

## Performance of Asphalt Mixes Containing RAP

*Taleb Al-Rousan*<sup>1)</sup>, *Ibrahim Asi*<sup>2)</sup>, *Omar Al-Hattamleh*<sup>1)</sup> and *Husam Al-Qablan*<sup>1)</sup>

<sup>1)</sup> Assistant Professor, Department of Civil Engineering, Hashemite University, Zarqa 13115, Jordan, Corresponding Author: Tel.: 00962-5-3903333 ext. 4383, Fax: 00962-5-3826348, E-mail: taleb@hu.edu.jo

<sup>2)</sup> Associate Professor, Department of Civil Engineering, Hashemite University, Zarqa 13115, Jordan

### ABSTRACT

Using Reclaimed Asphalt Pavement (RAP) in asphalt mixes has become a common practice in many countries. Experience indicated that the recycling of asphalt pavements is very advantageous from different perspectives. Some of the advantages of utilizing RAP include conservation of asphalt and aggregate resources, conservation of energy and reduction in life-cycle cost. In spite of that, RAP has never been used in Jordan. In this study, the suitability of asphalt mixes using RAP was investigated. Two hot asphalt mixes were prepared following gradations recommended by the Ministry of Public Works and Housing (MPWH/ Jordan). Marshall mix design procedure was used to determine the optimum asphalt content. The first mix was composed of 100% fresh aggregate and virgin asphalt and the second mix was composed of 30% RAP and 70% fresh aggregates and virgin asphalt. Marshall stability, loss of Marshall Stability, water sensitivity, indirect tensile strength, dynamic creep and fatigue tests were performed on samples of the two mixes. Comparing the results of the conducted tests indicated that the use of RAP in Hot Mix Asphalt (HMA) was advantageous in all properties measured except for the fatigue test, where shorter fatigue life was observed. The mix containing RAP showed less reduction in both loss in stability and loss in indirect tensile strength, improved stripping resistance and better creep performance than the mixture with fresh aggregates. Therefore, it is preferred to use mixes containing RAP in highways, where fatigue is not the predominant distress type.

**KEYWORDS:** HMA, Recycling, RAP, Fatigue, Rutting, Marshall stability.

### INTRODUCTION

The resulting materials during roadways maintenance and rehabilitation activities are usually known as Reclaimed Asphalt Pavements (RAP), which is normally produced by milling existing asphalt pavements or crushing materials resulting from old asphalt pavements removal. Since most of roadways are constructed using high-type bituminous pavements, RAP materials, if properly processed, will consist of high quality, well-graded asphalt coated aggregates. RAP materials are most

usually processed in central plants, but can be performed directly on site using appropriate machinery as in the cases of cold in-place or hot in-place (Turner Fairbanks Highway Research Center, 2001; Washington Asphalt Pavement Association, 2002).

RAP can be used in many highway construction applications as an aggregate substitute and asphalt cement supplement in recycled asphalt paving (hot mix or cold mix). In addition, it can be used as a granular base or subbase, stabilized base aggregate or as an embankment or fill material (Turner Fairbanks Highway Research Center, 2001). Using RAP in asphalt mixes has become a common practice in many countries, as indicated by (Thomas et al., 1998; Brown, 2005; Page, 1987; Page and

Murphy, 1987), because it helps in maintaining the existing roadway profile, conserving asphalt and aggregate resources, saving energy, reducing construction and life-cycle cost, providing asphalt mixes that are equal to or better than mixes with virgin asphalt and aggregates, achieving effective rehabilitation techniques and preserving the environment by reducing the amount of asphalt binder needed, in addition to reusing valuable or scarce aggregates and preserving valuable landfill space from unnecessary disposal of old pavement materials.

Over the past three decades, Jordan has invested a considerable amount of money in constructing roadways according to international standards. Due to the cruel environmental conditions and traffic loading, roads have shown early signs of distress (Suliman et al., 2004). Developed distress in early stages shortens the pavement service life and accelerates the need for major maintenance and rehabilitation. These operations usually generate a massive amount of RAP that can be considered a waste if not utilized in an appropriate way. Based on the statistics of the Ministry of Public Works and Housing (MPWH) in Jordan, it is estimated that 10,000 tons of RAP materials are produced yearly during maintenance activities on roads. Unfortunately, a slight percent of this RAP is being reused in some applications but not in re-asphalting jobs; while in the United States, for example, and according to documents published by the National Asphalt Pavement Association (NAPA), the Federal Highway Administration (FHWA) estimates that out of the 90 million tons of Hot Mix Asphalt (HMA) milled and removed each year, 90% is reused in highway applications in one form or another, including pavements, subbase and fill. About 1/3 of the 90 million tons is recycled into HMA (Brown, 2005).

A considerable amount of work has been done in studying the performance of recycled mixes. A number of researchers (Little and Epps, 1980; Little et al., 1981; Meyers et al., 1983; Brown, 1984; Kandahal et al., 1989) pointed out that recycled mixes performed equally or in some cases better than conventional mixes.

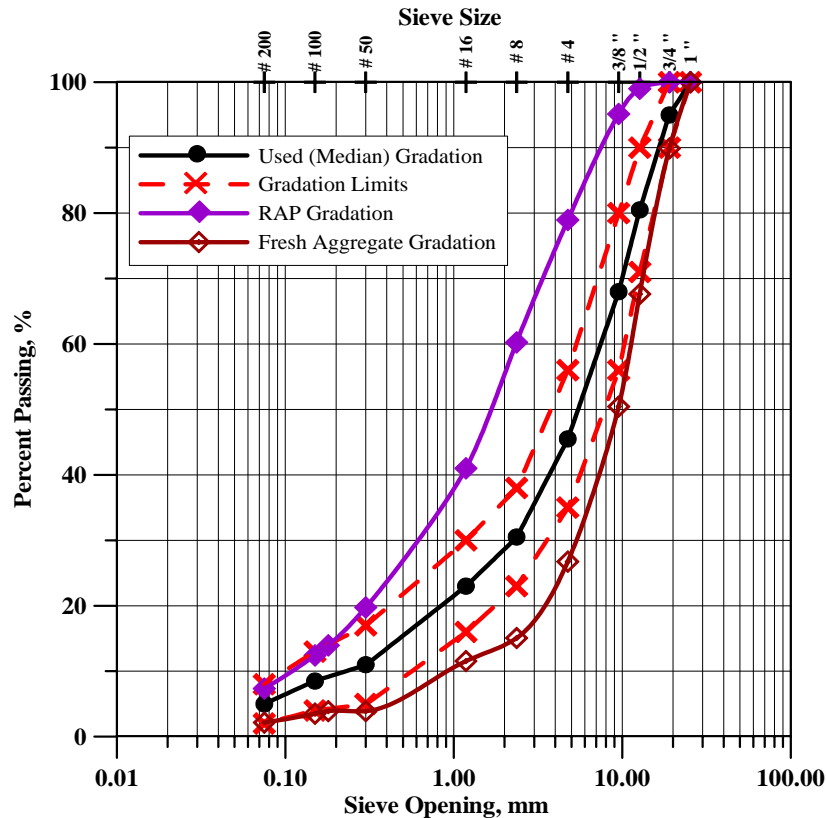
Kandahal et al. (1995) studied different field projects which have used recycled and virgin mixes. The study

included measuring some *in-situ* properties (such as air voids, resilient modulus and indirect tensile strength) and laboratory recompacted mix properties (such as gyratory stability and dynamic creep modulus), in addition to some recovered asphalt binder properties (such as penetration and viscosity). They indicated that the statistical analysis showed no significant differences between the properties of the virgin and recycled mix pavements which have been in service from 1.5 to 2.5 years. They also concluded that there was no statistically significant difference between recovered asphalt properties (penetration and viscosity) of recycled and virgin pavements in service.

The durability of the recycled mixtures was also evaluated by a number of researchers. In their study, Kiggundu and Newman (1989) indicated that recycled mixtures had better resistance to the action of water than the virgin mixtures. Another study by Dunning and Mendenhall (1978) showed that the durability of recycled asphalt concrete mixtures was better than that of the conventional mixtures.

Kandahal et al. (1995) pointed out that the properties of the recycled mixtures are believed to be influenced by the properties of the aged binder in RAP and the amount of RAP in the mixture. They also indicated that the amount of RAP used in the recycled mixture depends on the type of hot mix plant being used for preparing the mix, environmental considerations and gradation of the aggregate in RAP, especially the material passing #200 (0.075 mm) sieve size. Due to the various and obvious advantages of using RAP, many state highway agencies are moving toward rising the percentages of RAP in their hot-mix asphalt pavements (EPA and FHWA, 1993). RAP has been used in hot mix asphalt pavements in various percentages that reached in some cases up to 80% (EPA and FHWA, 1993), and most usually from 20-50% (Daniel, 2005; Lynn, 1992; Solaimanain and Tahmoressi, 1996).

The objective of this study is to investigate the suitability of using the local materials and the milled asphalt concrete waste in producing RAP that suits Jordan environmental and loading conditions.



**Figure (1): Ministry of Public Works and Housing (MPWH) specified gradation limits for heavy traffic loads wearing course, median gradation, rap aggregate gradation and added fresh aggregate gradation.**

#### STUDY APPROACH AND METHODOLOGY

In order to achieve the objective of this study, the following suggested approach was followed. Using the recommended gradation by the Ministry of Public Works and Housing (MPWH/ Jordan) for heavy traffic wearing course, two different hot asphalt mixes were prepared and compared. The basis of assessment is to use standard procedures described by the American Society of Testing and Materials (ASTM, 2000), and the American Association of State Highway and Transportation Officials (AASHTO, 1988), to measure some properties of the two hot asphalt concrete mixes, and then to compare their performance. The proceeding text provides detailed description of the adapted procedure.

#### Tests on Reclaimed Asphalt Materials

Reclaimed asphalt materials were brought from a

project site where milling operations are conducted to perform maintenance of some roadways in Amman/ Jordan. Representative samples of reasonable sizes from the site were selected following the (ASTM C-702) test procedure. This procedure is crucial to reduce bias due to unforeseen factors that would affect measurements. In order to estimate the amount of asphalt in the RAP material, extraction test (ASTM D2172-95) was performed followed by sieve analysis of the clean aggregate. The asphalt content of RAP was found to be 5.9%. Figure 1 shows the gradation of RAP aggregate. It can be noticed that RAP aggregate gradation is finer than the median recommended gradation by MPWH for heavy traffic loads wearing course. This is mainly due to the crushing of the aggregates during the milling process, in addition to the aggregate wear that occurs during mixing, compaction and traffic serving of the asphalt concrete

mix. Specific gravity and absorption of the RAP aggregate were calculated according to ASTM C127-88

(for coarse aggregates) and ASTM C128-97 (for fine aggregates) test procedures.

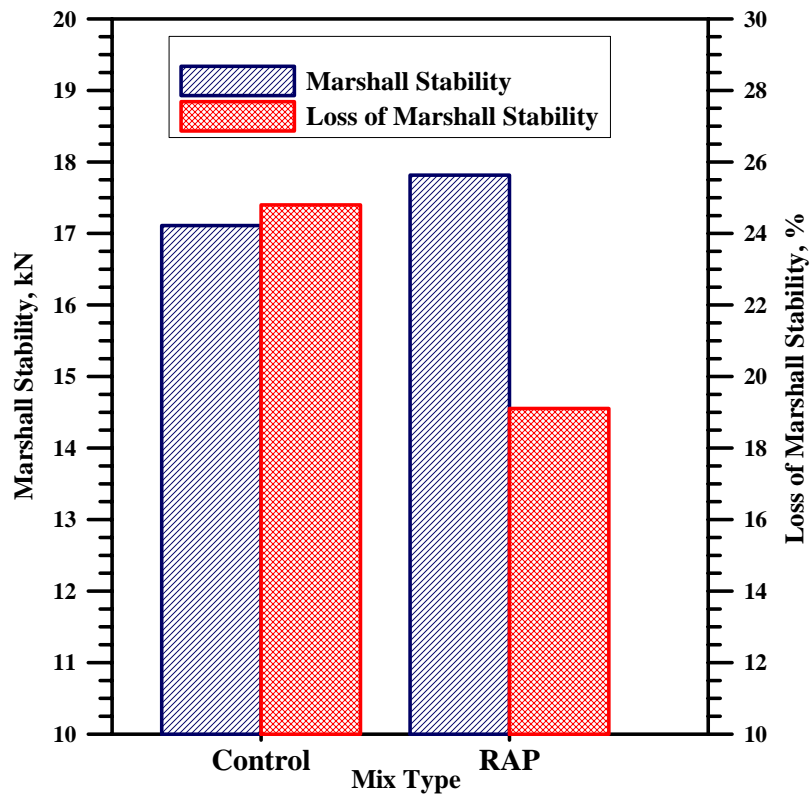


Figure (2): Marshall stability and loss of Marshall stability between control and RAP mixes.

**Preparation of the Asphalt Concrete Mixes**

The gradation results of the RAP materials (Figure 1) suggested that fresh aggregates should be mixed with the RAP material to meet MPWH standard recommended gradation. Two asphalt mixes were used to achieve the goals of this study. The first mix, called "Control Mix", was composed of 100% fresh aggregate and virgin asphalt; while the second mix, called "Rap Mix", was composed of 30% RAP (aggregate and asphalt), and 70% fresh aggregates and virgin asphalt. Marshall mix design procedure (ASTM D1559), which is currently used in Jordan for asphalt concrete mix design, was used to determine the optimum asphalt content (that produces 4% air voids) for the asphalt mixes used in the study. The Job Mix Formula results suggest that the optimum asphalt

content would be 5.5% of the total mix. Marshall stability, flow, voids filled with asphalt and voids in mineral aggregate values were checked to verify that they meet the specification limits of MPWH for heavy traffic loads wearing course.

**Suggested Performance Tests for Comparison**

In order to examine the suitability of asphalt mixes using RAP, the following tests were performed on samples from the two mixes: Marshall stability; loss of Marshall stability; water sensitivity; indirect tensile strength and dynamic creep. For consistency reasons, Superpave Gyrotory Compactor was used to compact the test samples at 4% air voids.

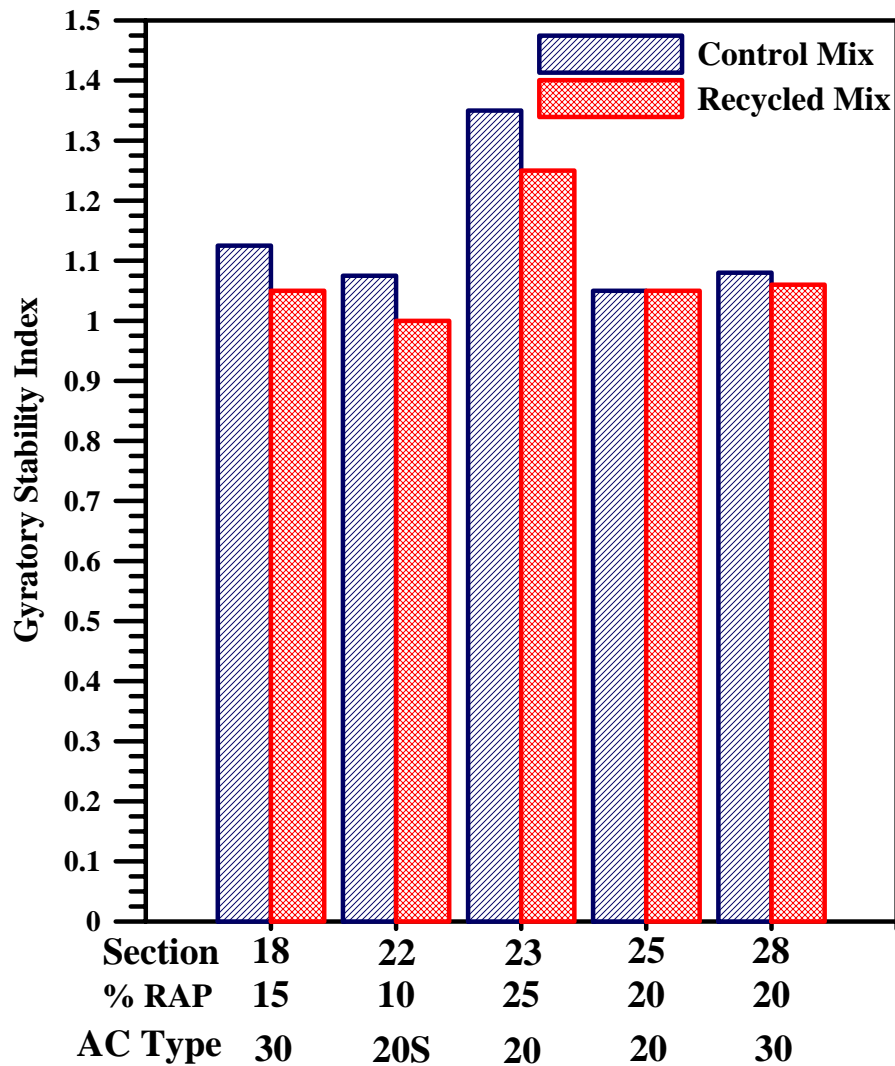


Figure (3): Gyratory Stability Index (GSI) for recycled and control mixes as reported by Kandahal et al. (1995).

#### PERFORMED PERFORMANCE TESTS AND RESULTS

##### Marshall Stability and Loss of Marshall Stability Test Results (ASTM D1559)

Six compacted samples from each mix were placed in a water bath at 60°C. After 30 minutes immersion in the water bath, three samples were tested for Marshall stability as described by (ASTM D1559) standard procedure. The remaining three samples were tested for

Marshall stability after 24 hours immersion to find loss of Marshall stability. Figure 2 presents the difference in Marshall stability and loss of Marshall stability between the two mixes ("Control Mix" and "Rap Mix"). Figure 2 clearly shows that the inclusion of the RAP aggregates and asphalt in the "RAP Mix" have improved the Marshall stability and reduced the loss of Marshall stability over the "Control Mix". It is believed that this can be attributed to the fact that RAP contains hardened asphalt, which will lead to increased stability due to

higher asphalt viscosity. Hardened asphalt is more viscous than virgin asphalt of the same type and grade. Therefore, when the two mixes are subjected to immersion, the stability of the "RAP Mix" will be less affected by hot water than that of the "Control Mix" that is completely made of fresh concrete.

These results of stability are supported by the findings of Kandahal et al. (1995). They have used the Gyrotory

Stability Index (GSI) as a measure of the stability of the mix. Figure 3 shows the GSI values of the recycled and control mixes. GSI values in excess of 1.0 indicate an increase in plasticity. The results shown in Figure 3 suggest that the GSI values for the two mixes are analogous, and there was no statistical significant difference between the recycled and control mixes.

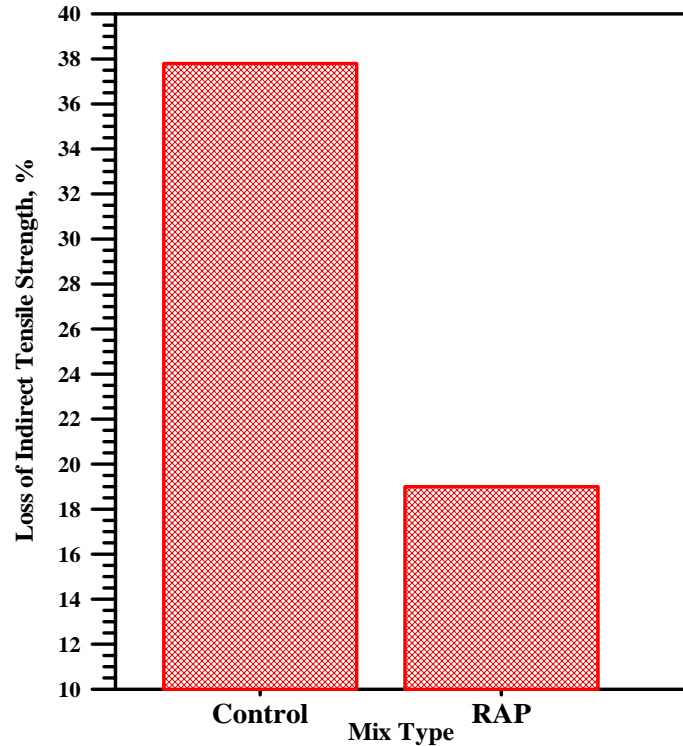


Figure (4): Loss of Indirect Tensile Strength (ITS) between control mixes and RAP mixes.

#### Water Sensitivity Test (Lottman Test AASHTO T-283-89)

The improvement in stripping resistance (water susceptibility) of the asphalt concrete mixes due to RAP usage in asphalt mixes was evaluated by measuring the loss or reduction of the Indirect Tensile Strength (ITS) after immersion in water for 24 hours at 60° C, according to AASHTO T-283 test procedure. Six samples of each mix were used. Three samples were tested for their initial ITS values. The other three samples were immersed in water for 24 hours at 60°C, and then immersed in a 25°C

water bath for 2 hours, before their final ITS values were obtained. Comparison of loss in ITS between "Control Mix" and "RAP Mix" is presented in Figure 4. It can be noticed clearly in Figure 4 that the loss in ITS for mixtures containing RAP is much lower than mixtures containing no RAP. This is attributed to the fact that RAP contains hardened asphalt that became more viscous as time passes. Thus, mixtures with more viscous materials will perform better under tension, which will lead to smaller reduction in tensile strength when exposed to severe conditions of high temperature and moisture.

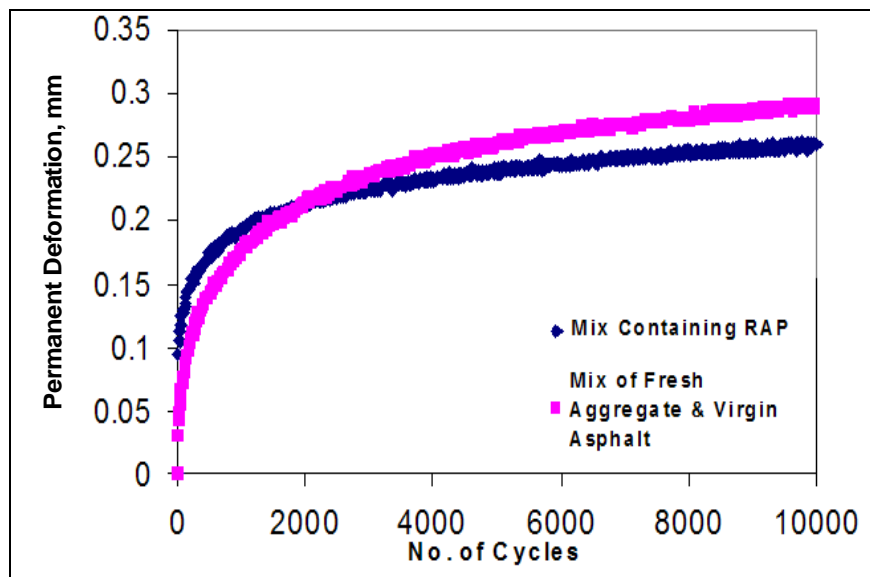


Figure (5): Average creep results of control and RAP mixes.

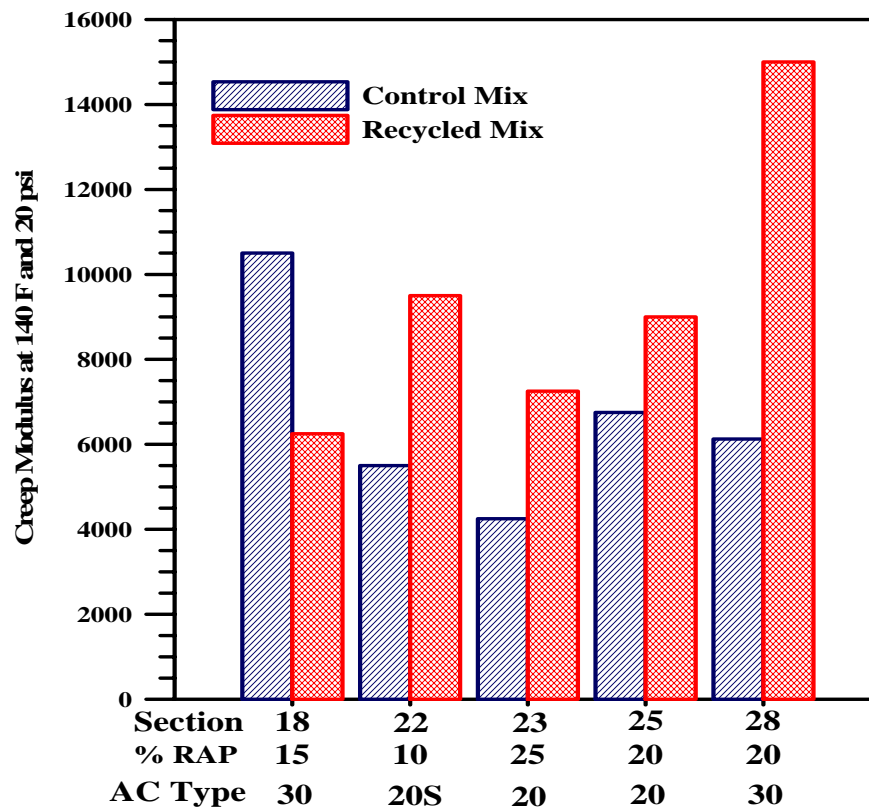


Figure (6): Creep modulus values as found by Kandahal et al. (1995).

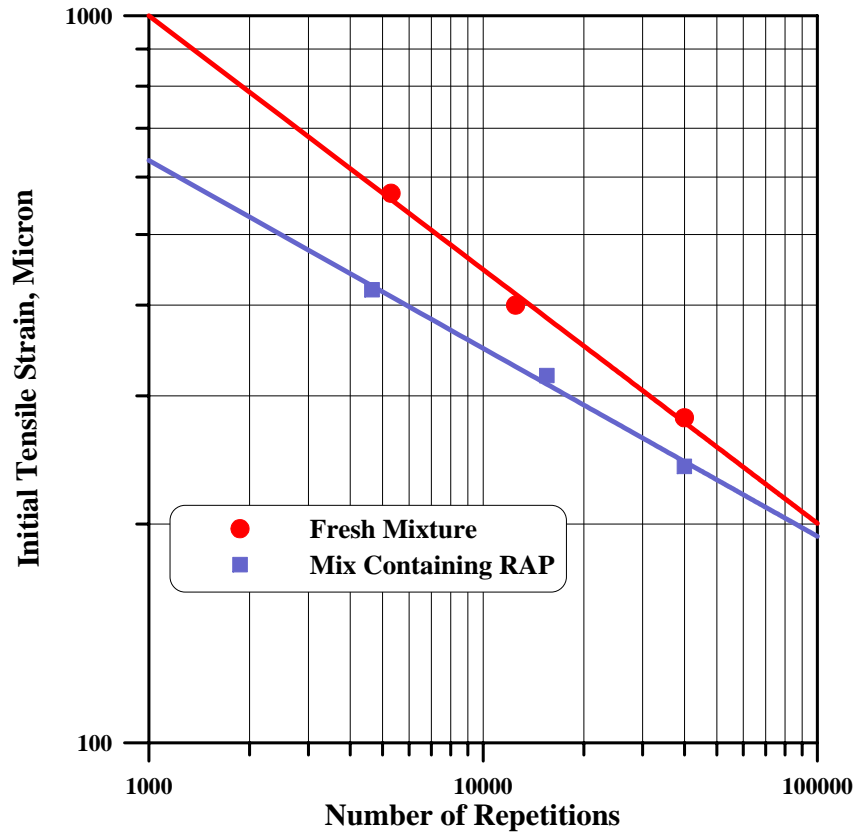


Figure (7): Fatigue behavior of the control and RAP mixes at 40°C.

This finding is supported by the findings of Kiggundu and Newman (1987) who indicated that recycled mixtures endure better resistance to the action of water than virgin mixtures.

#### Dynamic Creep Test

The dynamic creep test is a test that applies a repeated pulsed uni-axial stress on an asphalt specimen and measures the resulting deformations in the same direction using Linear Variable Differential Transducers (LVDT's). The test was performed in accordance with the protocol developed by NCHRP 9-19 Superpave Models, Draft Test Method W2 (Witezak et al., 2001). The applied stress on the specimen was a feedback haversine pulse. The pulse width duration was 100 milliseconds (ms), and the rest period before the application of the next pulse was 900 ms. The deviator stress during each loading

pulse was 207 kPa, and the contact stress was 9 kPa. The contact stress was applied so that the vertical loading shaft does not lift off the test specimen during the rest period. The test was performed at 40°C. The specimen's skin and core temperatures during the test were monitored by two thermocouples which were inserted in a dummy specimen and located near the specimen under test. The testing was continued until the maximum axial strain limit reached 10000 micro-strains, or until 10000 cycles, whichever occurred first. Three samples from each mix were tested. Figure 5 shows the relationship between the number of cycles and the axial accumulated permanent deformation for the mix. It can be noticed that mix samples containing RAP showed better creep performance than samples of mix made of fresh aggregate and virgin asphalt. Similar to the previous test, this behavior difference is attributed to the hardened



asphalt in RAP that possesses higher asphalt viscosity.

Similar results were obtained by Kandahal et al. (1995) as shown in Figure 6. The creep histogram in this figure shows that recycled mixes have higher resistance to permanent deformation compared to control mixes, although the statistical test showed that the differences are not statistically significant.

### Fatigue Performance

Samples from both mixes were tested diametrically under repeated pulsed uni-axial loading to determine the number of loading cycles required to fail the samples. To have a wide range of failure cycles, test samples were tested at different initial tensile strain levels. At least nine samples from each mix (three at each initial tensile strain level) were tested at 40°C. Figure 7 shows the results of these tests. In this figure, regression lines were drawn through the mean of samples at each strain level. The results show a linear relationship between the logarithm of applied initial tensile strain and the logarithm of fatigue life (number of applied load repetitions until failure). Figure 7 implies that mixtures not containing RAP will have longer fatigue life than mixtures containing RAP, which can be attributed to the existence of the aged asphalt in the RAP material.

### CONCLUSIONS

This paper presents a comparative study between the

currently used hot asphalt mixes in Jordan which use fresh aggregates and virgin asphalts and those mixes prepared using local RAP materials. Measurement of Marshal stability, loss of Marshal stability, water sensitivity, dynamic creep and fatigue tests were conducted, compared and analyzed. The results of the conducted tests indicate that the use of RAP in hot mix asphalt is advantageous. These results agree with and support previous research findings. Based on the performed tests, the following conclusions can be drawn:

1. The mix containing RAP showed less reduction in both loss in stability and loss in indirect tensile strength, improved stripping resistance, and showed better creep performance than the mixture made completely of fresh aggregates and virgin asphalt.
2. The study revealed that mixtures containing RAP may have shorter fatigue life due to aged asphalt that exists in the mix through RAP usage. Therefore, it is preferred to use mixes containing RAP in areas, where fatigue is not the expected predominant distress type.
3. It can be concluded that recycled pavements can generally perform as well as conventional pavements.
4. Finally, the authors believe that a construction of trial sections of recycled and conventional mixes, will verify the suitability of asphalt mixes containing RAP to Jordan climatic and loading conditions.

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