted using seventy-five blows from a Marshall hammer on each side of the specimen. Marshall specimens had been mechanically removed from the mold after specimens had been compacted & cooled to room temperature. Lastly, asphalt mixture type Marshall Specimens had been produced.

5.2 Indirect Tensile Strength

Compacted asphalt mix slice is tested for durability & resistance to water exposure using the indirect tensile strength test described in EN 12697-12 [7]. 6 samples from the control mix were examined to see whether indirect tensile strength had changed: 3 dry samples & 3 wet samples. Then, 6 samples from a modified control mix with forty percent RCA were evaluated to see if indirect tensile strength had changed: 3 dry samples & 3 wet samples. To quantify maximum load at fracture, the sample must be fastened among 2 load stripes & loaded radially at a speed of Fifty mm/min. ratio of strength measurements after & before water storage is then used to determine the indirect tensile strength ratio. Indirect Tensile Strength Ratio percent is calculated using the following equation:

ITSR (%) = (ITS-wet (MPa)/ITS-dry (MPa)) *100

5.3 Loss of Stability Test

To assess the researched mixtures' resistance to moisture damage, a loss of stability test, a condensed version of AASHTO-T165, was carried out [8,9,10]. By contrasting the stability of dry specimens with specimens that have spent twenty-four hours submerged in a water bath heated to sixty °C, this test aims to quantify the loss of stability caused by the action of water on compacted asphalt mixes. 6 samples: 3 dry samples & 3 wet samples which had been immersed in a water bath at sixty oC for 24 hours from the control mix had been tested to check the loss of stability of CM. Then, 6 samples: 3 dry samples & 3 wet samples which had been immersed in a water bath at 60oC for 24 hours from a modified control mix with40 percent RCA had been tested to check the loss of stability of (MCM). Loss of stability ratio percent is calculated using the following equation:

Loss of stability (%) = 100 - (Stability-wet (kg) / Stability-dry (kg)) *100

5.4 Permanent Deformation (Rutting) Test

The Permanent deformation test (the creep test) is an axial constant load compression test that measures the deformation behavior of the material [11,12]. test had been conducted using a consolidation-testing machine with some modifications to accommodate the size of the test specimen (Marshall specimen). Each specimen was pre-loaded by a weight of 8.16 kg (18 ib) to produce preconditioning stress of 0.01 Mpa for 2 minutes to press the protruding parts to define the best starting conditions of the test. The test progressed by applying a constant vertical stress level, $\sigma = 0.1$ Mpa in the axial direction of the tested sample in a very short time and then held constant until the test was completed (60 minutes) at an ambient temperature of 20oC. A dial gauge with an accuracy of 0.01 mm was used to measure the total vertical deformation of specimens (ΔH) under static load. Deformation readings are recorded from a dial gauge at suitable loading times; 5, 10, 15, 20, and so on to reach the test time at 60 minutes the same technique used by [13,14,15]. Figure (II) shows the rutting test machine.

Figure (II) : Rutting Test Machine

5.5 Fatigue test (The double punching test)

Fatigue properties of asphalt mixtures are assessed using a double punching test [16]. For this test, asphalt mixture cylindrical specimens with predetermined dimensions are used. Marshall cylindrical specimens with dimensions of 101.6mm in diameter & 63.5mm in height are the ones that were used. DPT's objective is to ascertain the asphalt mixture's tensile strength (σt) at a temperature of twenty°C, which acts as a predictor of its fatigue behavior.

A cylindrical specimen is placed between 2 steel punches with twenty-five mm diameter each throughout DPT. After that, a vertical loading rate of 1.27mm/min is applied to the specimen until it fails or collapses. tensile strength (σt) result obtained from this test sheds light on the asphalt mixture's fatigue resistance.

Tensile strength (σt) is calculated using the following equation:

$\sigma t = P / \pi \ (1.2bH - a\ 2)$

VI. RESULT & ANALYSIS

In the Marshall Stability test, the volumetric & physical properties of control specimens with recycled concrete aggregates & modified control specimens with recycled concrete aggregate had been examined to determine stability & flow values [18].

6.1 Marshall mix design for control mix with different bitumen ratio

Maximum load necessary to cause specimen failure when the load has been applied at a continuous rate of fifty mm/min has been the definition of stability of asphalt mix. The table below demonstrates that the asphalt mix's maximum stability is 1058 kg at a bitumen percentage of 4.75 percent, the maximum flow of asphalt mix has been 2.4 mm, bitumen content value that corresponds to the greatest stability, maximum density, & median of air voids is determined as the average of those bitumen content values. test outcomes are displayed in Table (V).

Table V: Control Mix Results for Different Bitumen Ratio (%)

Bitumen%	Unit weight (gm)	Air Voids %	VMA%	VFB%	Stability (kg)	Flow (mm)
4.5	2.29	2.37	15.29	84.46	971	2.56
4.75	2.29	3.32	15.64	78.75	1058	2.4
5.0	2.30	3.9	15.66	75.11	963	2.45
5.25	2.31	4.11	15.35	73.62	931	2.56

The obtimum bitumen for control mix is 4.75% for Stability 1058 kg, Flow 2.4mm,VMA 15.64%,VFB 78.75%,AV 3.32 and the cost for 1 m3 equal 2000 L.E.

6.2 Marshall mix design for modified control mix

Table (VI & VII & VIII & IX) display the mechanical characteristics for the modified control mix with various RCA percentages (20 & 30 & 40 & 50%).

Table VI: Modified Control Mix with 20% RCA for Different Bitumen Ratio (%)

RCA 20% Bitumen%	Unit weight (gm)	Air Voids %	VMA%	VFB%	Stability (kg)	Flow (mm)
4.5	2.19	8.08	15.25	60	734.3	2.56
4.75	2.19	7.92	15.86	56	830.04	2.16
5.0	2.22	6.57	15.84	70	774.97	2.59
5.25	2.27	4.6	15.28	80	753.97	2.61

The optimum bitumen for modified control mix is 4.75% for Stability 830 kg, Flow 2.16mm,VMA 15.86%,VFB 56%,AV 7.92 and the cost for 1 m3 equal 1970 L.E.

Table VII: Modified Control Mix with 30% RCA for Different Bitumen Ratio (%)

RCA 30% **Bitumen%**	**Unit weight (gm)**	**Air Voids %**	**VMA%**	**VFB%**	**Stability (kg)**	**Flow (mm)**
4.5	2.24	5.75	15.61	62.6	736.22	2.54
4.75	2.23	6.02	16.11	61.7	793.73	2.43
5.0	2.25	5.37	15.75	65.7	839.35	2.44
5.25	2.25	5.26	15.4	64	716.41	2.5

The optimum bitumen for modified control mix is 5% for Stability 839.3 kg, Flow 2.44mm,VMA 15.75%,VFB 65.7%,AV 5.37 and the cost for 1 m3 equal 1990 L.E.

Table VIII: Modified Control Mix with 40% RCA for Different Bitumen Ratio (%)

RCA 40% **Bitumen%**	**Unit weight (gm)**	**Air Voids %**	**VMA%**	**VFB%**	**Stability (kg)**	**Flow (mm)**
4.5	2.22	3.51	15.32	62	750.94	2.51
4.75	2.18	3.48	15.39	58.83	909.91	2.48
5.0	2.23	3.6	16.08	52.48	964.43	2.6
5.25	2.24	3.64	15.27	62.14	810.76	2.64

The optimum bitumen for modified control mix is 5% for stability 964 kg, flow 2.6mm,VMA 16.08%,VFB 52.48%,AV 3.6 and the cost for 1 m3 equal 1970 L.E.

Table IX: Modified Control Mix with 50% RCA for Different Bitumen Ratio (%)

RCA 50% Bitumen%	Unit weight (gm)	Air Voids %	VMA%	VFB%	Stability (kg)	Flow (mm)
4.5	2.19	3.12	11.2	62	894.55	2.12
4.75	2.21	2.95	13.93	61	987.68	1.95
5.0	2.21	2.88	15	60.5	1031.32	1.88
5.25	2.26	2.77	15.7	54.8	1084.69	1.77
5.5	2.26	3.1	16	64	1255	2.65
6	2.26	2.98	13.5	65	1077.28	1.98

The optimum bitumen for modified control mix is 5.5% for stability 1255 kg, flow 2.65mm,VMA 16%,VFB 64%, AV 3.1 and the cost for 1 m3 equal 2100 L.E.
Table (X) & Figures (III, IV, V, VI) display stability & flow & rigidity and cost findings for the control mix with different RCA percentages.

Table X: Stability & Flow & Rigidity Outcomes for CM & MCM with Different RCA Percentages

RCA percentage (%)	Optimum Bitumen%	Stability (kg)	Flow (mm)	Rigidity (kg/mm)	Cost (L.E)
0%	4.75	1058	2.6	407	2000
20%	4.75	830	2.16	384	1970
30%	5	840	2.44	344	1990
40%	5	965	2.6	371	1970
50%	5.5	1255	2.65	473	2100

The results of Marshall stability and flow tests versus bitumen ratio for CM & MCM with different percentage of RCA taking into consideration the cost factor according to the percentage of bitumen in the asphalt mixture indicates MCM with 40% RCA provides the lowest cost in all modified mixtures, which is 1970 Egyptian pounds per ton of asphalt. Despite RCA with 50% RCA achieving better stability results, the cost of this mix is higher than CM, as it consumes more bitumen.

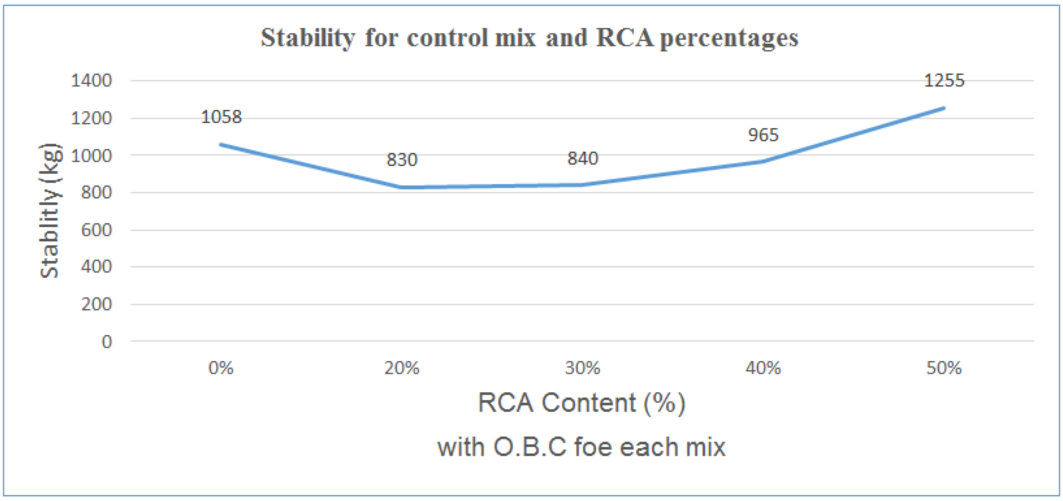


Figure (III): Stability for Control Mix and MCM with Different RCA Percentages

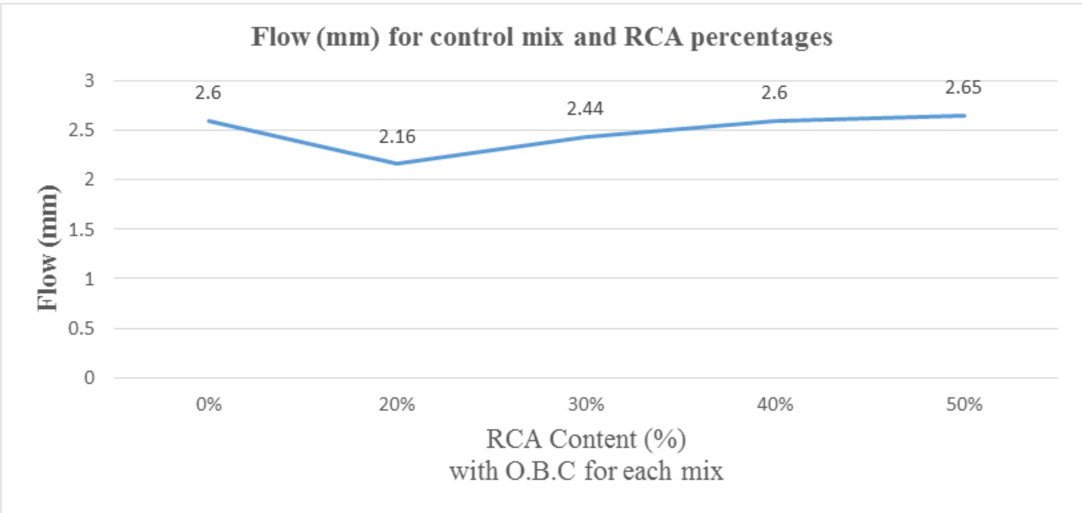
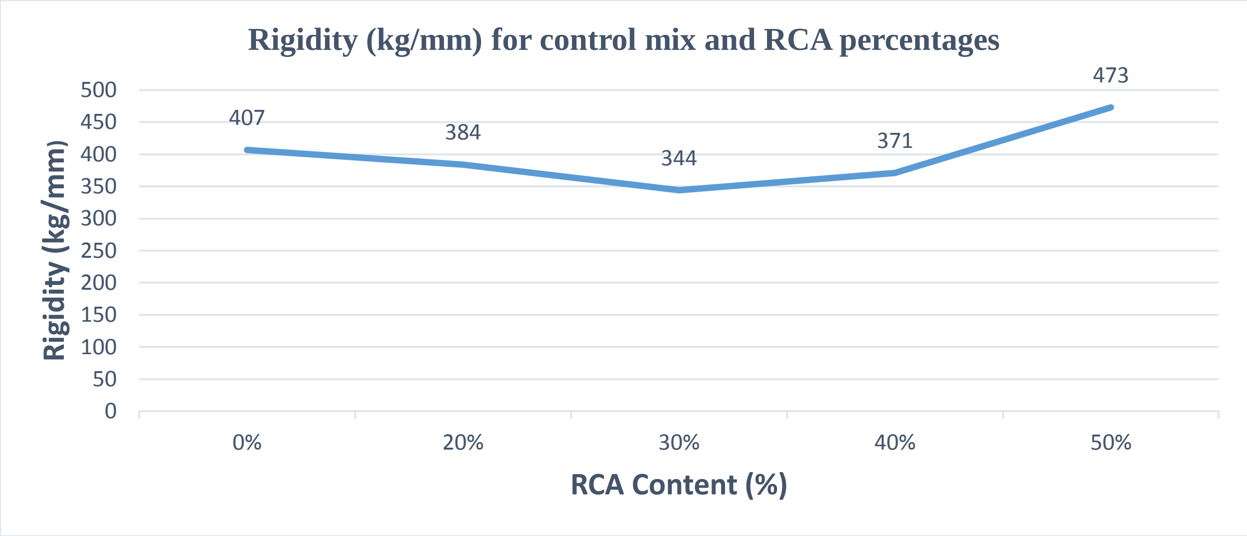
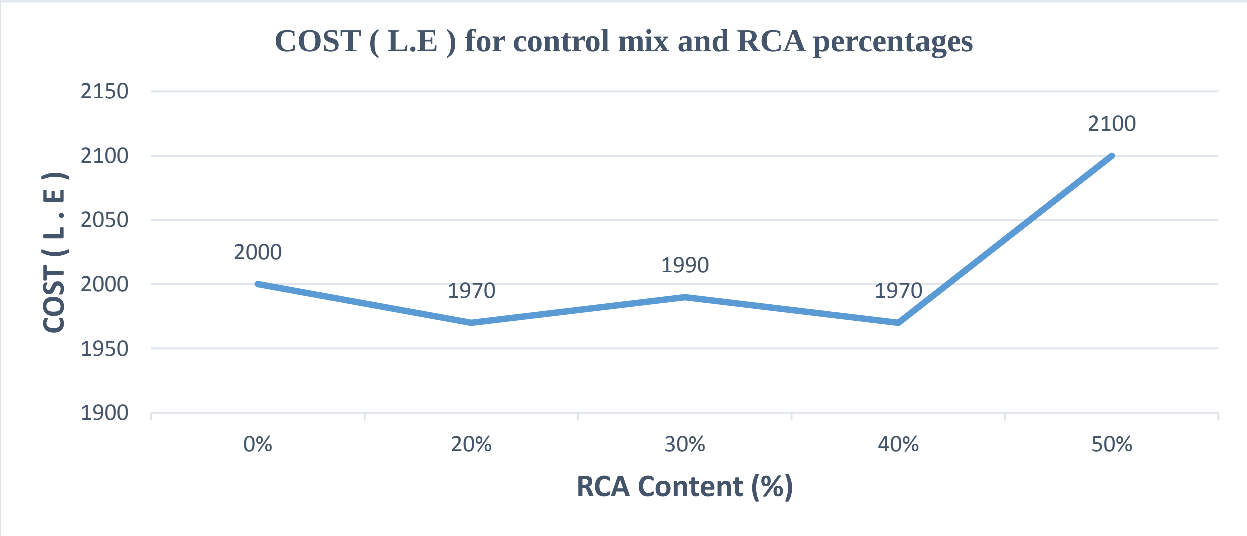


Figure (IV): Flow (mm) for Control Mix and MCM with Different RCA Percentages





Figures (V &VI): Rigidity & Cost of CM & RCA with Different Percentages of RCA

It had been observed from the table & figure that forty percent RCA content, as given in Table (X), & Figure (IV), provides asphalt mix with appropriate stability, flow, & rigidity and low cost .

6.3 Limits of Marshall Stability & Flow Values

Marshall Stability value for heavy traffic is 910 kg or greater.
340 kg is the required minimum Marshall stability value. minimum 0.25 mm unit flow value or minimum Marshall flow value is (2) or (8), respectively. Air voids as a percentage of mixture (3-5).

6.4 Indirect Tensile Strength Results

The following equation is used to calculate the indirect tensile strength ratio percent.
ITSR (%) = (ITS-wet (MPa)/ITS-dry (MPa)) *100
Table (XI) displays the outcomes of this test & ITSR (%).

Table XI: Indirect Tensile Strength Results & Calculated Percentage of Indirect Tensile Strength Ratio (%) for CM & MCM with 40% RCA

Mixture	ITS-dry (MPa)	ITS-wet (MPa)	ITSR(%)
CM	0.721	0.581	80. 58
MCM with 40% RCA	0.783	0.637	81.35

Amended mix with forty percent of RCA & ITSR value (%) meets local & global specification requirements. In The indirect tensile strength ratio ITSR (%) for the control asphalt mix & modified control mix with forty percent of RCA are shown In Figure (VII).

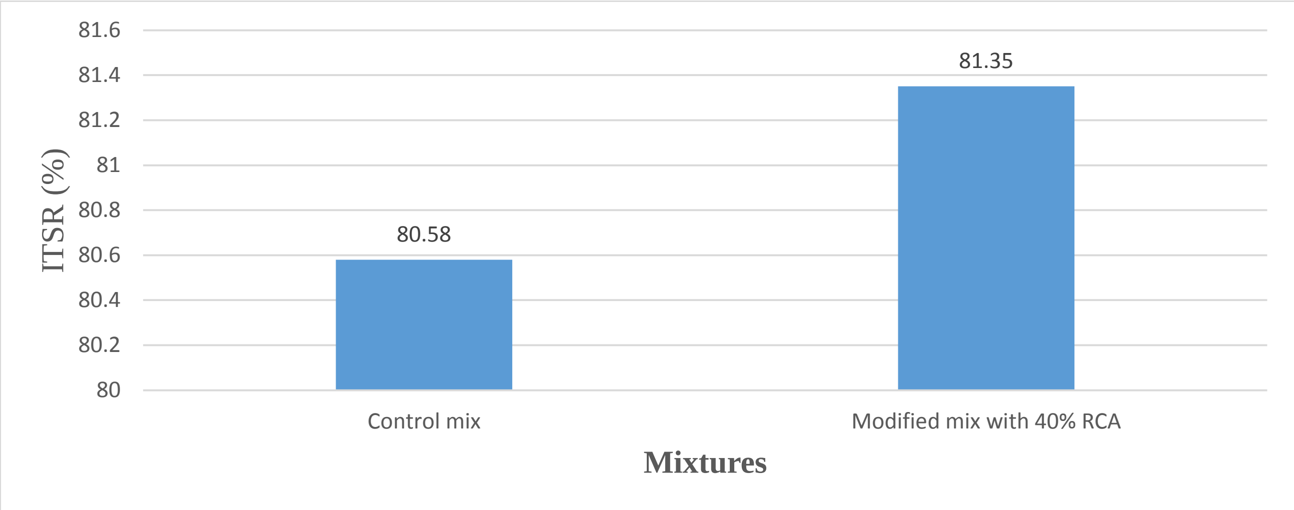


Figure (VII): Percentage of Indirect Tensile Strength Ratio ITSR (%) for CM & MCM with 40% of RCA

6.5 Loss of Stability Test Results

Results obtained from this test have been found in Table (XII). The stability of dry specimens for the control mix was 1058 kg (2333 ib) and the stability of specimens which are immersed in a water bath at sixty oC for 24 hours was 879 kg (1938 ib). The stability of dry specimens for the modified control mix was 965 kg (2128 ib) and the stability of specimens which are immersed in a water bath at sixty oC for 24 hours was 824 kg (1817 ib). Moreover, the loss of stability value is decreased at MCM with 40% RCA (14.61%) than that at CM (16.92 %). This means the improvement of mix durability and emphasis on the recommendation of using the mix of MCM with 40% RCA in asphalt paving.

Table XII: Shows Loss of Stability Test Results

Mixture	Stability-dry (kg)	Stability-wet (kg) after 24 hours	Stability loss
CM	1058	879	16.92
MCM with 40% RCA	965	824	14.61

6.6 Permanent Deformation Test (Creep Test) Results

Table (XIII) & Figure (VI) for the investigated mixes (CM and MCM with 40% CRA) presents the results of the creep test in terms of deflection (ΔH), as a marker for mix resistance to permanent deformation, for investigated hot asphalt mixes.

From the table, it may be noticed that for the two mixes deflection value rises as time rises, with decreasing rate. values of deflection at the end of test time are 0.33 and 0.28 mm for CM, and MCM with 40% RCA, respectively.
Based on these values, it can be stated that MCM with 40% RCA achieves the lowest deflection value as compared to CM, and hence, it is anticipated to resist permanent deformation more than CM.

Table XIII: Permanent Deformation Test (Rutting Test) Results (Deflection Versus Time)

Time (minutes)	Recorded Deflection (ΔH) (mm)	
	CM	MCM with 40% RCA
0	0	0
5	0.18	0.16
10	0.23	0.2
15	0.26	0.22
20	0.28	0.24
25	0.3	0.25
30	0.31	0.26
35	0.32	0.27
40	0.33	0.28
45	0.33	0.28
50	0.33	0.28
55	0.33	0.28
60	0.33	0.28

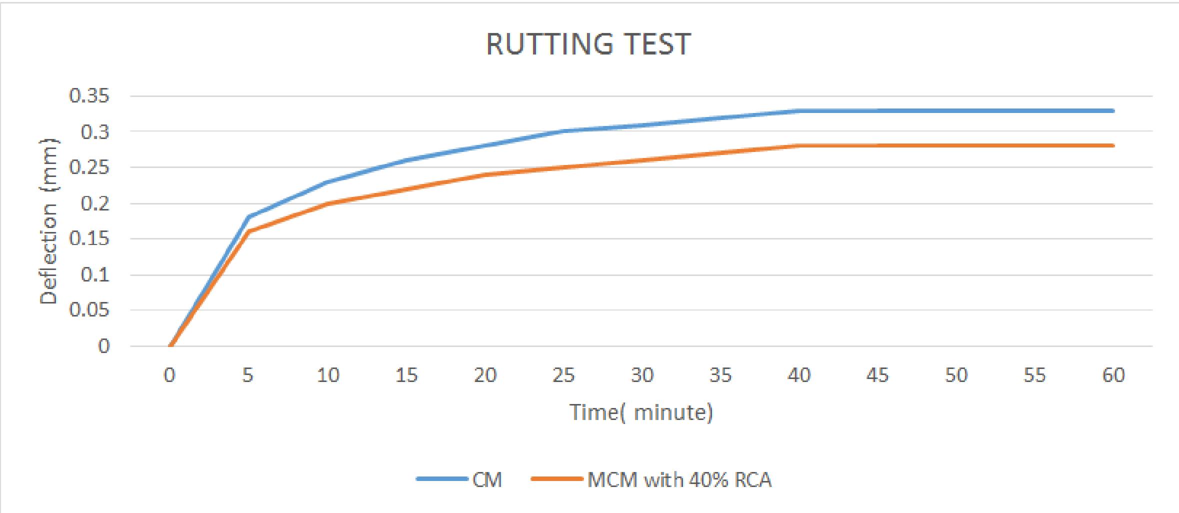


Figure (VI): Permanent Deformation Test (Rutting Test) Results (Deflection Versus Time)

6.7 Fatigue Test (The Double Punching Test) Results
Tensile strength (σt) was calculated using average failure loads of 3 specimens for each mixture (CM and MCM), as shown in Equation (1).

$$\sigma t = P / \pi (1.2bH - a\ 2) \quad \text{----------- Equation (1)}$$

Where σt has been tensile strength (kg/cm2), P has been collapsing load (kg), b has been sample radius (cm), H has been sample height (cm), & has been steel punch radius (cm).
Figure (VII) indicates tensile strength values of the control mix (CM) & modified control mix with 40% RCA at 20 oC. The result showed the same tensile strength of CM and MCM with 40% RCA content. This indicates MCM with 40% RCA content has the same resistance as CM to fatigue cracking.

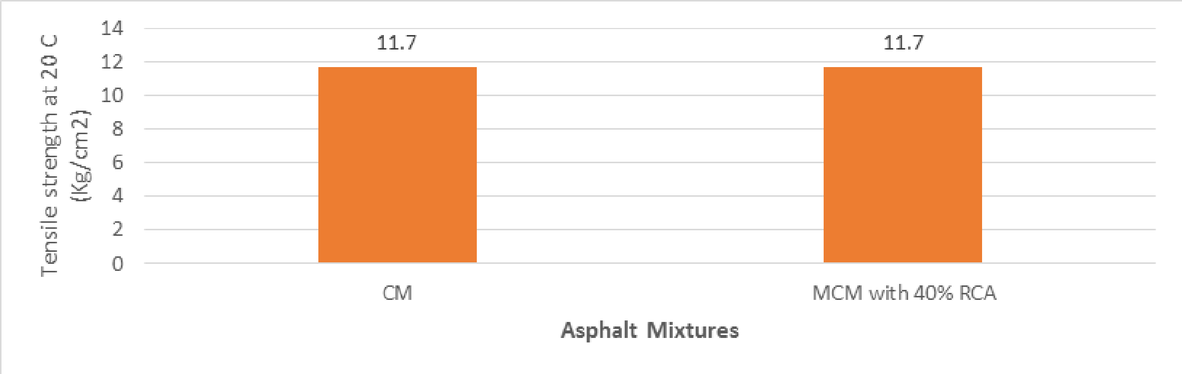


Figure (VII): Tensile Strength at twenty C as an Indicator for Asphalt Mixture's Fatigue

VII. CONCLUSION

In this research different percentage of RCA were tried (20% &30% &40% and 50%) and were tested using stability, resistance to fatigue, permanent deformation, & loss of stability and indirect tensile strength test .
The outcome are listed below.
1. For modified control specimens, Marshall Stability achieves the best outcomes at fifty percent RCA in asphalt binder (1255 kg).
2. At forty percent RCA concentration, asphalt mix has appropriate stability (965 kg), flow (2.6 mm), stiffness (2.6 kg/mm), & loss of stability (14.61%).
3. Modified control mix with 40% RCA achieves the lowest permanent deformation (Rutting) value as compared to CM, and hence, it is anticipated to resist permanent deformation more than CM.
4. The result showed the same tensile strength of CM and MCM with 40% RCA content. This indicates MCM with 40% RCA content has the same fatigue resistance.
5. The results of Marshall stability and flow tests versus bitumen ratio for CM & MCM with different percentage of RCA taking into consideration the cost factor according to the percentage of bitumen in the asphalt mixture indicates MCM with 40% RCA provides the lowest cost in all modified mixtures, which is 3,500 Egyptian pounds per ton of asphalt. Despite RCA with 50% RCA achieving better stability results, the cost of this mix is higher than CM, as it consumes more bitumen.

VIII. RECOMMENDATION

1. Additional research using various recycled concrete aggregate concentration levels is required.
2. Additional research is required to create an asphalt mixture using waste engine oil & recovered concrete aggregate.
3. To confirm that improved adhesion among aggregate & bitumen is the cause of the increase in stability at fifty percent of RCA, more tests such as indirect tensile fatigue test, 4-point bending test, etc. will be conducted in subsequent studies.
4. Local governments should permit the use of recycled concrete aggregate in construction projects, particularly for creating asphalt mixtures.
5. To determine the performance of fresh hot mix asphalt including recycled concrete aggregates, it is encouraged to apply & evaluate material in the field.

REFERENCES

[1]. Naser, A. M., Abd El-Wahab, H., Moustafa El Nady, M. A. E. F., EA Mostafa, A., Lin, L., & Sakr, A. G., 2019. Preparation and characterisation of modified reclaimed asphalt using nanoemulsion acrylate terpolymer. Pigment & Resin Technology, 48(5), 363-374.
[2]. Afshar, T., Disfani, M. M., Arulrajah, A., Narsilio, G. A., & Emam, S., 2017. Impact of particle shape on breakage of recycled construction and demolition aggregates. Powder technology, 308, 1-12.
[3]. Kavussi, A., Hassani, A., Kazemian, F., & Taghipoor, M., 2019. Laboratory evaluation of treated recycled concrete aggregate in asphalt mixtures. International Journal of Pavement Research and Technology, 12, 26-32.
[4]. Pasandín, A.R., and Pérez, I., 2013. Laboratory evaluation of hot-mix asphalt containing construction and demolition waste, Construction and Building Materials, 43, 497–505.
[5]. Mostafa, A. E. A., 2016. Investigating the effect of using recycled materials in highway construction. International Journal of Scientific & Engineering Research, 7(2), 362–368.
[6]. American Association of State Highway and Transportation Officials (AASHTO), 2015. Standard Method of Test for Resistance to Stability and Plastic flow of Asphalt Mixtures Using Marshall Apparatus. AASHTO T 245. AASHTO, Washington DC.
[7]. Grönniger, J., Wistuba, M.P., Renken, P., 2010. Adhesion in Bitumen-Aggregate-Systems Road Materials and Pavement Design, 11(4), pp. 881-898.

[8]. Mostafa, A. E. A. (2005). The stripping susceptibility of airfield asphalt mixes: the development of guidelines for a laboratory test method (Doctoral dissertation, Carleton University).
[9]. Mostafa, A., Abd El Halim, A., Hassan, Y., & Scarlett, J., 2003. Laboratory testing of moisture susceptibility of asphalt concrete mixes-An overview. In Maintenance and Rehabilitation of Pavements and Technological ControlInstituto dos Estrados de Portugal, Auto-Estrados de Norte, SA, Galp Engeria, Monte and Monte, SA.
[10]. Mostafa, A., Amir, E. H., Bekheet, W., Abd El Halim, A. O., & Easa, S., 2005. Reducing susceptibility of flexible pavements to moisture induced damage through superior compaction technology. In Proc. Canadian Society for Civil Engineering, 6th Transportation Specialty Conference.
[11]. Omar Abd El Halim, A. E. H., Said, D., & Mostafa, A., 2009. A protection of the environment through the prevention of surface cracking. The Open Civil Engineering Journal, 3(1).
[12]. El-Zohairy, Y. M., 1989. Effect of Creep on Asphaltic Mixtures Under Wheel Loads. M. Sc., Thesis, Alexandria University.
[13]. Abdel-Motaleb, E. M., 1996. Effect of Mixing Technology on Hot Asphaltic Mixtures Properties. M. Sc. Thesis, Zagazig University.
[14]. Abdel-Motaleb, E. M., 2001. Development and Evaluation of More Rational Stability Criterion for Asphalt Paving Mixes. Ph. D. Thesis, Zagazig University.
[15]. Mohamady, A., Abdel-Motaleb, E., M., and Mahgoub, H., 2013. Investigation of Recycled Building Materials for Flexible Pavement Mixes in Egyptian Low Volume Roads. TRB 2013 Annual Meeting Conference, presented on Monday January 14th 2013 in session number 284 (Aggregates in Asphalt Concrete Mixtures), paper number 13-3526.
[16]. Wen, H., Bhusal, S., & Li, X., 2013. Double punch test: simple performance test to evaluate the fatigue and rutting potential of asphalt concrete. Journal of materials in civil engineering, 25(5), 645-652.
[17]. Ewa, D. E., Ukpata, J. O., Akeke, G. A., Etika, A. A., & Adah, E. I., 2022. Use of waste glass fines to improve rigidity ratio of asphalt. Cogent Engineering, 9(1), 2107197.

Abbreviations and Acronyms

HMA	Hot Mix Asphalt
CM	Control Mix
MCM	Modified Control Mix
RCA	Recycled concrete aggregate
SG	Specific Gravity
CDW	Construction and Demolition Waste