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POSSIBILITY OF UTILIZING RECYCLED CONCRETE AGGREGATES IN HMA MIXTURE

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ABSTRACT

Environmental and economic considerations have encouraged civil engineers to find ways to reuse recycled materials in new constructions. The objective of this research was studying the possibility of utilizing recycled concrete RC in a surface course of hot mix asphalt HMA mixtures and evaluating the volumetric and mechanical properties of hot mix asphalt mixtures containing recycled concrete aggregates. For this purpose, the performance of HMA mixtures containing various percentages of RC has been evaluated based on experimental tests, such as Marshall Stability MS, Marshall flow, Marshall stiffness, and Indirect tensile strength ITS. 90 specimens contain 5% asphalt bitumen and RC in various percentages (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%) were mixed with virgin crushed stone aggregates and compacted by using Marshall Compactor to produce HMA specimen then Marshall mix design method was used to measure the optimum RC content.

The results of MS and flows slightly decreased with the addition of RC. Marshall stiffness values for 10 percent RC was higher than the Control Specimen CS and the others. ITS values decreased with increasing RC.

A mixture without recycled concrete RC and varies gradation of maximum size of (1 $\frac{1}{2}$, 1, and $\frac{1}{2}$) inches was prepared as control mix to CM test the Marshall stability –flow , ITS, and temperature sensitivities properties of mixes with 58% (optimum percent) of RC that is obtained from a mix design that was investigated in this study. Specimens showed slightly improvements in Marshall Stability, flow, and ITS as compared with CM.

KEYWORDS: Asphalt; Concrete; Reuse; Sustainable environment

امكانية استخدام الخرسانة المعادة كركام في الخلطة الاسفلتية الحارة

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الخلاصة

نظرا للظروف البيئيةُ والاقتصادية اتجه المهندسون المدنيون لإيجاد الطرقِ لإعادة استعمال انقاض المواد في العمليات الإنشائية الجديدةِ. ان الهدف من هذا البحثِ هو دراسة إمكانيةِ استعمال الخرسانة المعادة كركام (RC) في الخلطات الاسفلتيةِ (HMA). و تقييم الخواص الحجميةَ والميكانيكيةَ للمزيجِ الحاوية على خرسانة معادة حيث تم اجراء فحوصات مختبرية لهذا الغرضِ كما تم فحص الأداء لخلطات تَحتوي علي نِسَب مئويةَ مُخْتَلِفةَ من الخرسانة المعادة واعتماد اجراء فحوصات مختبريةِ مثل فحص الثبات والتدفق لمارشال، تصلّب مارشال، مقاومة الشدّ غير مباشرة لها , وعليه تطلب العمل تحضير 90 نموذج خلطة اسفلتية مكون من 5 % وزنا" اسفلت و نِسَب وزنية مُخْتَلِفةِ (10 %, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% و100 %) خُلِطتْ مَع ركام من الحجر المكسر ورصت باستعمال مطرقة مارشال ومن ثم احتساب النسبة المثلى للخرسانة المعادة الواجب اعتمادها كركام مع الحجر المكسر في الخلطة الاسفلتية .

وقد اعطت النتائج تناقص خفيف في قيم الثبات والتدفق بإضافة الخرسانة المعادة بينما كانت قيم الصلابة لنسبة 10% RC اعلى منها للخلطة القياسية.

تم تحضير خلطات قياسية ولكن بثلاث قيم مقاس اقصى وهي 2/1, 1, 2/1 1 بوصة ومقارنة نتائج فحص المارشال ومقاومة الشد غير المباشرة والتحسس للحرارة لها مع خلطات اسفلتية ممزوجة بنسبة مثلى للخرسانة المعادة تمثل 58% من وزن الركام كانت متحصلة من هذه الدراسة ومنه تبين ان الخلطة ذات الواحد انج حجم اقصى للركام حسنت المقاومة ككل ولو بشكل ضئيل . وبهذه الحالة فان استعمال الخرسانة المعادة في الخلطات الاسفلتية ذات المزيج الحار يعطي نتائج ايجابية بدلاً من أنْ يَكُونَ تلوثَ بيئيَ .

1. INTRODUCTION

Asphalt concrete is used substantially in road construction all over the world, therefore, large quantities of materials are ud in road construction. The aggregate materials used in road construction generally cost a great amount. What’s more, the quantity of good quality aggregate is decreasing more and more. These amounts can be decreased by using suitable waste materials. Potential harmful effects of stone quarries will be reduced and energy savings can be achieved as well. Significant gains can be accomplished in the context of sustainable development (Chen and Wu, 2011; Arabani and Azarhoosh, 2012).

It is noted that the subject takes exceptional importance for countries that suffer from wars and crises that produce tons of construction and demolition waste as a result of the bombing of various weapons, and where the Arab region taken from wars lion's share was necessary for us to think about solutions sound for such problems. It is found through studies that it can recycle 80-90% of demolition waste and residues, including concrete. Since the recycling of concrete process provides the following (Do and et al., 2008):

- Reducing the use of natural resources
- Reducing the cost of production and transfer of these raw materials
- Reducing the material transferred to landfills.

Some of the recycled materials mentioned above are used instead of both aggregate and bitumen, and different results are observed by using different wastes. To set an example, as a result of using waste concrete particles in the asphalt concrete mixtures, it is observed that the stability and flow values in the asphalt mixture remain within specification limits, and those materials can be evaluated as aggregate in bituminous layers of highway pavements with moderate and low traffic capacities (Arabani and Azarhoosh, 2012; Rawshan,2006). Some additives and wastes are used in bitumen to provide modification. Additionally, some improvements have been observed in rheological properties (creep, elastic recovery, and complex modulus) of bitumen by adding cement (Rawshan, 2006). Summarizing the studies for using waste materials in asphalt concrete, such as waste glass, steel slag, tires, and plastic identified as solid waste (Roberts, 1996) emphasizes that waste materials should be used in road construction for the technical and financial aspect, and that would prevent environmental contamination and provide a clearance of deposition sites.

In this respect, it has become compulsory to do a research for using those wastes in asphalt concrete, and many studies continue to improve the performance of asphalt concrete. It has become the aim of researchers to provide better performance values using waste materials with less substance in the mixture. In this way, both the economization of the materials and prevention of environmental contamination are accomplished.

The recycled concrete RC is the remains of demolished or destroyed constructions. In this study, experimental study is performed to investigate the effect of RC on the properties of HMAs. The RC is added to asphalt concrete in 10, 20, 30, 40, 50.60, 70, 80, 90, and 100 percent by weight of aggregate.

2. MATERIALS AND METHODS

Recycled aggregates employed in this research were provided by collecting concrete and cement blocks from the construction debris of Al-Najaf city which is displayed in Fig. 1, then crushing and breaking them into the size of natural aggregates.

Fig. 1. Al-Najaf city location.

The aggregates characteristics were determined through experiments, such as aggregation, Los Angeles abrasion test, determining percentage of fractured pieces in coarse aggregates, density, and water absorption test. After breaking the construction residues in the crusher, aggregates were transferred to the dryer and heated at 145 °C. After cooling materials (24 hours later), samples were prepared for the tests mentioned earlier.

The widely applied bitumen in asphalt concretes is pure bitumen with penetration grade of (40-50). Appropriate penetration grade should be selected based on local weather conditions and the traffic of heavy vehicles. According to south Al-Najaf 's weather condition 40-50, bitumen was selected for the research. Characteristics of the bitumen utilized in this research are in Table 1.

To evaluate the performance of aggregates from constructional debris in asphalt mixtures, ten different designs with recycled aggregate percentage of 0, 10, 30, 40, 50, 60, 70, 80, 90, and 100 were prepared, and the tests mentioned earlier were conducted on them. Naming each of designs is associated with the amount of construction debris in it; for example, RC30 is a mix design with 30% of aggregates from construction debris.

Aggregates grading is one of the most important factors that affects the strength and bearing capacity of asphalt concrete. Grading is usually performed by using sieves No. 4, 8, 16, 30, 50, 100, and 200 (ASTM D448-12) (ASTM D5821-13, 2013) as obvious in Fig. 2.

Suitable asphalt aggregate gradation is selected due to several factors, such as pavement type, type and location of the desired layer in the pavement, asphalt layer thickness, and the grain size (ASTM D1073-11) (ASTMD448-12, 2012). Aggregates used in asphalt concrete must have a sufficient strength to withstand the weight of heavy vehicles and rollers. Also, several tests were conducted on the aggregates by using Los Angeles abrasion machine and their results are tabulated in Table 2.

The purpose of asphalt concrete mixture design is to choose the best and most cost-effective aggregates and bitumen mixture which should provide the following features for asphalt concrete:

- Enough strength to withstand the loads caused by traffic without deformation.

- Limit the air voids to a maximum amount in order to reduce air and water penetrate in the asphalt.

- Efficient enough to be easily spread and compacted.

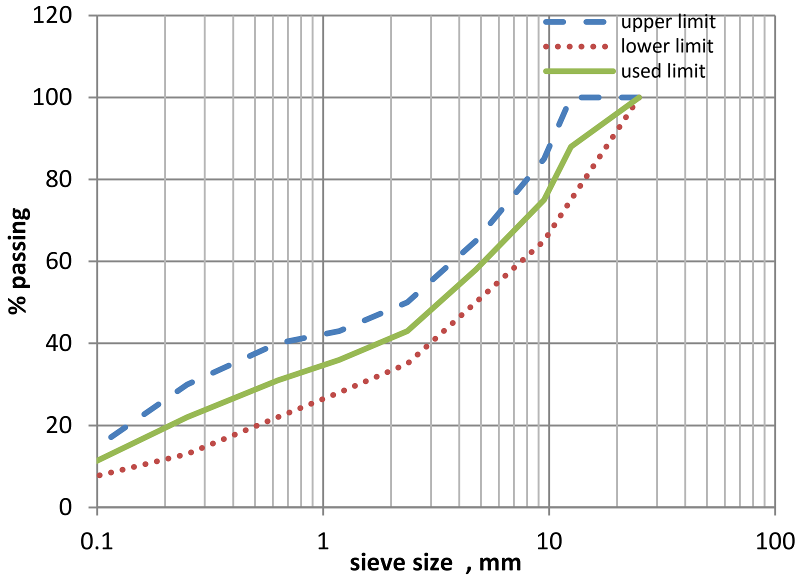

Fig. 2. Aggregate gradation curve.

Table 1. Physical Properties of Bitumen Used in Mix Designs

Property	Unit	SSHTO Specification (ASTM,2003)	ASTM Designation (ASTM D5821-13, 2013)	Result
Penetration at 25°C	mm/10	40 - 50	D5	43
Flash point	°C	>232	92	278
Ductility at 25°C	5cm/min,(cm)	>100	D113	>100
Softening point	°C	-	36	55

Considering the aggregation and facilities, ASTM D 1559 method (ASTMD448-12, 2012) was adapted for preparing bitumen asphalt samples in this research. Sample preparation consists of the three following phases, heating the aggregates and bitumen separately, mixing them, and then compressing the mixture. Firstly, aggregates and bitumen were heated separately. Coarse and fine aggregates mixed according to the ratios obtained from gradation test and heated as well as bitumen (ASTM, 2003; AASHTO, 2003). After heating the aggregates and bitumen, they need to be mixed well in order to have the entire surface of the aggregates coated with bitumen, considering that temperature must not be below120°C. As the purpose of Marshall strength test is to determine the best bitumen percentage, three samples of 5 percentage of bitumen were prepared for each RC0, RC10, RC30, RC40, RC50, RC60, RC70, RC80, RC90, and RC100 asphalt mixture designs, totally 48 Marshall samples. After mixing bitumen and aggregates about 1200 g of each mixture collected separately in a cylinder with 4 inch (101.6 mm) in diameter and 2.5 ± 0.05 inch (63.5 ± 1.27 mm) in height and compacted using a 4.5 kilograms rod falling from 45cm height, 75 times for each sample (ASTM D5821-13, 2013; ASTMD448-12, 2012). After that the samples remained in 60° C warm water for 30 minutes.

Table 2. Physical Properties of Recycled Concrete and Crushed Stone Aggregate Used in Mix Designs

Property	ASTM Designation (ASTMD448-12, 2012)	Aggregate Results: Crushed stone RC0	Aggregate Results: Recycled concrete RC 10 30 50 70 90 100	AASHTO Specification (ASTM,2003;ASTM, 2003)
Course aggregate				
Bulk specific gravity	C-127	2.611	2.201 2.24 2.271 2.288 2.289 2.294 2.298	2.5-2.75
Apparent specific gravity		2.687	2.455	-
Percent wear by Los Angeles abrasion, %	C-131	21.00	28 31 32 36 40 48	<45
Soundness loss by sodium sulfur solution ,%	C-88	3.200	4.400	<10
Fractured pieces		80.00	87 88 94 94 95 98	>95
Fine aggregate				
Bulk specific gravity	C-128	2.620	2.078	2.5-2.75
Apparent specific gravity		2.670	2.001	-
Water absorption,%	C-128	2.710	7.981	
Mineral Filler aggregate				
Specific gravity		2.610	-	

To accommodate indirect tensile strength test, twelve specimens are prepared by Marshall Method then be tested. The prepared specimens are cooled at room temperature for 24 hours as well as immersed in a water bath at different test temperatures (5, 25, and 40 ˚C) for 30 minutes. For each mix combination, three specimens are tested and the average results are reported. The indirect tensile strength ITS is calculated as follows (TRB, 2003):

$$ITS = 2\,P_{ult} / \pi\, t\, D \qquad (1)$$

Where: Pult = Ultimate load up to failure (N)

t = Thickness of specimen (mm)

D = Diameter of specimen (mm)

The temperature susceptibility is calculated, as below:

$$TS = [(ITS)\ t0 - (ITS)\ t1] / (t1 - t0) \quad (2)$$

Where: (ITS) t_0 is the indirect tensile strength at t0 (˚C)

(ITS) t_1 is the indirect tensile strength at t_1 (˚C)

$t_0 = 25$˚C, $t_1 = 40$ ˚C

The optimum RC content is used to design 12 specimens, and the procedure was all the same as described earlier. So three samples for each three mix designs have maximum particles size of ($\frac{1}{2}1$, 1, and $\frac{1}{2}$) inches (totally 21 samples) were prepared with the same procedure for Marshall Test and ITS test.

3. RESULTS AND DISCUSSION

Air voids analysis was carried out in accordance with ASTM D 3203 (Wu and et al., 2011). The air voids value of the specimens was measured using value of calculated theoretical maximum density which is measured and illustrated in Fig. 3.

Aggregate weight loss percentage of RC0, RC10, RC30, RC40, RC50, RC60, RC70, RC80, RC90, and RC100 using Los Angeles abrasion test method of ASTM (ASTM D448-12, 2012) and AASHTO (AASHTO, 2003) (500 rpm) was determined. The results of this experiment are shown in Table 2. Los Angeles abrasion test was performed on coarse aggregates (sieve No. 4). The results show that by increasing the percentage of recycled aggregates in the composition of the mixture has led to the increase of materials abrasion percentage. This is due to the mortar adhered to recycled aggregates.

Sand equivalent values of aggregates finer than sieve No. 4 using ASTM D2419 (ASTMD448-12, 2012) and AASHTO T176 (AASHTO, 2003) are also shown in Table 2.

The results show that increasing the percentage of recycled aggregates in the composition of the mixture increases the sand equivalent value, which determines the high quality of fine recycled aggregates. The reason is that washed sand is used in construction cement which has higher sand equivalent value. Lower percentage of fractured particles of natural aggregates in comparison of recycled aggregates is due to rounded corners of natural aggregates.

Results of Marshall test (ASTM D5821-13, (2013); ASTMD448-12, 2012) determining the physical and mechanical properties of different mix designs are shown in Fig. 4.

With comparison of different asphalt concrete mix designs it is concluded that the major impact of increasing the percentage of recycled aggregates in asphalt concrete mixture design is on reducing the strength of the Marshall specimens. But increasing the recycled aggregates reduces the other parameters which can be recovered by increasing the bitumen which is not economical.

According to increases the strength of the Marshall specimens and pore space filled with bitumen (VFA), and it also decreases air void (Va). Comparing virgin asphalt mix designs shows that the true specific gravity of the sample (depending on the quality of the aggregate), reduces by increasing percentage of recycled aggregates. But like conventional asphalt mix designs with increasing percentage of recycled aggregates strength of samples are greatly reduced in sulfur asphalt mix designs.

The recycled concrete aggregate improved ITS results for mixtures with maximum aggregate size of 1 $\frac{1}{2}$ and $\frac{1}{2}$ inches, but slightly increased result was found at 1" maximum aggregate size. In general, the mixture containing recycled concrete is less sensitive to temperature than that for virgin mixture at both of 1" and 1 $\frac{1}{2}$ " maximum aggregate size while the $\frac{1}{2}$ " maximum size kept the mixtures have same value of temperature sensitivity.

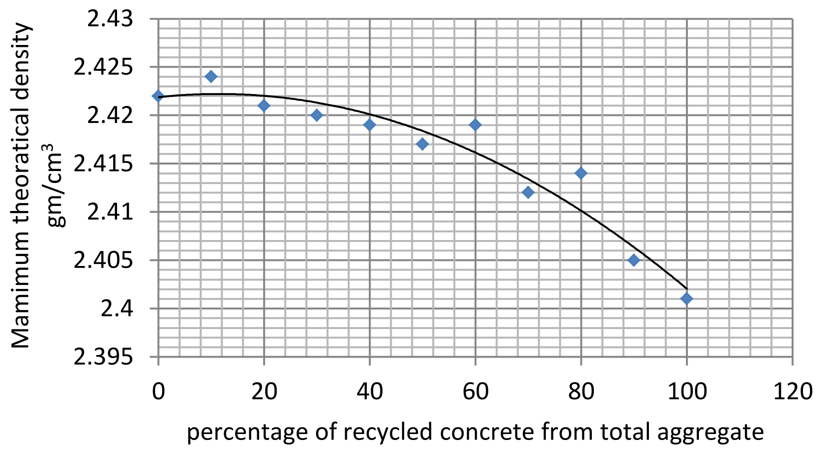

Fig. 3. Maximum theoretical density against percent of recycled concrete aggregate.

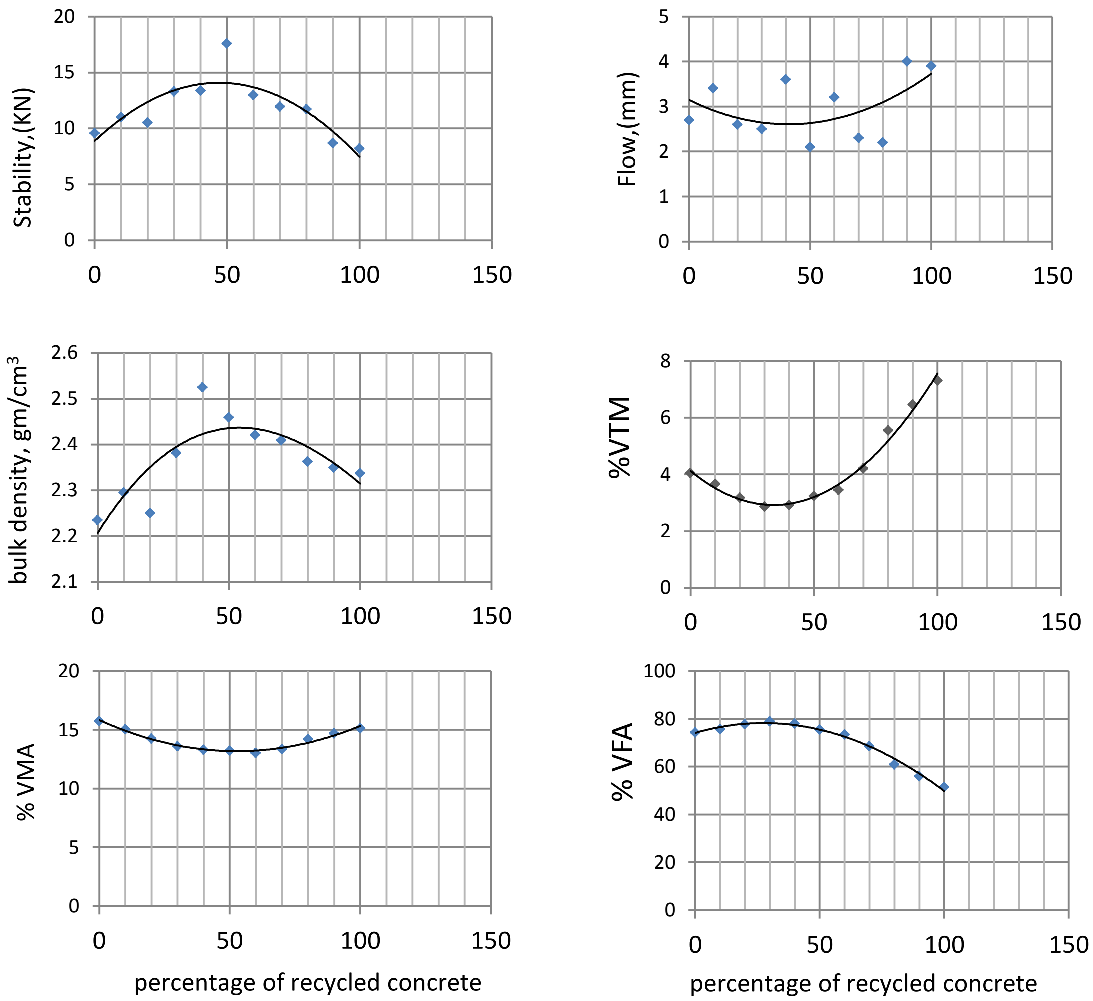

Fig. 4. Marshall test against recycled concrete aggregate percent.

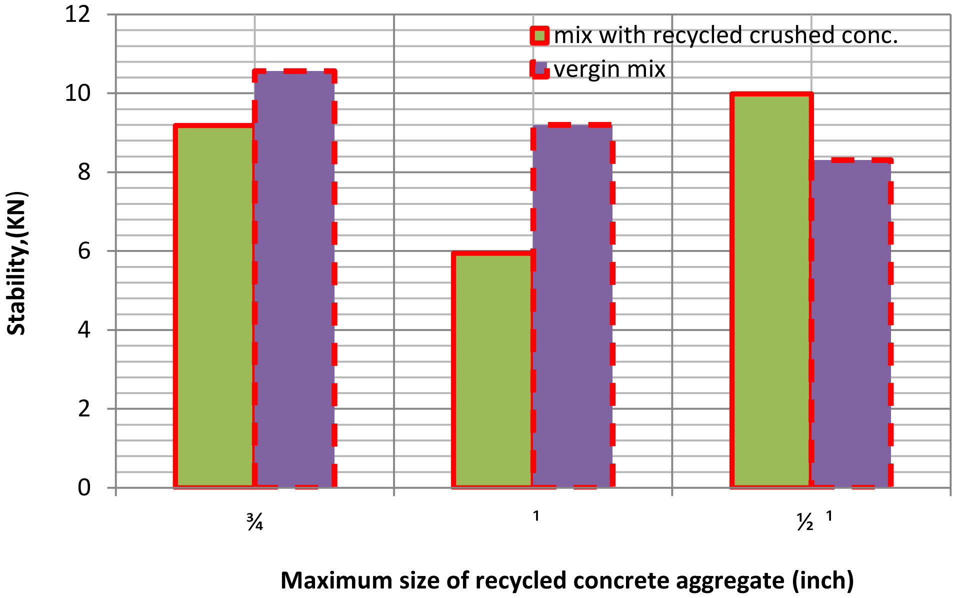

Fig. 5. Marshall Stability against maximum size of recycled concrete aggregate.

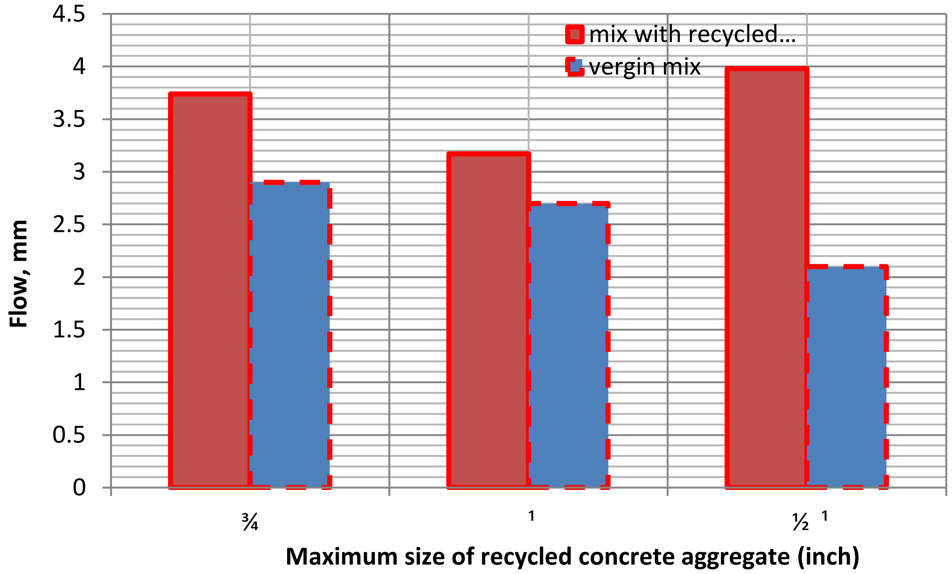

Fig. 6. Marshall Flow against maximum size of recycled concrete aggregate.

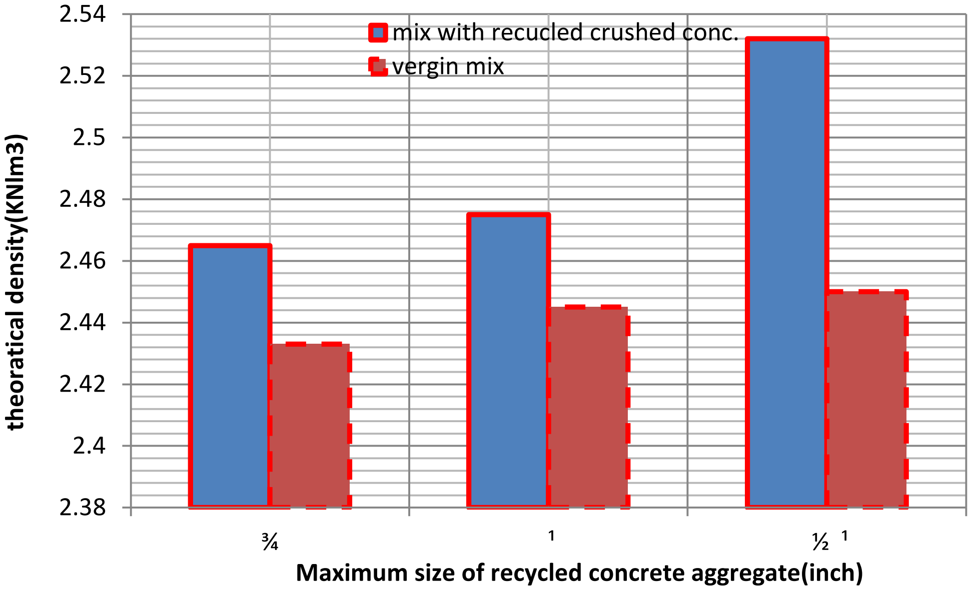

Fig. 7. Theoretical density against maximum size of recycled concrete aggregate.

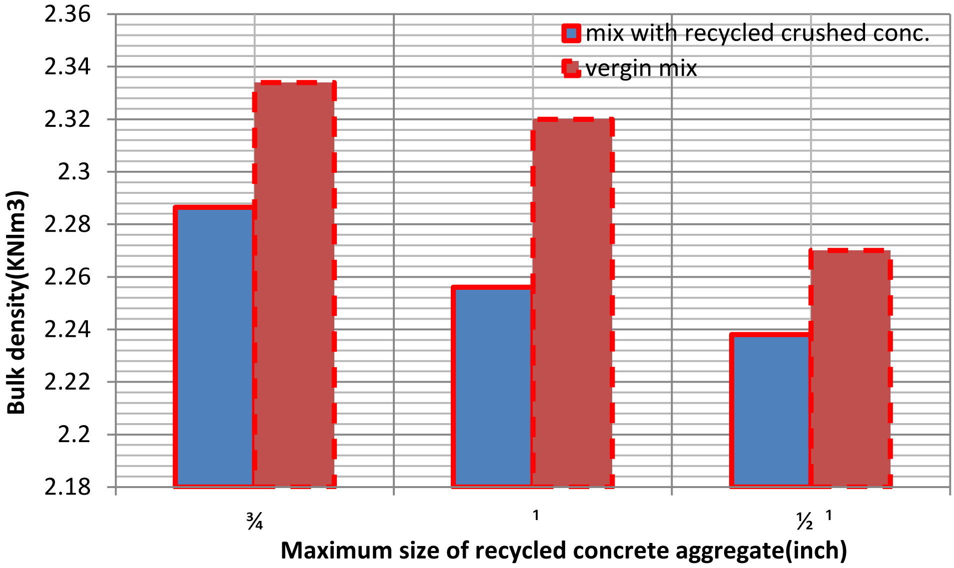

Fig. 8. Bulk density for compacted mix against maximum size of recycled concerte aggregate.

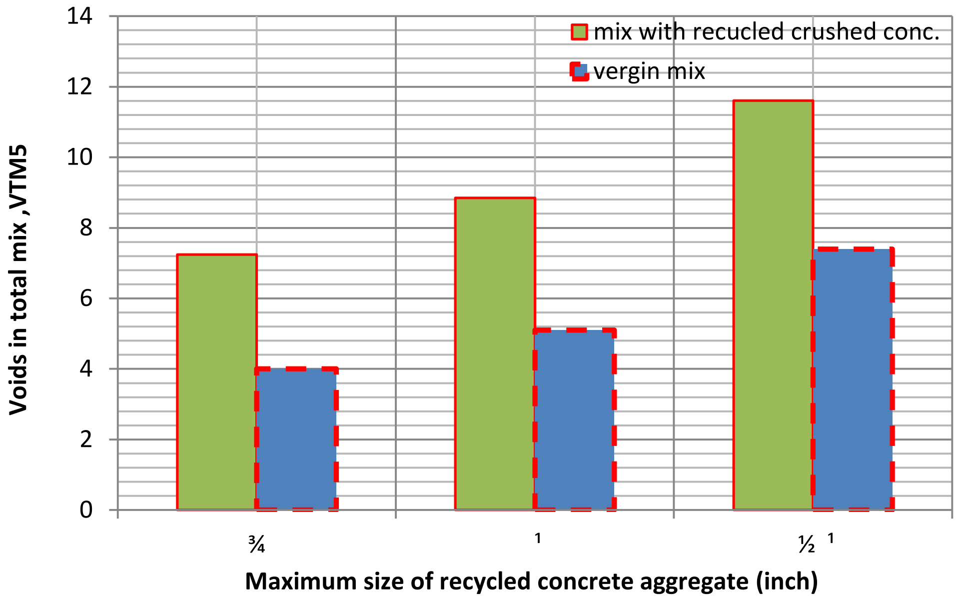

Fig. 9. VTM against maximum size of recycled concrete aggregate.

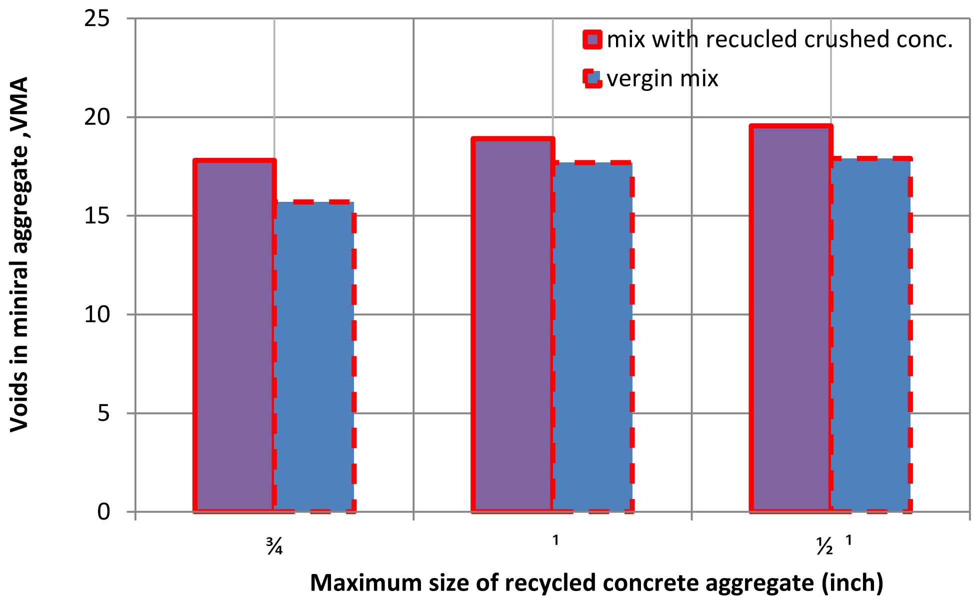

Fig. 10. VMA against maximum size of recycled concrete aggregate.

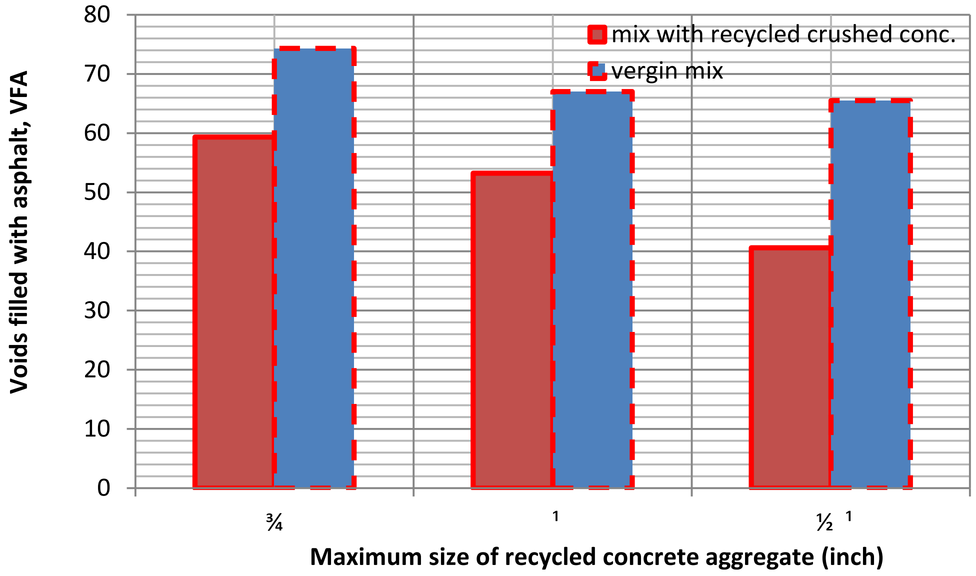

Fig. 11. VFA against maximum size of recycled concrete aggregate.

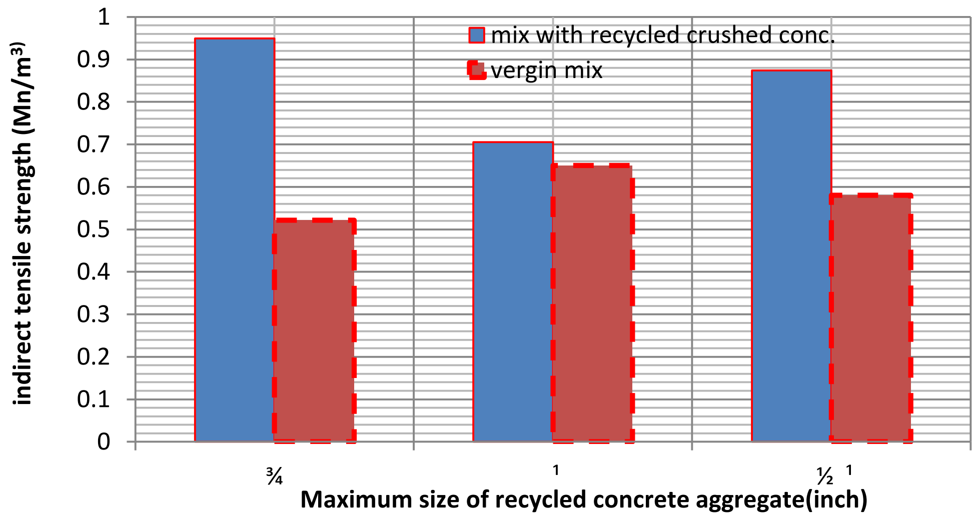

Fig. 12. Indirect tensile strength against maximum size of recycled concorete aggregate.

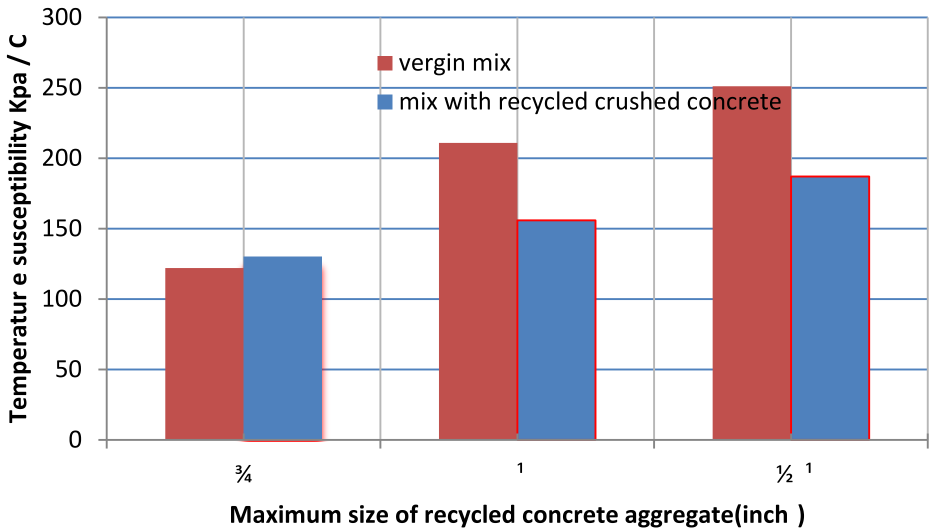

Fig. 13. Temperature susceptibility against maximum size of recycled concorete aggregate.

4. CONCLUSIONS

Within the limitations of materials and testing program, the following principles conclusions are made:-

1. Even though utilizing RC in asphalt mixtures could affect the volumetric and mechanical properties of the mixtures, but based on the demands of the project and traffic volume, using specific 58% amounts of RC in HMA mixtures can easily satisfy the standard requirements. These findings can promote the reuse and recycling of waste materials, especially RC, in pavement industries to generate economic and environmental benefits in the future.
2. The indirect tensile strength insignificantly increases in mix with recycled concrete aggregate.
3. The properties of asphalt concrete mixes are affected by recycled concrete such as Marshall stability-flow in addition to volumetric properties, such as VMA, VTM, and VFA.
4. Maximum size of crushed concrete aggregate is influencing the asphalt concrete mix properties as compared with virgin mix.
5. Typical indirect tensile strength was found in mix with 1.5 inch max size aggregate.
6. Increasing in Marshall stability significantly was noticed in the mix with 3/4 inch maximum size aggregate.
7. Deteriorating in Marshall flow value was obvious in mix with 1.5 inch maximum size aggregate.
8. Using crushed concrete aggregate is benefit since it is available in all of sites, and therefore is being cheap.
9. The appropriated indirect tensile strength values in mix of crushed concrete aggregate enables the user from placing it in the surface pavement layer.

10. Improvement in resistance to indirect tensile and the sensitivity to temperature especially for mixture with recycled concrete aggregate at ($1^1/_2$) inches.

5. REFERENCES

American Association of State Highway and transportation Officials (AASHTO) (2003):" Standard Specifications for Transportation Materials and Methods of Sampling and Testing", 17th edition: Washington D.C.

Arabani M. and Azarhoosh A. R., (2012). The Effect of Recycled Concrete Aggregate and Steel Slag on the Dynamic Properties of Asphalt Mixtures. Journal of Construction and Building Materials, (35), 1-7.

American Society for Testing and Materials(ASTM),(2003):" Road and Paving Materials; Vehicle Pavement Systems" , Annual Book of ASTM Standards, , Section 4, Volume 04.03.

ASTM D5821-13, (2013). Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate, ASTM International, West Conshohocken, PA, www.astm.org

ASTMD448-12, (2012). Standard Classification for Sizes of Aggregate for Road and Bridge Construction, ASTM International, West Conshohocken, PA, www.astm.org

Chen M., Lin J. and Wu S., (2011). Potential of Recycled Fine Aggregate Powder as Filler in Asphalt Mixture. Journal of Construction and Building Materials, (25), 3909-3914.

Do H. S., Mun P. H. and keun R. S., (2008). A study on Engineering Characteristics of Asphalt Concrete using Filler with Recycled Waste Lime .Journal of Waste Management., (28), 191–199.

Rawshan Ara Beguma, Chamhuri Siwar , Joy Jacqueline Pereira , and Abdul Hamid Jaafar (2006) “A benefit–cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia” Resources, Conservation and Recycling, 48, pp:86–98

Roberts F., P. Kandhal, E. Brown, D. Lee, and T. Kennedy (1996):" Hot Mix Asphalt Materials, Mixture Design, and Construction", 2nd edition, Lanham, Maryland, NAPA Education Foundation.

Transportation Research Board (TRB) (2003):" Moisture Sensitivity of Asphalt Pavements", A National Seminar, San Diego, California, February.

Wu S., Zhu J., Zhong J. andWang D., (2011). Experimental Investigation on Related Properties of Asphalt Mastic Containing Recycled Red Brick Powder. Journal of Construction and Building Materials, (25), 2883–2887.