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Evaluation of Recycled Cement Concrete (RCC) as Filler for Asphalt Mixture

Asst. Lecturer. Abbaas Inaayah Kareem
Highway & Transportation Engineering Department, College of Engineering
Al Mustansiriyah University
kkkabbaas@yahoo.com

Abstract:

The main objective of the present study is to evaluate the potential use of recycled cement concrete (RCC) as filler for asphalt mixture. The large amount of construction and demolition (C&D) waste of cement concrete especially after 2003 may produce many serious landfill problems and cause environmental pollution. It is necessary to reuse this waste material to avoid such problems. In this study the recycled cement concrete (RCC) is used as filler for asphalt mixture. Laboratory tests undertaken include Marshall tests to determine the optimum asphalt content (OAC) for control and alternative mix, x-ray diffraction test, chemical composition test, scanning electron microscopy (SEM) test and static creep test. The results show that the recycled cement concrete (RCC) as filler has lower calcite (CaCO3) percent and higher quartz (SiO2) percent than ordinary portland cement. The results also indicate that the application of recycled cement concrete as filler for hot mix asphalt can improve the rutting resistance and stiffness modulus and reduce permanent strain especially in hot region. It was also concluded that the use of RCC as filler for asphalt mixture needs projects with good quality control to avoid bad compaction in the field, so it is not recommended to use this material in projects where bad quality control is exists.

Key Words: Recycled cement concrete (RCC), filler, asphalt mixture, C&D waste, chemical composition test, x-ray diffraction test, scanning electron microscopy (SEM) and static creep test.

تقييم الكونكريت الأسمنتي المعاد تدويره كمادة مالئة للخلطة الإسفلتية

م. م. عباس عناية كريم
قسم هندسة الطرق والنقل
كلية الهندسة / الجامعة المستنصرية

الخلاصة :

الهدف الرئيسي من الدراسة الحالية هو لتقييم قابلية استخدام الكونكريت الأسمنتي المعاد تدويره كمادة مالئة في الخلطة الإسفلتية. الكميات الكبيرة من مخلفات الإنشاء والهدم من مادة الكونكريت الأسمنتي خصوصا بعد 2003 ممكن ان ينتج مشاكل طمر جدية ويسبب تلوث بيئي. من الضروري إعادة استخدام مخلفات هذه المادة لتجنب مثل هذه المشاكل. في هذه الدراسة الكونكريت الأسمنتي المعاد تدويره أستخدم كمادة مالئة في الخرسانة الإسفلتية. الفحوصات

ألمختبريه التي تم أجراءها تتضمن، فحوصات مارشال لتحديد قيمة الإسفلت المثلى للخلطة القياسية والبديلة، فحص الـ x-ray diffraction، فحص الـ chemical composition، فحص الـ scanning electron microscopy وفحص الزحف الساكن. النتائج أظهرت بأن الكونكريت الأسمنتي المعاد تدويره (RCC) والمستخدم كمادة مالئة يمتلك نسبة أقل من (CaCO3) ونسبة أعلى من (SiO2) مقارنة بالأسمنت البورتلاندي الاعتيادي. النتائج أظهرت كذلك بأن أستخدام الـ (RCC) كمادة مالئة في الخلطة الأسفلتية الحارة بالأمكان ان يحسن مقاومة التخدد ومعامل الصلادة ويقلل التشوه اللدن خصوصا في المناطق الحارة. كذلك أستنتج بان استخدام الـ (RCC) كمادة مالئة في الخرسانة الاسفلتية يحتاج لمشاريع ذات سيطرة نوعية جيدة لتجنب الحدل السيء في الموقع، لذا لا يوصى بأستخدام هذه المادة في مشاريع حيث السيطرة النوعية الرديئة موجودة.

1. Introduction

In Iraq there is a large amount of cement concrete waste produced every year, especially after 2003. This is a consequence for the vast quantities of construction and demolition (C&D) waste of cement concrete material. The opening of many structural laboratories in most Iraqi governorates led to an increase in the cement concrete waste from the destructive tests as shown in **Plate No. 1**. This type of waste may named as construction waste (CW). The successive wars since the 1980s along with the terrorist operations have caused the destruction in the infrastructure and key facilities in the country, a situation which created thousands of tons of cement concrete waste which is termed as demolition waste (DW). The large amount of construction and demolition waste (C&D waste) of cement concrete materials after 2003 may produce many serious landfill problems and cause environmental pollution. It is necessary to reuse this waste material to avoid such problems.

Plate No. (1): Cement Concrete Waste, Structures Lab. /Al-Mustansiriya University.

Huang Y. and et al. [1] 2007 concluded that the use of secondary (recycled aggregate), instead of primary (new aggregate) helps easing landfill pressures and reducing demand of extraction.

Mills-Beale J. and You Z. [2] 2010 investigated the viability of using recycled concrete aggregate for a typical light duty asphalt highway and concluded that the use of recycled concrete aggregate would save some amount of compaction energy.

Arabani M. and Azarhoosh A. R. [3] 2012 concluded that the use of recycled concrete aggregate as fine aggregate in asphalt mixtures and steel slag as fine or course aggregate produced Marshall stability increased and flow decreased.

There are many other researchers who investigated the use of recycled waste solid materials as filler in asphalt concrete, and found that such alternative filler may improve the engineering characteristics of asphalt concrete to some extent. Chen M. and et al. [4] 2011 investigated the potential of use recycled fine aggregate powder (RFAP) as filler in asphalt mixture. The results from this investigation indicate that the use of RFAP can improve the properties of asphalt mixture, such as including water sensitivity and fatigue resistance.

Wu S. and et al. [5] 2011 performed an experimental study to investigate some properties of asphalt mastic with recycled red brick powder (RBP). The results from this experimental study indicate that RBP may have some positive effect on high-temperature properties but some negative effect on low-temperature properties of asphalt mastic.

Do H.S. and et al. [6] 2007 conducted laboratory tests to study the possibility of using recycled waste lime (RWL) as filler in asphalt concrete. They concluded from various test results that a waste lime can be used as mineral filler and can greatly improve the resistance of asphalt concrete to permanent deformation at high temperatures.

The present study investigated the ability of use recycled cement concrete (RCC) as filler in asphalt mixture. The chemical composition, x-ray diffraction and scanning electron microscopy are tests performed to comparison between conventional filler (ordinary portland cement filler-OPCF) and alternative filler (Recycled cement concrete filler-RCCF).

The static creep test is used to measure the compressive properties and characterize the plastic flow behavior of the mix in terms of viscoplastic strains. The creep test is a simple tool to characterize permanent deformation (rutting) for asphalt mixtures. Albaiti H. K. [7] in 2004 mentioned that the flexible pavement has two failure mechanisms that are of particular interest to highway engineers; excessive permanent deformation of the whole structure and cracking of the bituminous layer. Albayati [8] in 2006 documented that the permanent deformation was selected as the most serious problem for highways and runways in the United States among all the distresses in asphalt pavements. Therefore, in the present study, static creep test conduct to check the benefit of involves the recycled cement concrete filler (RCCF) into HMA in terms of rutting resistance, stiffness modulus and permanent strain. The test was conducted at different test temperature and compaction effort (number of blow/face). This would permit the creep test to account for serious problems in the field today due to bad compaction.

2. Materials and Method of Testing:

2.1 Materials

The materials used in this study are locally available. The experimental work materials have been bruoght from exists pavement plants included aggregate, filler and asphalt cement. All these materials were currently used in road construction in Iraq. The altenative recycled cement concrete filler (RCCF) was produced using the waste of cement concrete materials from cube test in the structures laboratory/Al-Mustansiriya University. First the waste was crashed using a steel rod, then it ground five times using a small German grinder in asphalt laboratory.

2.1.1 Asphalt Cement

One type of asphalt cement was used, (40-50) penetration grade from Daurah Refinery. The physical properties of the asphalt cement used are presented in **Table (1).**

2.1.2 Aggregate

The crashed aggregate was brought from the hot mix plant of Ammanat Baghdad at Al-Taji. It was originally brought from Al-Nibaee quarry, it is consists of hard, tough grains, free of injurious amount of clay, loam or other deleterious substance. The course aggregate consists of hard, strong, durable pieces, free from coherent coatings. The aggregate was sieved and recombined in the proper proportions to meet the wearing course gradation as required by State Commission for Roads and Bridges (SCRB) specification [9] 2003.The maximum size of aggregate of 19 mm was used in this study. The gradation curve for the aggregate is shown in **Figure (1).**The chemical composition and physical properties of the aggregate are shown in **Tables (2) and (3)** respectively.

2.1.3 Mineral Filler

Two types of mineral filler are used in this study: the first one is ordinary Portland cement filler OPCF, it was brought from local market; this type was manufactured by Al-mass factory. It is thoroughly dry and free from lumps or aggregations of fine particles. The second is recycled cement concrete filler RCCF, it was obtained from grinding of the waste of concrete cement cubes resulting from destructive tests in the structures laboratory/Al-Mustansiriya University, **Plate No. (1).** At once, the waste of cement concrete was crashed using a steel rod and then it ground five times using a small Germany grinder in the asphalt laboratory Al-Mustansiriya University. The chemical composition and physical properties for OPCF and RCCF are shown in **Table (4).** The two fillers used are shown in **Plate No. 2 and 3** respectively. The OPCF is used as control filler and RCCF is used as alternative filler instead of OPCF.

Table .(1) Physical Properties of (40-50) Asphalt Cement.

Tests	Units	Results
Penetration (25 °C, 100g, 5 sec.) ASTM D 5	1/10mm	49
Ductility (25°C, 5 cm/min). ASTM D 113	cm	100^{+}
Softening Point (Ring and Ball). ASTM D 36	°C	50
Specific Gravity at 25 °C. ASTM D 70*	….	1.03
Flash Point. ASTM D 92	°C	326
After thin film oven test		
Penetration (25 °C, 100g, 5 sec.) ASTM D 5*	1/10 mm	31
Ductility (25°C, 5 cm/min). ASTM D 113*	cm	100^{+}

* The test was done in cooperation with National Center for Construction and Laboratories (NCCL).

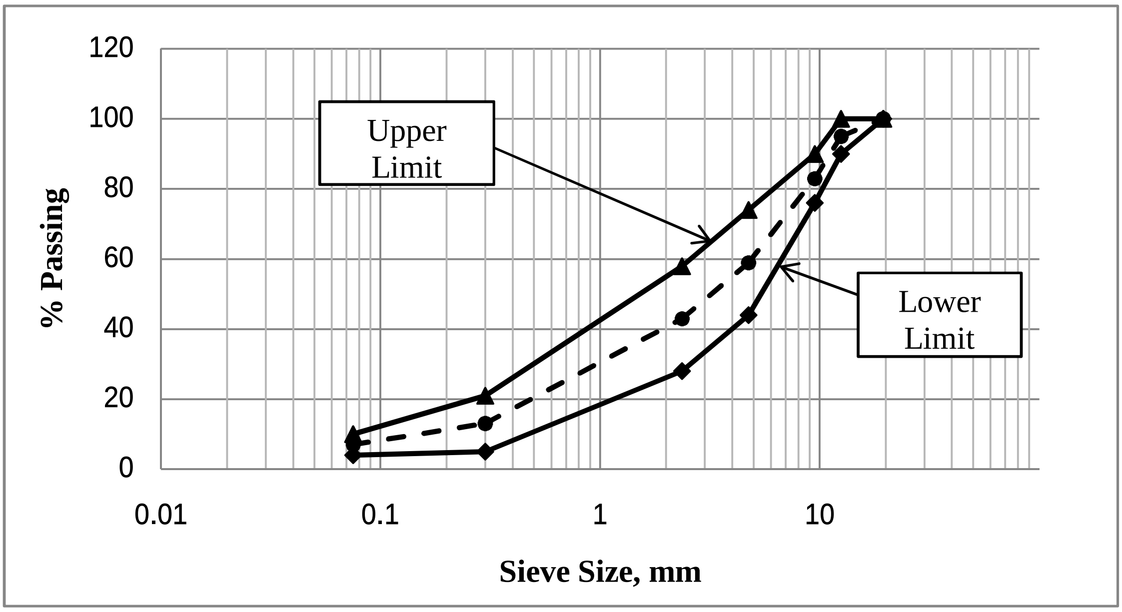


Fig .(1) Selected Gradation for Aggregate Used.

Table .(2) Chemical Composition of Al-Nibaee Aggregates.

Chemicals compound	**Results***
Sio2	82.1
CaO	5.3
MgO	0.79
SO_3	2.2
Al_2O_3	2.3
Fe_2O_3	1.19
Loss on Ignition	5.2
Total	99.08
Mineral composition	
Quartz	79.9
Calcite	11.19

* The test was done in cooperation with National Center for Construction and Laboratories (NCCL).

Table .(3) Physical Properties of Al-Nibaee Aggregates.

Property	*Coarse Aggregate*	*Fine Aggregate*
Bulk Specific Gravity (ASTM C127 andC128)	2.600	2.639
Apparent Specific Gravity (ASTM C 127 and C 128)	2.645	2.662
Percent Water Absorption (ASTM C127 and C 128)	0.435	0.762
Percent Wear (Los-Angeles Abrasion) (ASTM C131).	21.55	…

Table .(4) Chemical Composition and Physical Properties of OPCF and RCCF.

*Chemical Composition**	*Filler Type*	
	OPCF	*RCCF*
SiO_2	21.51	31.99
CaO	62.52	31.12
MgO	3.77	2.33
SO_3	1.58	1.58
Al_2O_3	5.64	4.24
Fe_2O_3	3.35	2.37
Loss on Ignition	1.34	25.37
Total	99.44	99
Description	*(Calcium Magnesium Alminium Silicate) , Portlandite*	*Calcite , Quartz , Dolomite , Kaolinite*
Physical Properties		
Specific Gravity	3.13	2.45
%Passing Sieve No. 50	100	100
%Passing Sieve No. 200	95	96

*The test was carried out in the Central Laboratories Department in Iraqi Geological Survey.

Plate No. (2) Ordinary Portland Cement Filler (OPCF).

Plate N0. (3) Recycled Cement Concrete Filler (RCCF).

3. Methods of Testing

3.1 X-ray Diffraction test

This test was used to characterize the crystallographic structure of OPC and RCC fillers; it was carried out in the Central Laboratories Department in Iraqi Geological Survey.

3.2 Chemical Composition Test

This test was used to determine the elements percent in control filler (OPCF) and alternative filler (RCCF) used in this study; it was carried out in the Central Laboratories Department in Iraqi Geological Survey.

3.3 Scanning Electron Microscopy (SEM) test

This test was used to show the microscopic morphology of fine particles for two filler used; it was carried out at the Nano Research Center at the University of Technology.

3.4 Resistance to Plastic Flow of Asphalt Mixture (Marshall Method)

This method was used to determine the optimum asphalt content OAC for control and alternative mix which is involved the determination of the resistance to plastic flow of marshall specimens of asphalt paving mixtures loaded on the lateral surface using marshall apparatus according to ASTM [10] (D 6926-04).

After preparing the specimens according to the standard marshall method, they are transferred to a smooth flat surface and allowed to stand overnight at room temperature. Then, they carefully extruded from the mold. Marshall stability and flow tests are performed on each specimen. The cylindrical specimen is placed in water bath at 60 ˚C for 30 to 40 minutes, and then compressed on the lateral surface at constant rate of 2in/min. (50.8mm/min) until the maximum load (failure) is reached. The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination are prepared and the average results are reported.

The bulk specific gravity and density are determined in accordance with ASTM [10] (D 2726). Theoretical maximum specific gravity of void less mixture is determined in accordance with ASTM [10] (D 2041) and the volumetric properties are then calculated.

3.5 Static Creep Test

The diametric-indirect tensile creep test has been used to determine the stiffness of control mix with OPCF and alternative asphalt mixture with RCCF by measuring strain-time values.

The marshall specimens are used in this test after they are allowed to stand at room temperature for (24) hours, and then each specimen is immersed in a water bath at the desired temperature (20°C, 40°C or 60°C). The specimen is subjected to a static stress of 0.141 MPa for 1 hours, and the vertical deformation is recorded at certain time of loading (0.1,0.25,0.5,1,2,4,8,15,30,45,and 60 min.). The load is then released, and the recovered strain for 1 hour is recorded, at the same time periods.

The vertical strain is calculated by using equation No. (1):

$$\varepsilon_{mix} = \Delta H / H_0 \qquad \text{.............................(1)}$$

where: -

ε_{mix}: the vertical strain in (mm/mm).

ΔH : The total vertical deformation at certain loading time in (mm), and

H_0 : The original diameter of specimen in (mm).

The stiffness modulus of the mixture is calculated using equation No. (2) :

$$S_{mix} = \sigma / \varepsilon_{mix} \qquad \text{............................. (2)}$$

where: -

S_{mix}: Stiffness modulus of the mixture at the desired loading time and temperature in (N/mm^2).

σ: constant stress in (N/mm^2),and

ε_{mix}: Vertical strain in (mm/mm).

Three specimens are prepared for each mix combination.

4. Testing Program

The testing program consists of four main steps:

1. Making a comparison between OPCF and RCCF through x-ray diffraction test, chemical composition test and scanning electron microscopy (SEM) test.
2. Determining the OAC for control mix with ordinary Portland cement filler OPCF, and alternative mix with recycled cement concrete filler RCCF. Both mixtures are prepared with one type of asphalt cement (40-50) penetration grade, one nominal maximum size of aggregate (12.5 mm) and one aggregate gradation.
3. Preparing marshall specimens with three compaction efforts (25, 50, and 75) blows/face. The 25 and 50 blows/face was to simulate bad compaction in the field due to poor quality control.
4. Conducting static creep test with three temperatures (20ºC, 40ºC and 60ºC). The specimen with 25 and 50blows/face was tested in 20 ºC and 40 ºC, while specimen with 75blows/face was tested in 20ºC, 40ºC and 60 ºC.

5. Results and Discussion

5.1 Comparison between OPCF and RCCF

5.1.1 X-ray Diffraction test

Figures (2) and (3) respectively show the results of XRD analysis for OPCF and RCCF. The results show that the main components of RCCF are calcite $CaCO_3$ and quartz SiO_2, and there is a little amount of dolomite and kaolinate. These results correspond with the results of chemical composition test in **Table (4).**

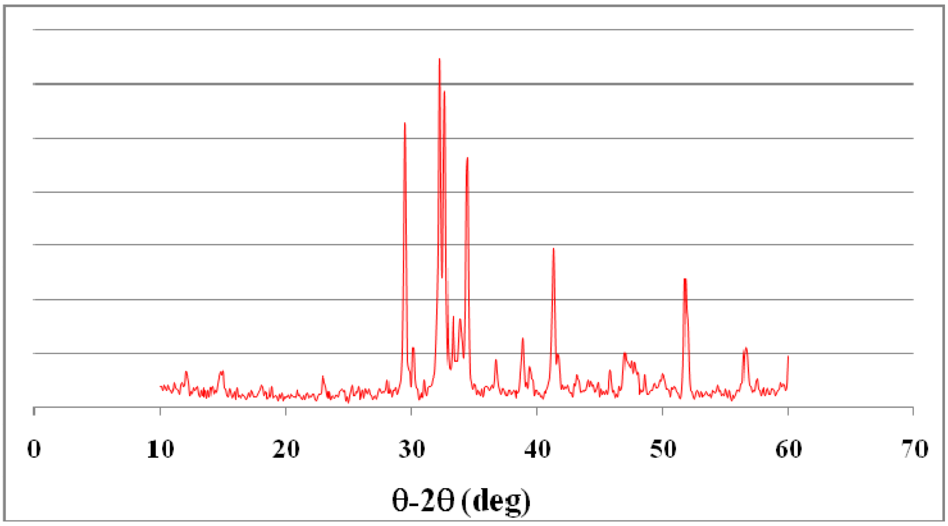


Fig .(2) X-ray Diffraction Spectrum of OPCF.

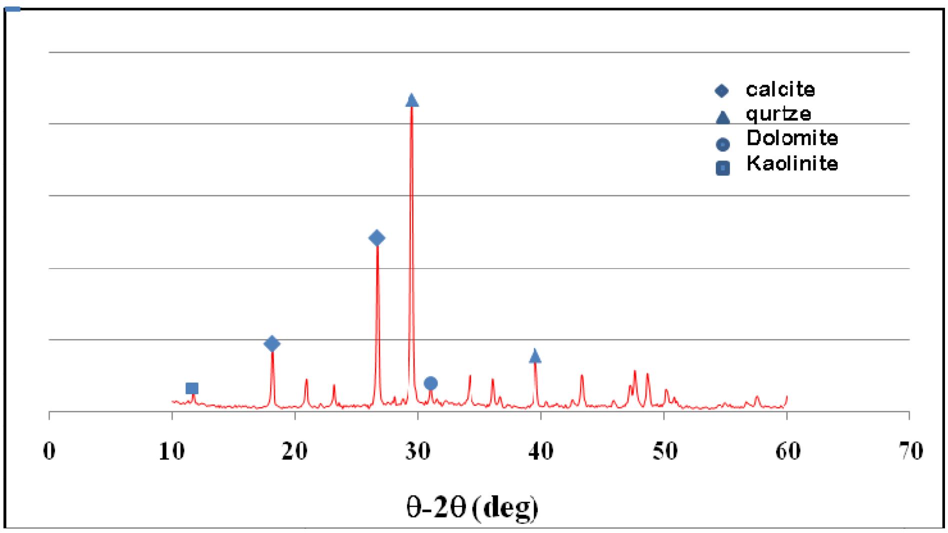


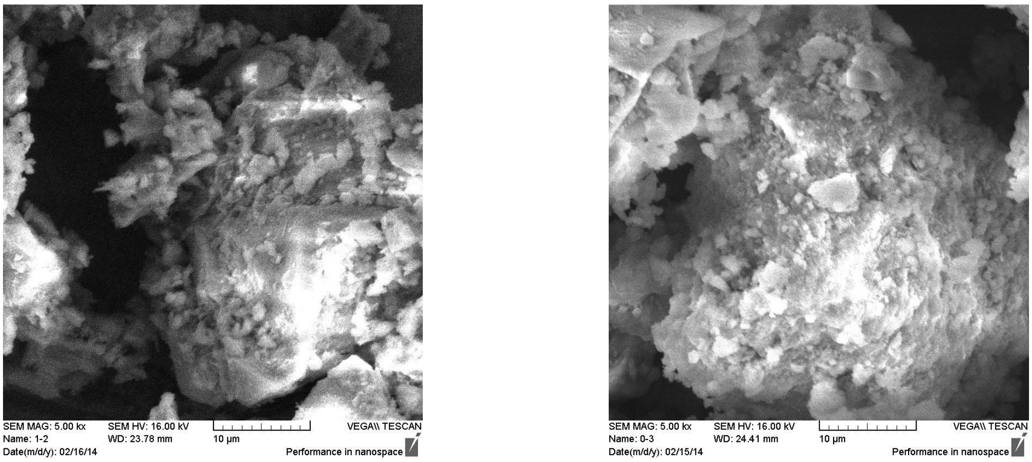
Fig .(3): X-ray Diffraction Spectrum of RCCF.

5.1.2 Chemical Composition Test

The chemical composition for OPCF and RCCF is shown in **Table (4).** The results reveal that the main elements component of RCCF is the same main elements component for OPCF which are the calcite ($CaCO_3$) and quartz (SiO_2). But the RCCF has lower calcite ($CaCO_3$) percent and higher quartz (SiO_2) percent than OPCF.

5.1.3 Scanning Electron Microscopy (SEM) Test

The **Figure (4)** shows the SEM for RCCF and OPCF. Images (a) and (b) show the OPCF and RCCF particles respectively magnified 5000 times.



(a) **(b)**

Fig .(4): (a) and (b) are SEM *5000 for OPCF and RCCF particles respectively.

5.2 Resistance to Plastic Flow of Asphalt Mixture (Marshall Method)

The standard marshall design procedure is used to determine the OAC for asphalt mixture with two different types of filler, one aggregate gradation and one type of asphalt cement. The OAC for mixture with OPCF and RCCF is 5.1% and 6% respectively. The magnification of the RCCF and OPCF particles to 5000 times show that the surface of RCCF particles is rougher than the surface of OPCF particles as shown in **Figure (4) images (a) and (b).** This may be yield the high absorption percent of asphalt cement when used the RCCF.

The marshall properties at the OAC for two mixes are shown in **Table (5).** The results of marshall tests show that the RCC mix needs high asphalt cement percent than OPC mix to reach the OAC, which is mean more cost if the RCCF is used in constructed a flexible pavement layer.

To construct 6 cm layer of asphalt cement concrete from these two mixtures for a road of one kilometer length and 6 m width, the following quantity of asphalt cement is required:

For RCC mix; weight of total mix in ton = [(100000*600*6)*2.33]/1000000 = 838.8 Ton. The weight of asphalt cement = 838.8*0.06 = 50.328 Ton.

For OPC mix; weight of total mix in ton = [(100000*600*6)*2.32]/1000000 = 835.2 Ton. The weight of asphalt cement = 835.2*0.051 = 42.595 Ton. The increase in asphalt quantity (which is equal to 7.733 Ton in case of used RCCF) can be compensated for by the lesser cost of RCCF material, provided that processing RCCF material is taken care of by a government institution such as Amanat Baghdad.

Table .(5) Marshall Properties for Two Asphalt Mixtures at O.A.C.

Mix Type	Density, gm/cm³	Stability, kN	Flow, mm	VTM, %	VMA, %	VFA, %	Marshall Stiffness, kN/mm
Alternative Mix with RCCF	2.33	9.6	3.7	3.2	16.7	82	2.59
Control Mix with OPCF	2.32	8.4	3.4	4.7	17.7	73	2.47

5.3 StaticCreep Test

The diametric-indirect tensile creep tests are performed on Marshall specimens at optimum asphalt content (OAC) for the control and alternative mix under constant stress of 0.141MPa, at 20˚C, 40˚C and 60˚C test temperature for one hour loading followed by one hour of unloading. The marshall specimens were prepared with three compaction efforts (25, 50, and 75) blows/face. The 25 and 50 blows/face was to simulated bad compaction in the field due to poor quality control. The results for each series of specimens are discussed separately.

5.3.1 Specimen with75 blow/face

These specimens are tested at 20˚C, 40˚C and 60˚C respectively. The creep test results for this series presented in the form of strain-time curves for two mixes are shown in **Figure (5). Figure (6) and (7)** show the permanent strain values at the end of the testing process and stiffness modulus for the two mixes during the loading period.

The overall results reveal that the increasing test temperature make the strain-time curve more diverged with high amount of permanent deformation, the value of permanent deformation increased and the stiffness modulus decreased.

The results clearly show that the RCC mix has lower strain and permanent strain values and higher stiffness modulus values than OPC mix over a wide range of testing temperature.

The results reveal that the RCC mix at 20°C has higher value of permanent strain than OPC mix, and the behavior of OPC mix at the unloading hour is better than RCC mix as shown in **Figure (5) and (6).** It can be conclude that at high temperature the use of RCCF in pavement surface course will increase the resistance of this layer to permanent deformation (rutting) as compared with conventional mix with OPCF. And the behavior of RCC mix at low temperature needs more investigation.

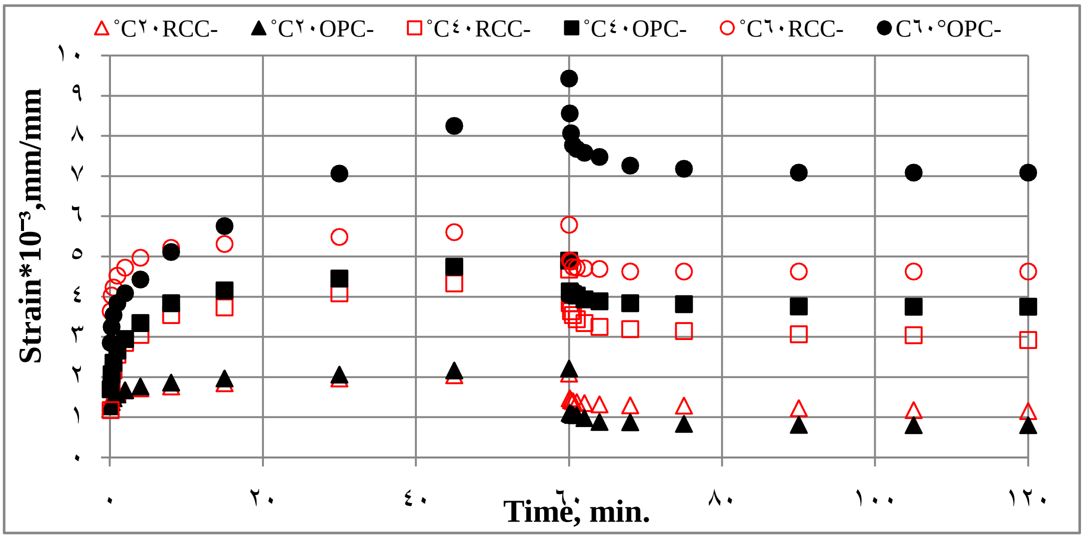


Fig .(5) Effect of Testing Temperature on Strain-Time Relationship for control and Alternative Mix for Specimens with 75blow/face.

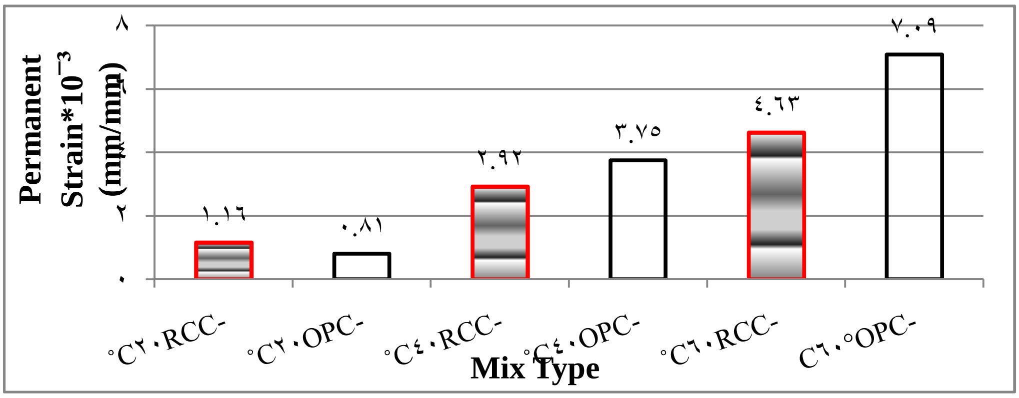


Fig .(6) Permanent Strain at the End of Testing Process for Specimens with 75blow/face.

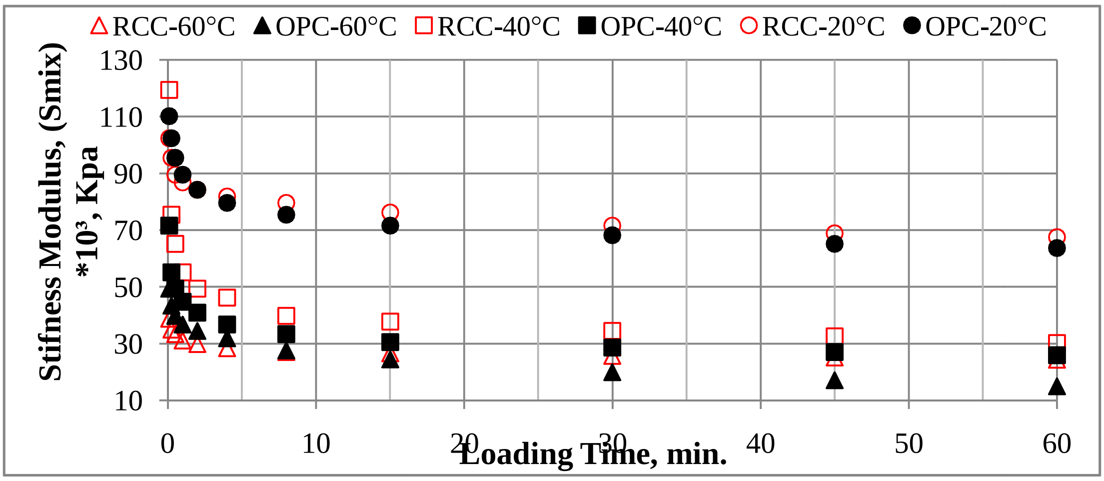


Fig .(7) Stiffness Modulus for Specimens with 75blow/face under Constant Stress of 0.141Mpa and Testing Temp. =20°C, 40°C and 60°C.

5.3.2 Specimen with50 blow/face

This series of specimens are tested at 20˚C and 40˚C. Figures (8), (9) and (10) show the strain-time relationship, permanent strain and stiffness modulus respectively for OPC mix and RCC mix. The results reveal that the OPC mix at 40°C has higher values of strain and permanent strain and a lower value of stiffness modulus. That is to say, the reduction in number of blow/face to a certain extent does not affect the results trend of the two mixes.

At 20°C the RCC mix has higher value of strain and permanent strain and lower value of stiffness modulus. It seems that the behavior of OPC mix at low test temperature is better than RCC mix and the use of RCCF in hot mix asphalt in cold region will produce high permanent deformation (rutting) in the pavement surface layer.

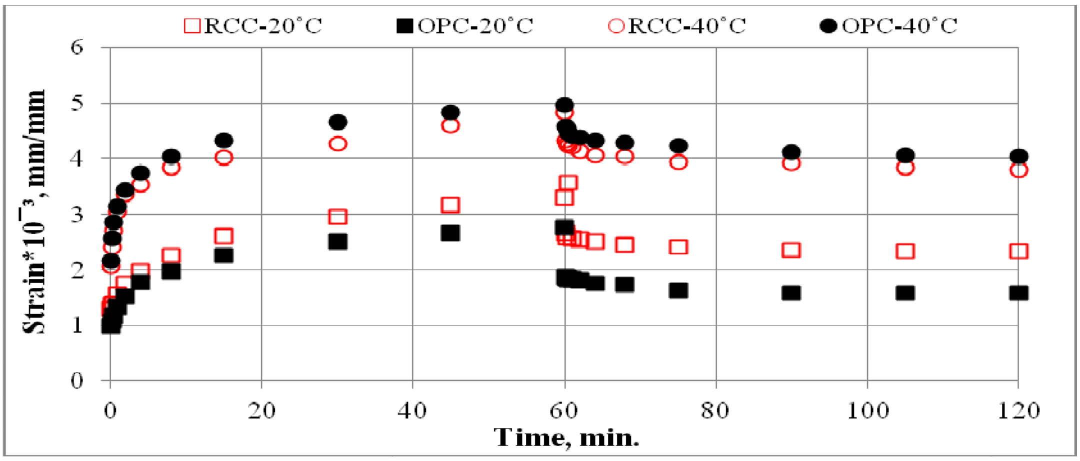


Fig .(8): Effect of Testing Temperature on Strain-Time Relationship for

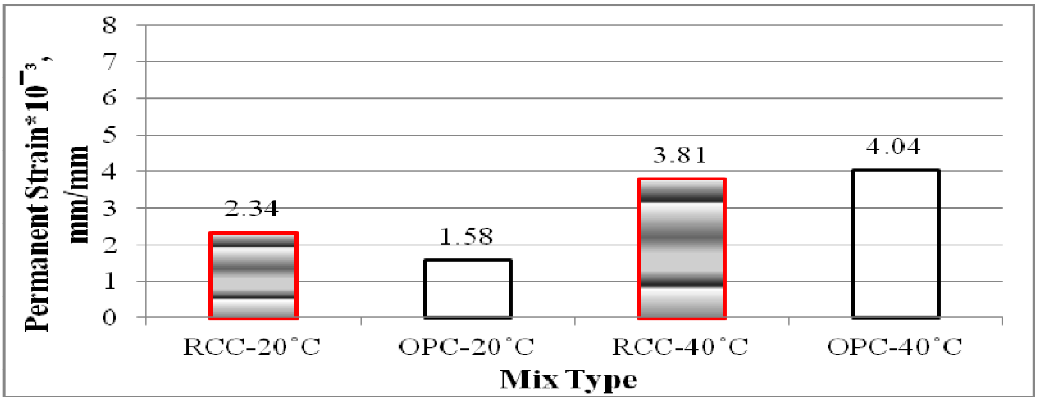


Fig .(9) Permanent Strain at the End of Testing Process for Specimens with 50blow/face.

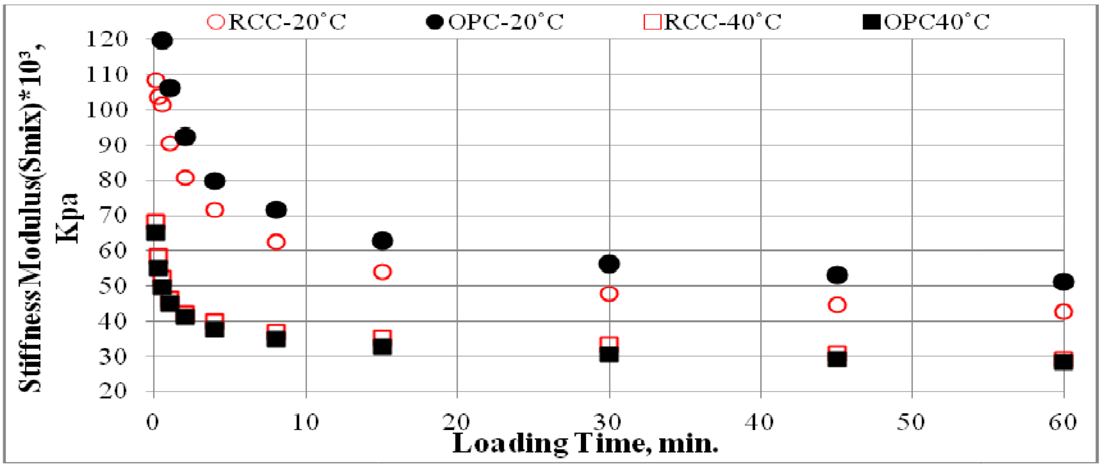


Fig .(10) Stiffness Modulus for Mixes with 50blow/face under Constant Stress of 0.141 Mpa and Testing Temperature of 20°C and 40°C.

5.3.3 Specimen with 25blow/face

Figures 11, 12 and 13 show the results of strain-time relationship, permanent strain and stiffness modulus for conventional and alternative mix with 25blow/face. As shown in these figures the performance of OPC mix in temperature 20˚C and 40˚C is better than RCC mix in terms of less value of strain and permanent strain and high value of stiffness modulus. These results reveal that the behavior of OPC mix at low compaction effort (25blow/face) will be better than the behavior of RCC mix. The results confirm that the use RCCF as alternative filler in asphalt mixture needs projects with good quality control to avoid bad compaction in the field, so it is not recommended to use this material in projects where bad quality control is exists. Furthermore, the constructed surface asphalt concrete layer in cold region using the recycled cement concrete filler (RCCF) will produce high permanent deformation (rutting) as compared with another layer constructed with ordinary portland cement filler (OPCF).

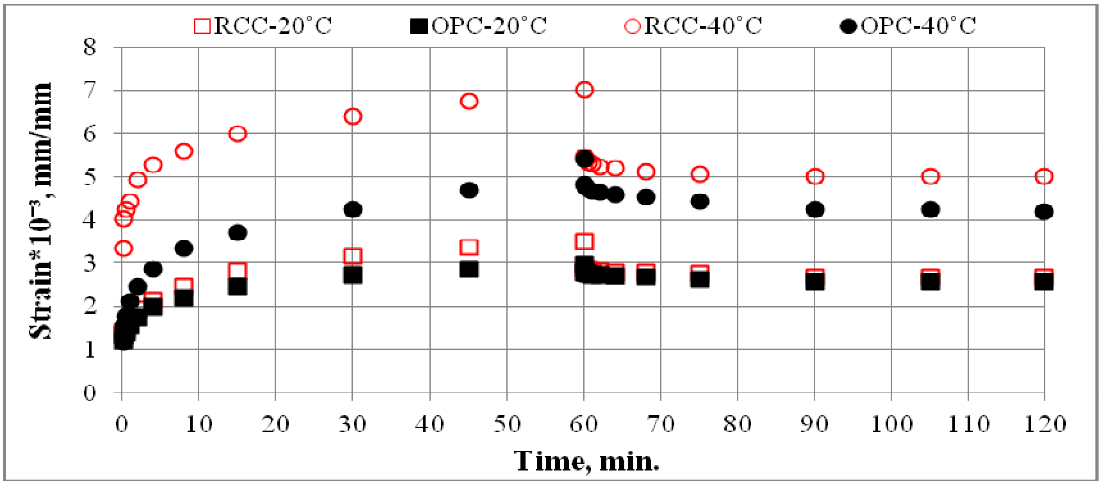


Fig .(11): Effect of Testing Temperature on Strain-Time Relationship for Two Mixes with 25blow/face.

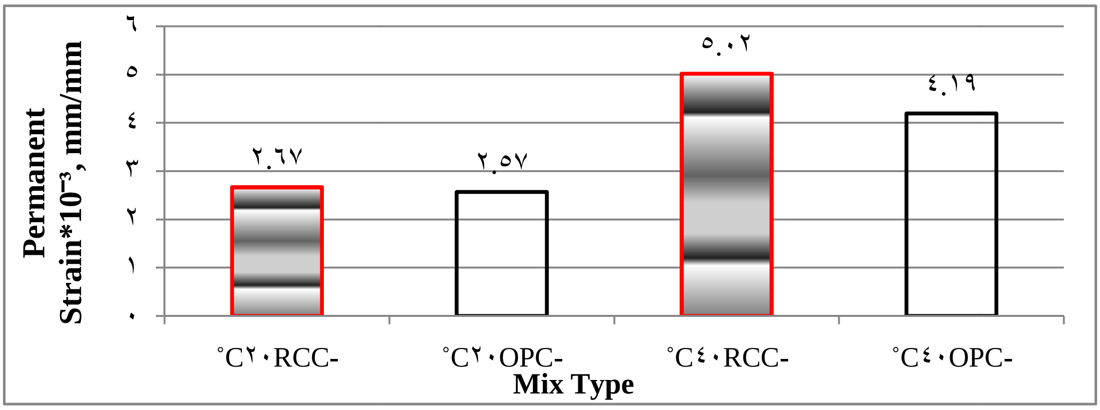


Fig .(12) Permanent Strain at the End of Testing Process for Two Mixes with 25blow/face.

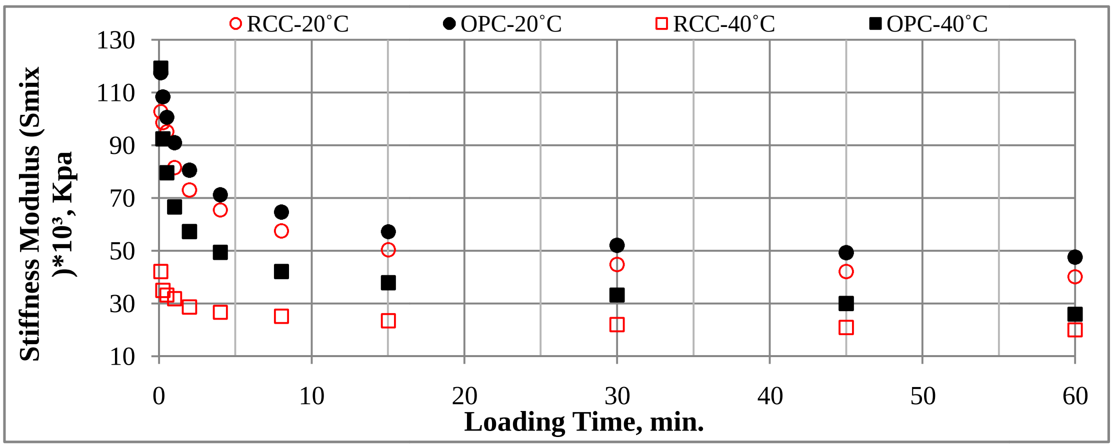


Fig .(13) Stiffness Modulus for Two Mixes with 25blow/face under Constant Stress of 0.141Mpa and Testing Temperature of 20°C and 40°C.

6. Finding and Suggestions

This study was carried out to evaluate the ability of use recycled cement concrete RCC as filler instead of conventional filler (ordinary portland cement filler OPCF) in HMA. And based on the results of the testing program and analyses the following conclusions can be drowned:

1. The x-ray diffraction test and chemical composition test results reveal that the main components of RCCF are calcite $CaCO_3$ and quartz SiO_2, and there is a little amount of dolomite and kaolinite. And the RCCF has lower calcite ($CaCO_3$) percent and higher quartz (SiO_2) percent than OPCF.
2. The scanning electron microscopy (SEM) test results show that the surface of RCCF particles is rougher than the surface of OPCF particles.
3. The increase in asphalt quantity in case of using RCCF can be compensated for by the lesser cost of RCCF material, provided that processing RCCF material is taken care of by a government institution such as Amanat Baghdad.
4. The RCCF is valuable material and can improve the resistance of asphalt mixture to permanent deformation especially in hot region.
5. The use of RCCF in HMA at cold region leads to increase the value of permanent deformation (rutting) in asphalt surface layer.
6. The use of RCCF in HMA required good quality control in the field, so it is not recommended to use this material in projects where bad quality control is exists.
7. The findings from this study need further laboratory and field tests to support the conclusions and suggestions.

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