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PERFORMANCE EVALUATION OF HOT MIXTURE RECLAIMED ASPHALT PAVEMENT

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Abstract

In recent years, the use of recycling materials is one of the most feasible pavement rehabilitation alternatives, and a variety of recycling techniques are now available to deal with explicit pavement structural needs. The aim of this study was to investigate and evaluate the suitability of using Reclaimed Asphalt Pavement (RAP) materials in highway construction and rehabilitation. Reclaimed materials from three sites in Nineveh Governorate in Northern Iraq were sourced out for this work. The RAP materials were mixed with virgin material for wearing course construction. A series of tests were conducted on specimens made of RAP with 30%, 100%, control mixes without RAP, and core and beam obtained from the field. Tests were performed to evaluate the examined characteristics of studied hot mix asphalt (HMA). Results from the three different sources were considered consistent as they exhibited slight irregularities. The asphalt mixture of 30% RAP had increased more than 20%, 4.5%, and 10% in Marshall stability, tensile strength ratio, and flexural modulus at 0 ºC respectively concerning control mixture. Also, a reduction concerning a reference mixture of 13%, 74%, and 46% in cohesion value, fatigue life, and rut depth respectively. Therefore, they presented the best mixture performance among the percentage ranges tested.

Keywords: Fatigue, HMA, Performance characteristics, Permanent deformation, Reclaimed asphalt pavement (RAP), Recycling.

1. Introduction

As highway pavement approaches its end of service life, the grinded materials – recognized as Reclaimed Asphalt Pavement (RAP) - continue to sustain significant engineering properties. This quality makes RAP materials to be an attractive source of recyclable material that can be mixed with new asphalt mixtures to reduce quantities of needed virgin material, and consequently conserve the natural resources that can be an exceptional commodity in many countries.

Therefore, recycling of asphalt pavements is a very profitable approach from economical, technical, and environmental views [1]; also, the use of RAP in new pavement construction contributes to sustainable construction and considered eco-friendly [2, 3]. Additional benefits of using RAP comprise the conservation of existing roadway profile, utilizing less energy, and reductions in the amount of waste produced. Also, asphalt mixes containing RAP can be comparable to the virgin asphaltic mixtures without negatively influencing the mechanical properties of the mixtures [4]. On the other hand, the inaccurate use of RAP causes a reduction in pavement performance [5-7].

Conventional percentages of RAP used in HMA is in the range of 20-50% [8]. However, the many advantages this practice have made many highway agencies using as high as 80% of RAP in some HMA applications [9], However, a correctly designed and produced RAP must have identical performance to a mixture created completely of new materials [6].

Substantial savings have been reported by many highway organizations when using RAP [10] since using of RAP in new asphalt mixtures can reduce the quantities of fresh materials (asphalt and aggregates) required per ton of mixture with a consequent overall reduction in material costs. It was appraised that using RAP in HMA provided cost saving that ranged from 14 to 34 percent when RAP content extended from 20 to 50 percent of the total blend [11]. In Alaska, saving in cost analysis is estimated at $13.3/ton in materials cost when RAP content of 25% is added to the asphalt mix [12]. Therefore, the use of RAP can produce economic and environmental profits; while, the confirmation of suitable RAP managing and usage in HMA is required to ensure suitable pavement performance. The quality of the fresh aggregates and virgin asphalt, age of milled pavement, as well as the amount of RAP material highly influence the mixture properties.

Previous local researches performed on the use of RAP in highway pavement are scattered in results [13, 14]. It was felt that an in-depth study on RAP usage in local construction status will be useful.

The goal of this study is to evaluate pavement performance for hot asphalt mixtures using RAP from three sites. RAP was presented into the asphalt blends at the level of 30% replacing the fresh component in the mixtures. Control mix without RAP and with 100% RAP was also prepared. All mixtures were examined using the standard laboratory tests outlined below.

2. Materials and Methods

In this research, the RAP material was obtained from three roadway sites in Nineveh Governorate. The site locations are:

- Gateway of Mosul city in Mosul-Kirkuk road (Road A); date of paving, 1986.

- Gateway of Mosul city in Mosul-Erbil road (Road B); date of paving, 1984.
- Gateway of Mosul city in Mosul-Dohuk road (Road C); date of paving, 1989.

Figure 1 shows road sites locations on Mosul map. The asphalt contents of the RAP were determined according to ASTM specification D2172 [15]. A group of three representative samples of RAP for each road were utilized to determine the aggregate gradations and asphalt contents. Virgin asphalt of grade 50-60 was obtained from Qayara Refinery. Physical properties of the virgin asphalt are listed in Table 1. New aggregates were obtained from a local asphalt plant in the city of Mosul. Physical properties were determined according to ASTM [15] on samples of RAP and fresh aggregates. The findings are summarized in Table 2.

Fig. 1. Road site locations.

Table 1. Physical properties of virgin asphalt.

Properties	Condition of test	ASTM designation no.	Value
Penetration	25 ˚C,100 gm, 5 s	D-5	54 (0.1 mm)
Softening point	(ring and ball)	D-36	55 ˚C
Specific gravity	25 ˚C	D-70	1.045
Ductility	5 cm/min, 25 ˚C	D-113	100^+ cm
Flashpoint	Cleveland open cup	D-92	248 ˚C
Viscosity	135 ˚C	D-2170	760 cSt
Properties after thin film oven test D1754			
Loss on weight	163 ˚C, 5 hr	D-1754	0.302%
Penetration of residue	25 ˚C, 100 gm, 5 s	D-5	63%
Aged softening point	(ring and ball)	D-36	61 ˚C
Ductility of residue	5 cm/in,25˚C	D-113	32 cm

Table 2. Properties of RAP and fresh aggregates.

Properties		Bulk specific gravity	Water absorption	Angularity	Toughness	Fracture
		ASTM C-127 and C-128			ASTM C-131	ASTM D-5821
RAP (Road A)	**Coarse**	2.633	0.786	> 100	21.4	98
	Fine	2.279	1.201	69.7	------	------
	Filler	2.370	-------	-------	------	------
RAP (Road B)	**Coarse**	2.607	0.791	> 100	20.3	98
	Fine	2.267	1.213	75.6	------	------
	Filler	2.410	-------	------	------	------
RAP (Road C)	**Coarse**	2.591	0.711	> 100	24.0	97
	Fine	2.266	1.182	68.3	------	------
	Filler	2.420	-------	------	------	------
Fresh aggregate	**Coarse**	2.668	0.673	> 100	18.7	95
	Fine	2.523	1.096	62.8	------	------

Aggregate gradation of the RAP and the cut-off aggregate samples gradation are shown in Figs. 2(a) and (b) respectively. Recommended gradation limits were set in accordance with ASTM specification D3515 [15] for dense mixes of a nominal maximum size of 12.5 mm. The RAP material was mixed with the virgin aggregate at their middle gradation limits so that the final blended specimens retained the same gradations as their parents' materials. The RAP aggregate gradations were found to be finer than the middle gradation limits. This is considered acceptable since aggregate crushing and breakage are expected due to mixing and compaction during construction and subsequent trafficking during its service life or during the milling process. Ordinary Portland cement, provided by Badoosh Cement Factory, was used as a filler. The Portland cement has a specific gravity of 3.15.

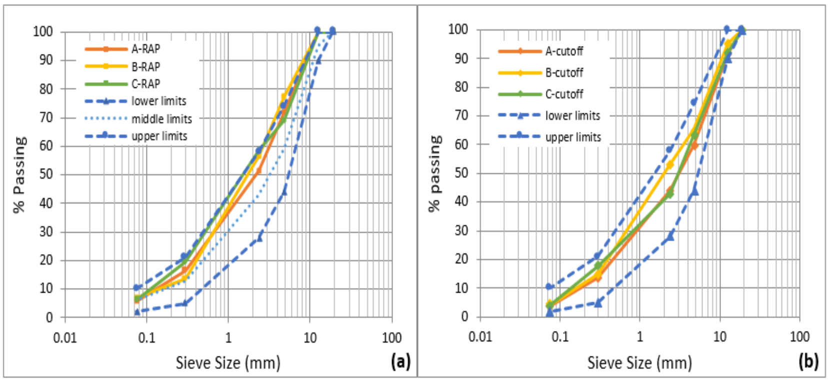

Fig. 2. (a) RAP gradations and selected aggregate gradation and (b) Cut-off gradations.

2.1. Mixture design

To determine optimum asphalt content of the mixture, specimens of 4, 4.5, 5, 5.5, and 6 % by weight (virgin asphalt cement to total mix) were prepared in accordance with Marshall method [15]. Three samples for each percentage of asphalt content were examined. The samples were compacted by applying 75 blows for each face. The optimum asphalt content was taken as the average of the asphalt content identical to maximum bulk specific gravity, maximum stability, and 4% air voids in accordance with the testing method explained by Asphalt Institute [16]. The optimum asphalt content was found to be 5.1%; this target optimum asphalt content was employed in producing the other mixtures to preserve uniformity over this study. Abdul-Mawjoud and Ismaeel [13] recommended RAP, in which, was insert into the asphalt mixtures at a rate of 30% integral with a virgin component of the mixture. Furthermore, specimens of 100% of RAP (as-is RAP) and extracted cut-off from the paved (field specimens) also prepared for each road. A control mix was produced with 100% virgin materials, enabling a comparison of the properties of recycled asphalt mix.

2.2. Performance tests

The performance tests used in this research to determine the influence of RAP on the properties of HMA mix was conducted on: (1) a conventional mix made of 100% virgin materials, (2) on the RAP mix and (3) the extracted cut-off (field specimens) from the three roads.

Marshall test in accordance with ASTM specification D1559 [15] was conducted to find the influence of RAP on Marshall properties of HMA mix. A tensile strength ratio (TSR) test in accordance with ASTM D4867 [15] was performed to evaluate the moisture susceptibility of the mixture. Six Marshall specimens were arranged for virgin and each of three roads mixtures for RAP and field specimens, three specimens for each dry and wet group were evaluated. A tensile strength ratio of wet to dry groups were computed based on the indirect tensile strength tests at a temperature of 25 °C. The higher value of TSR means less strength influenced by the water soaking condition, therefore, more water-resistant. Putman and Amirkhanian [17] indicated the requirement value of TSR in HMA should be more than 85%.

For tests at low temperature, flexural tests as described in ASTM specification D78 [15] were carried out using beam specimens of (300×48) mm, 60 mm thick cut from (300×300) mm, 60 mm thick compacted slab prepared by roller compaction machine (progressed by Road Research Laboratory). Three samples for each RAP and cut-off (field specimens) from each road were utilized for each temperature of the test. Specimens were tested at different temperatures of 0 °C and -ve10 °C.

A cohesion rating was conducted using a cohesiometer test described at ASTM specification D1560 [15] on Marshall samples, the higher value of cohesion indicates a better cohesive performance of mixture. Creep test usually includes the utilization of static load over a presented period of time and measuring the output strain. Creep test -as described by Liu [18] was performed on Marshall samples, the load used was 100 kPa during the vertical diameter plane, the values of deformation were recorded of one hour of loading pursued by one hour of recovery. The test was performed at two different temperatures of 25 °C and 40 °C.

The impedance to fatigue was executed on beam samples obtained from sawed roller-compacted slabs with a dimension of (400×300) mm, 50 mm thick prepared in agreement with EN 12697-33 [19]. The dimension of beams was (400×63) mm, 50 mm high. The fatigue test was carried out according to AASHTO T 321 [20].

Three specimens for each type of RAP were used, a constant strain mode of loading with a repetitive four points loading were applied on each specimen. A repeated sinusoidal (haversine) load was utilized to the two inner clamps, while the outer clamps supplied the reaction load. The beam testing is executed at three various strain levels of 250, 400, and 750 micro-strain at a constant frequency of 5 HZ with a temperature of 20 ˚C. The test was achieved as the beam attained a 50% reduction of the specimen's initial stiffness. Fatigue testing apparatus is illustrative in Fig. 3.

The test of permanent deformation was performed by wheel tracking apparatus on a compacted slab specimen of (300×300) mm, 60 mm thick intended by the roller compaction machine. The prepared slab was stored and tested at 60˚C, for a wheel load of 700 Newton, and 10000 cycles at speed of 26.4 repetitions/minute. Figure 4 presents the slab sample in the apparatus. AASHTO specification recommends maximum deformation of 20 mm [20] whereas, British Standard recommends 15 mm [19].

Fig. 3. Fatigue testing equipment.

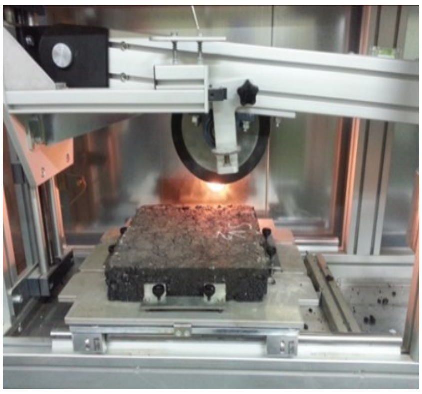

Fig. 4. Wheel tracking apparatus.

3. Results and Discussion

3.1. Marshall properties

The Marshall properties of the blends from the three road sites were determined and the outcomes are demonstrated in Fig. 5. It was found that mixtures containing 100% RAP retained higher values for Marshall stability compared with control and 30% RAP mixtures.

Such finding is comparable with Oner and Sengoz [21], and Kayedi et al. [22] results. This can be assigned to that RAP had stiff asphalt causing higher stability. It is also shown that mixtures with 100% RAP had greater stability than specimens obtained from the field for the mixtures of the three road sites. This may be attributed to the crushing of the aggregate during milling and re-compaction for the 100% RAP.

Figure 5 also showed that the flow values are greater than 2 mm only for control and 30% RAP for all types of mixtures while, the unit weight declined, and air voids elevated as increasing the proportion of RAP. This is due to difficulties associated with the compaction for the stiffer mixtures.

It is also shown that the unit weight values of the field obtained specimens are greater than the corresponding values of 100% RAP, while air voids are reversed, this is due to densification of field obtained specimens as a result of traffic movement during its service lives. The differences between the values of the mixtures for the three roads for each % RAP were insignificant.

Voids in mineral aggregate and voids filled with the binder are reduced as the percentage of RAP content increased for the mixtures of the three road sites, their values for 30% RAP is above 15 and 70 respectively. These results are comparable with the work by Hussain and Yanjun [23].

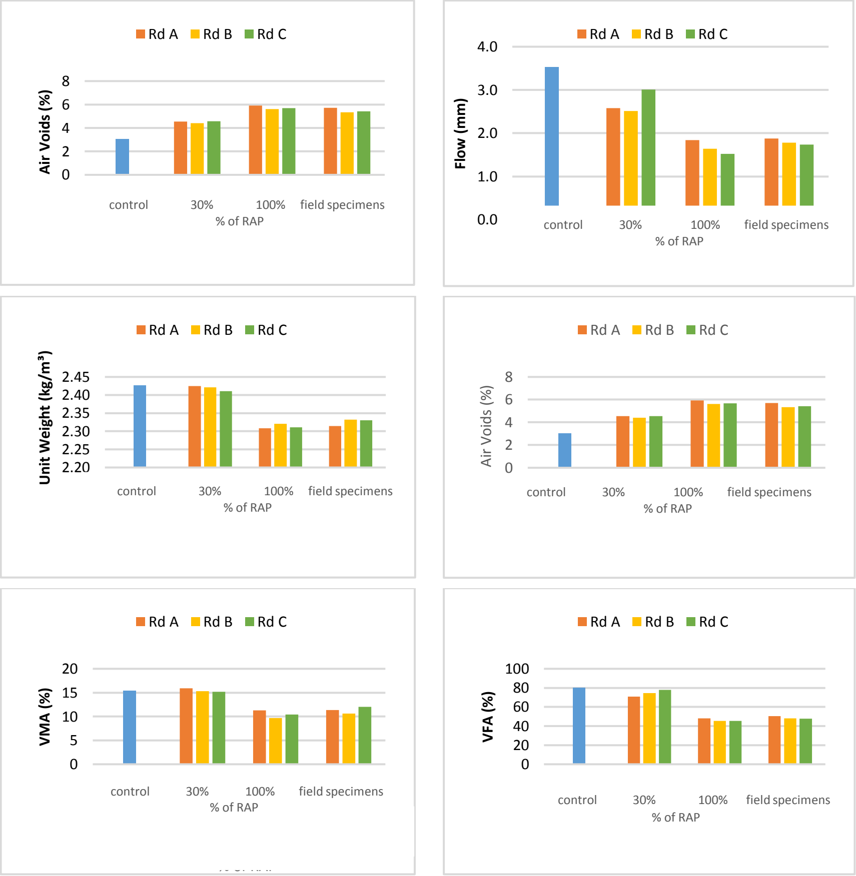

Fig. 5. Marshall properties.

3.2. Moisture susceptibility

Indirect tensile strength (ITS) was performed on the RAP mixtures for the three road sites. Figure 6 shows the result of indirect tensile strength, which indicate that the values for both testing temperatures of 100% RAP and field obtained samples are greater than 30% RAP. Coefficient of variations (COV) from control mixture for 30% RAP, 100% RAP, and field obtained samples for Road A were found to be 43%, 133%, and 175%, respectively for dry samples, while COV for testing wet samples, were 52%, 143%, and 236% respectively. The increase in values of ITS with the increasing of % RAP for both testing temperatures could be the result that RAP have stiff and more viscous asphalt, so, mixtures behave better under tension.

Figure 7 shows the results of tensile strength ratio. It is evident that the values of TSR increase with the increased percentage of RAP for the three mixtures, therefore, suggesting enhanced resistances of asphalt mixture to moisture exposure. These results are compatible with the findings of Sarsam and Al Zubaidi [14] and Singh et al. [24], but not in agreement with the works of Tabakovic et al. [25]. Whereas, the results from Sondag et al. [26] showed no notable variation with moisture sensitivity. However, the highest values of TSR among the three roads are for Road B, this may be attributed to the oldest mixtures from the three types. In addition, the values of TSR for 100% RAP are greater than field obtained specimens for all mixtures. This may be due to re-compaction processes and changing the path of voids for the mixtures of 100% RAP.

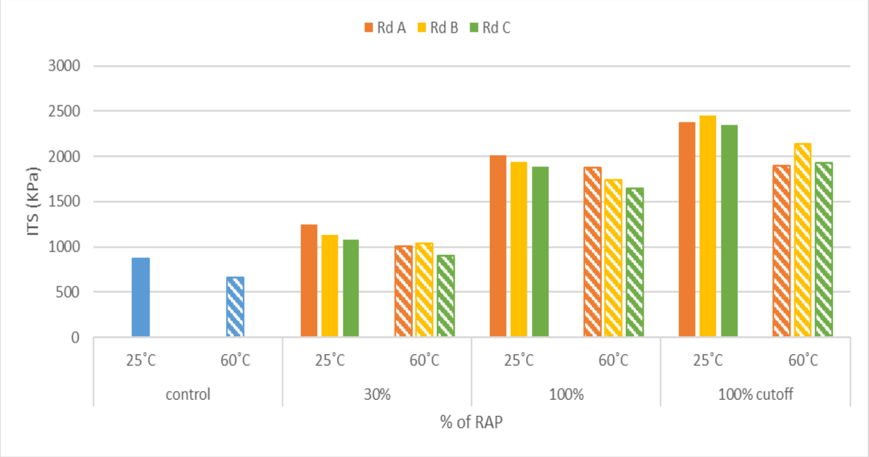

Fig. 6. Indirect tensile strength against % of RAP.

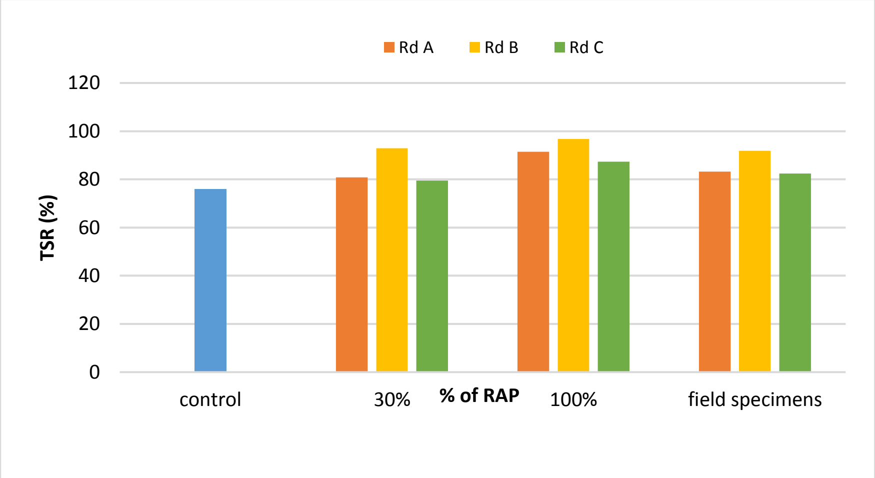

Fig. 7. Tensile strength ratio against % of RAP.

3.3. Effect of low temperature on flexural modulus

The outcomes of flexural modulus for the RAP mixtures from the three road sites tested at 0 and -10 °C are shown in Fig. 8. For Road B, the results show that values of flexural modulus values of control mix at 0 °C increased by 13% for 30% RAP, whereas the values decreased by 25% and 45% with the 100% RAP and field obtained specimens respectively. Hence, the mixture with 30% RAP provides higher modulus values than the control tests. For comparable temperatures, inverse correlations between the flexural modulus and the levels of RAP are evident in all the tests; however, the lowest value is found to be for field obtained specimens.

Figure 9 shows the findings of stiffness modulus, it is shown that for Road C, the 30% RAP afford the highest values in stiffness modulus for 0 and –ve10 °C for the increase of 80% and 43% respectively from control mixtures. These results agree with the findings of Sarsam and Shujairy [27].

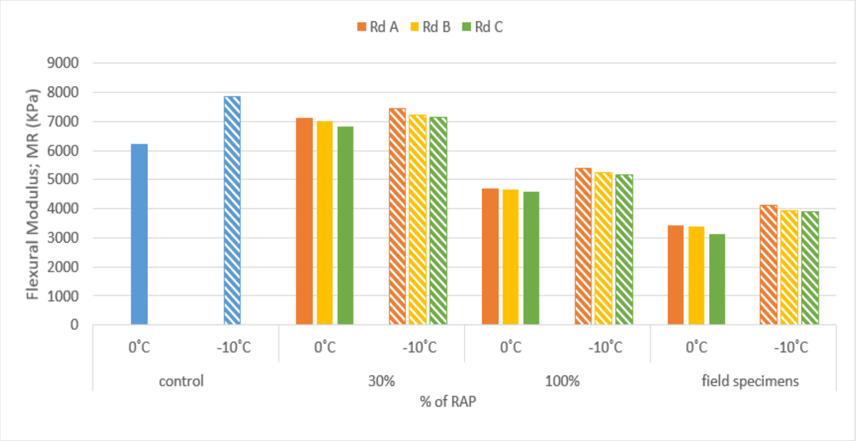

Fig. 8. Flexural modulus against % of RAP.

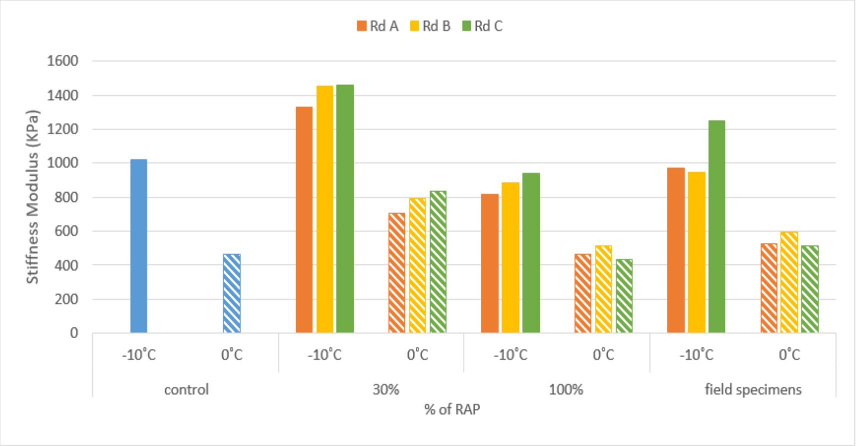

Fig. 9. Stiffness modulus against % of RAP.

3.4. Cohesion resistances

Cohesion resistance results are illustrated in Fig. 10. Findings exhibit a reduction in the cohesion values compared to control mixture as a result of the stiffer properties of their recycled mixtures. However, the lower cohesion values are for 100% RAP. The reduced cohesion values of Road B for 30% RAP, 100% RAP, and field obtained specimens from the control mixture are 25%, 37%, and 35% respectively.

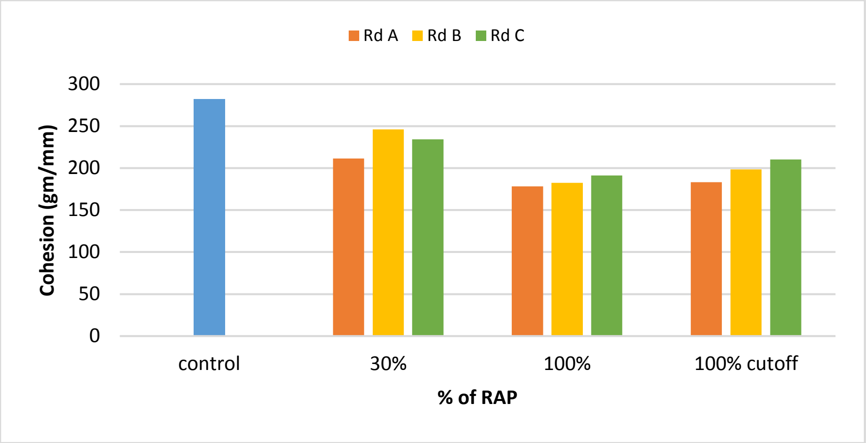

Fig. 10. Cohesion values against % of RAP.

3.5. Creep results

The outcomes of static creep test were shown in Fig. 11. Tests were performed over 1.0 hour of loading pursued by 1.0 hour of recovery at two temperatures namely 25˚C and 40˚C. The measured responses display that the highest vertical deformation is for control mixture and lowest one is for 100% RAP for all mixtures of the road sites, this may be attributed to the hardness of the asphalt mixtures. The result is inconsonant with the outcomes of Richardson and Lusher [28].

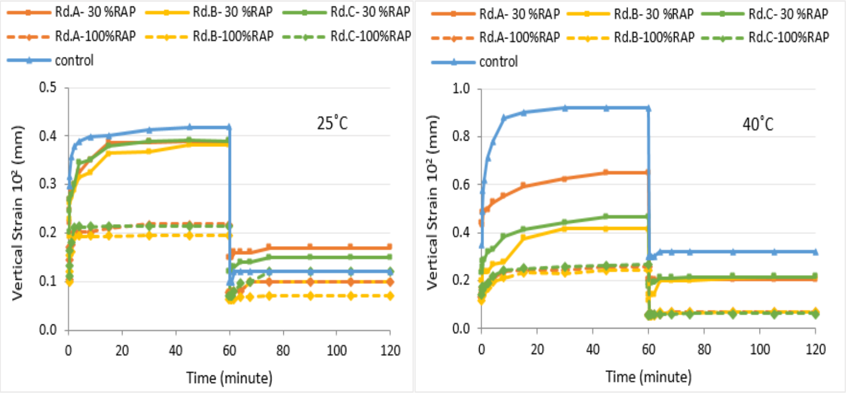

Fig. 11. Time-displacements response against % of RAP at temperatures of 25 and 40˚C.

3.6. Fatigue properties

The fatigue life of RAP mix was appraised on beams using a repetitive four-point loading under constant strain mode of loading. The fatigue test was executed at a temperature of 20 ˚C with different strain levels namely 250 με, 400 με and 750 με with a constant frequency of 5 HZ. Figure 12 shows the relation between % RAP and fatigue life at the three strain levels.

Regression lines were plotted over each strain level. It is shown that a linear relationship involved among log of initial tensile strain and log of fatigue life. The highest fatigue life is shown for virgin (control) mix because the existing asphalt in the virgin mix is the softest one; therefore, the mix was more flexible and exhibit preferable fatigue resistance.

This outcome is inconsonant with the conclusions of Yang and Lee [29] and Gao et al. [30] whereas, the outcomes were incompatible with the outcomes of Huang et al. [31] and de Picado Santos et al. [32]. It is also shown that the lowest fatigue life among the three sites for all strain level is for Road B, this may be due to the RAP material, which was exposed to traffic load and various environmental conditions for a longer time. However, according to Huang [33], the relation between fatigue life and tensile strain level can be expressed:

$$N_f = K1(\in_t)^{K2} \tag{1}$$

where,
N_f = No. of load repetitions to access failure,
$\in_t$ = max. tensile strain, and
$K1$, $K2$ = coefficients depending on material properties

The values of the coefficients $K1$ and $K2$, as well as fatigue life for various RAP mixtures, are presented in Table 3. It is clear that longer fatigue life is for a virgin mix. The reduction in fatigue life for 30% RAP and 100% RAP of Road B mix from control mix are 88%, and 98% respectively at 250 με strain level, whereas for 400 με strain level the reduction in fatigue life 86%, and 98% respectively and for 750 με strain level the reduction 77%, and 95% respectively. Figure 13 shows the lowering in % stiffness against fatigue life for the mix of Roads A, B, and C at 250 με strain level. It is shown that a sharp reduction in % of stiffness with fatigue life at higher RAP level of 100% due to the stiffer asphalt in RAP.

Table 3. Material coefficient values and fatigue life (N_f) with percent of RAP.

Percentage of reclaimed asphalt mixture	$K1$	$K2$	Fatigue life (N_f)		
			250 με	400 με	750 με
0% - control	1.00E-05	-2.64	44663	15583	2499
30% - Road A	6.00E-06	-2.574	12340	3420	725
30% - Road B	1.00E-04	-2.139	5360	2210	517
30% - Road C	2.00E-06	-2.715	15982	3700	796
100% - Road A	2.40E-03	-1.552	888	512	164
100% - Road B	7.00E-04	-1.684	714	384	114
100% - Road C	0.0086	-1.402	904	563	197

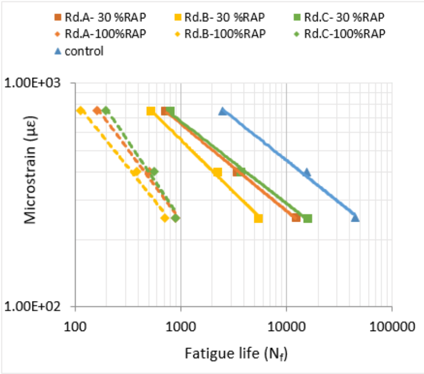

Fig. 12. Fatigue life against strain levels.

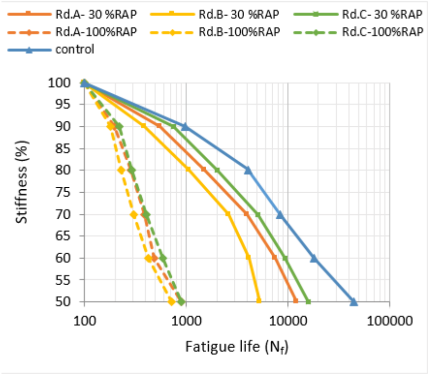

Fig. 13. Percent stiffness against fatigue.

3.7. Permanent deformation

The rut depth results for the RAP mixtures from the three road sites are displayed in Fig. 14. The amount of load employed was 700 Newton with 10000 cycle repetitions at a temperature of 60 ˚C. It is clear from the figure that the permanent deformation resistance of the mixes including RAP is higher than the control mix. Reduction in rut depth for Road C mix at RAP percent of 30%, 100% and field obtained specimens from control mixture are 47%, 71% and 75% respectively, this behaviour can be described by stiffer asphalt in RAP mixes providing mixes with higher rigidity thus, further resistant to permanent deformation. This finding agrees with the outcomes of Ma et al. [34], Teguedi et al. [35], and Cooper et al. [36]; but disagrees with the outcome of Arshad et al. [37].

It is also displayed that the permanent deformation resistance for all mixes of field obtained samples are higher than mixtures of 100% RAP, this may be attributed to compaction processes from the passage of vehicles during the life of the roads.

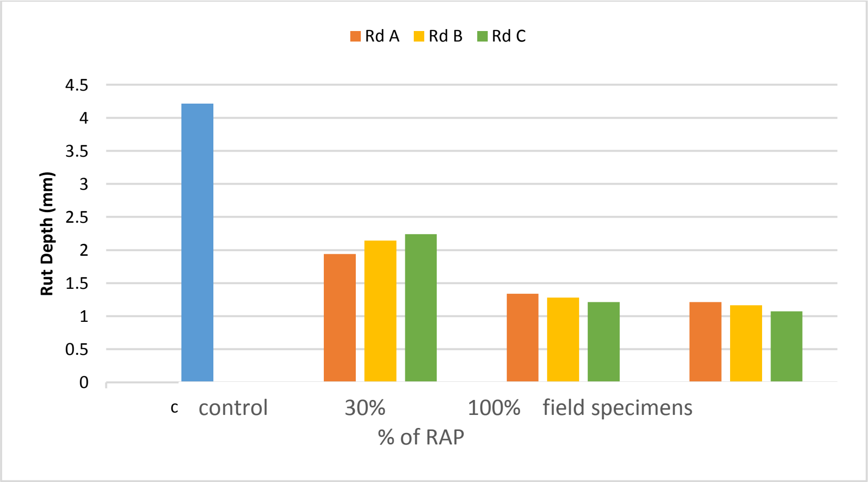

Fig. 14. Values of rut depth against percent of RAP.

4. Conclusions

Based on the observations made, the following conclusions can be made:

- The highest values of Marshall stability are for mixtures containing 100% RAP comparing with virgin, 30% RAP, and field obtained specimens mixtures. Air voids elevated as % of RAP increase, whereas values of flow, unit weight, Voids in mineral aggregate and voids filled with binder inclined with the rising of RAP levels. Values of Marshall stability at 30% RAP increase compared with control mixture by 20%, 48%, and 34% for roads of A, B, and C respectively.
- Increasing RAP percentage increase the tensile strength ratio (TSR) for all mixtures and increasing the resistance to moisture damage.
- The highest values for flexural modulus at temp. of 0 °C are for mixtures with 30% RAP, while flexural modulus at –ve10 °C decrease with increasing of RAP level; however, the lowest value for flexural modulus is for field obtained specimens.
- For all mixtures studied, lower values of cohesion were achieved with an increasing percentage of RAP as a result of the harder nature of a recycled mix; however, mixtures with RAP had preferable creep performance compared with a virgin mix.
- Higher fatigue life is shown for the control mix, whereas shorter fatigue life was noticed as % RAP increased. At 30% RAP and 250 $\mu\varepsilon$ strain level, the lowering in fatigue lives from the control mixture of roads A, B, and C were 72%, 88%, and 64% respectively. Rutting performance was enhanced with the use of RAP mixture.
- There are slight differences in obtained values between the three sites; this is due to the use of materials from the same sources. However, test results of mixtures containing 30% RAP complied with the specification criteria and can be used successfully in highway pavement.
- Additional testing such as direct shear rheometer to evaluate the stiffness of RAP binder, and dynamic modulus to evaluate the performance tests on asphalt mixtures are recommended in order to confirm using RAP in highway construction.

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