Evaluation performance of base course mixture containing reclaimed asphalt pavement (RAP)

Karim Al helo ^{1,*}, Zaynab Qasim ¹, and Ahmed Majeed ¹

¹ Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

Abstract. This paper presented the effect of addition of Reclaimed Asphalt Pavement (RAP) on performance of mixture with (20%, 30%, 40% and 50%) RAP as proportion of asphalt mix. To compare with virgin mixture marshall flow and stability test was used to evaluated durability performance with (0,1,3, and 7) days immersion and Wheel Truck test was used to evaluated the resist to rutting. The best gradation and optimum asphalt content was selected according to Superpave system. Superpave Gyrotory Compactor (SGC) was used to compact mixture with 100-mm diameter. The test results indicated that addition of RAP to mixes showed significant increase on resistance of Durability and Rutting.

1 Introduction

Recycling Hot Mix Asphalt (HMA) material results in a reusable mixture of aggregate and asphalt binder known as Reclaimed Asphalt Pavement (RAP) , [1]. Asphalt paving technologists reacted to this situation by developing recycling methods to reduce the demand on asphalt binder and thereby, reducing the costs of asphalt paving mixtures. Many practices that were initially developed during that period are still in use today and have become part of routine operations for pavement construction and rehabilitation, [2]. The asphalt pavement recycling methods include hot Mix recycling, cold and hot in place recycling, and full depth reclamation, [3]. There are three major causes for preferring the RAP on the virgin materials: the increase in asphalt binder and crude oil cost, reduction of quality aggregates, and the pressing demand to save the environment, [4]. For performance tests Li et al. in 2005 studied the properties of low and high temperature of RAP binder by using two fresh asphalt grades; (PG 58-28) and (PG 58-34) and mixes with three contents of RAP (0, 20%, and 40%), [5].

It found that $G^*/\sin\delta$ value is increasing with increase in RAP content which means its more stiffer than mix without RAP. At low temperature, e.g. -24 °C, both the stiffness from failure temperature and the BBR test increase and the m-value is decreases when percentage of RAP increases. Also, they indicated that the fresh asphalt has less stiffness than the RAP asphalt. Only when the percentage of RAP is higher than 20% by weight a considerable variation is shown. The preceding researches on mechanical properties of RAP mixtures indicated that using RAP give a good performance to resist rutting but lower resistance to low temperature cracking due to affected by stiff asphalt of the RAP. The change in properties of asphalt can be significant only

when using high content of recycled asphalt pavement (more than 20-30%). Pradyumna, et al. in 2013 indicated that hot mix recycling with 20% RAP can have better performance to those of new conventional hot mix asphalt mixtures, [6]. Various performance tests such as Retained Stability, Indirect Tensile Strength (ITS) and wheel tracking test were adopted. For Retained Marshall Stability for virgin mix was (85.6%) and for RAP mix was (88.1%). While rut depth for virgin mix was obtained 8.20 mm, whereas for 20 % RAP mix, it was 7.6 mm only after 20,000 passes. Van et al. in 2015 designed surface mixtures (1/2 in) content high RAP and binder graded PG 70-22, [7]. Three Hot Mix Asphalt (HMA) test sections with RAP amounts of 30.0, 35.5, and 39.2% were constructed. RAP materials were fractionated to meet Superpave mix design requirements. After 20,000 passes were applied using a Hamburg wheel tracking device, rut depths were less than 3 mm for all field mixtures. Izaks et al., in 2015 studied two RAP sources, first source of RAP is (A7); the second source of RAP is (A6) to be compared with control mixture (AC16), [8].

They noted that the largest average rut depth of 3.4 mm for the AC-16base/bin. (A6) with 30% RAP mixture with lowest asphalt content shows high resistance to permanent deformations, having an average rut depth value of 1.8 mm. Celauro et al., in 2010 used high content of reclaimed asphalt (0%, 40%, and 50%), which were investigated in a laboratory to design surface course (types U3 and U5) with thickness (3 and 5 cm, respectively), binder courses (types BiK2 and BiK3 and base course (type BiK1) with different binder content (K0, K1, K2, and K3). Rutting test was adopted for surface course only (U5), [9]. Marshall Stability for all mixtures was studied, it can be noted that each mixture which was taken into account in that study no only met the minimum levels for Marshall Stability according to

* Corresponding author: karim.alhelo@yahoo.com

Italian Specifications but also with higher performances pursued by this study.

Also showed that the rut depth is decreasing with increase in RAP content which is affected by hardening the total binder in the mixture as well as it can be observed the mixture with recycled materials have good rutting resistance even though with high asphalt content less than rut depth for control mix.

2 Materials

2.1. Asphalt cement

The grade of binder that was used (AC 40-50) or PG (64-16) was obtained from the Al-Dora Refinery, south-west of Baghdad. The testing results conformed to Iraqi specification, [10] and ASTM Requirement. The physical properties of binder are show in Table 1.

Table 1. Properties of Asphalt Cement

Property	ASTM designation	Test results	SCRB specification
Penetration, (25°C, 100 g, 5s), 0.1 mm	D-5	47.3	40-50
Softening Point. (°C)	D-36	51.5	-
Ductility at 25 C, 5cm/min, (cm)	D-113	>100	>100
Specific Gravity	D-70	1.03	-
Rotational Viscometer, at 135°C (Pa.sec)	D-4402	0.537	-
Rotational Viscometer, at 60°C (Pa.sec)	D-4402	0.15	-

2.2. Aggregate

The crushed quartz aggregate used in this work was obtained from Al-Sedour quarry; this aggregate widely used in local asphalt paving in Baghdad. The physical properties of used aggregate were showed in Table 2.

2.3. Mineral Filler

The filler used in this work was Portland cement brought from Al-Mas Company which provided from local market. The physical properties of Portland cement are presented in Table 3.

2.4 Reclaimed Asphalt pavement

The reclaimed asphalt pavement materials (RAP) was brought from stoke of Reclaimed Asphalt for Mayoralty of Baghdad-project office at Altalbia-region in Baghdad city. Extraction test was conducted on the reclaimed asphalt pavement to extraction the asphalt from aggregate and filler. The testing has been procedure according to (ASTM-D2172). The percent of asphalt

cement was (4%) and gradation of RAP aggregate is determined and added to new materials according to (Iraqi specifications SCRB-R9), as shown in Table 4, [11].

Table 2. Physical properties of aggregate

Laboratory Test	ASTM designation	Test results	SCRB Specification
Coarse aggregate			
Apparent specific gravity	C-127	2.66	-
Bulk specific gravity	C-127	2.61	-
Water absorption, %	C-127	0.66	-
Percent wear by (Los Angeles abrasion), %	C-131	14.6	35-45 Max
Soundness loss by sodium sulfate solution, %	C-88	3.12	10-20 Max
Fractured pieces, %	D 5821	96%	95 Min
Fine aggregate			
Apparent specific gravity	C-128	2.66	-
Bulk specific gravity	C-128	2.62	-
Water absorption, %	C-128	0.68	-

Table 3. physical properties of Portland cement

Property	Test results
Specific Gravity	3.2
%Passing Sieve No.200 or (0.075 mm)	100

3 Mix design

Superpave design system was adopted to select design aggregate structure and design binder content for getting optimum asphalt pavement. Aggregate gradation was selected according to ASTM and Iraqi specifications (SCRB, R9) for base course. Figure 1 shows the selection gradation of blend. Four content of binder were selected as (3.45%, 3.95%, 4.45%, and 4.95%). The design asphalt binder content is established at 4.0% air voids the design asphalt binder content was 4.42%. All other mixture properties were checked at the design asphalt binder content to verify that they meet specifications for base course.

Table 4. Selected gradation of RAP aggregate

Standard Sieves (mm)	% Passing by weight, (SCR-BR9)	%Passing by weight (RAP)
19	100	100
12.5	90-100	99
9.5	76-90	97
4.75	44-74	73
2.36	28-58	54
0.3	21-5	30

Fig. 1. Selected blend of aggregate gradation

3.1 Sample preparation

Specimens are required to be mixed and compacted under equiviscous temperature conditions corresponding to viscosities of 0.17 ± 0.02 and 0.28 ± 0.03 Pascal-seconds (Pa·s), respectively. Depending on traffic level in Baghdad ESALS ranged (3 million to < 10 million), [12]; each specimen compacted using Suprapave Gyratory Compactor (SGC) to design number of gyrations (100 cycle) and diameter of samples was 100 mm.

The Sample was prepared as following:

- Heating the Reclaimed asphalt pavement at 110°C for (1-2) hour.
- Heating the Aggregate to (170°C).
- Heating the asphalt at (160°C).

After heating the aggregate and asphalt mixed together and then heating reclaimed asphalt pavement is added to mixture. The percent of reclaimed asphalt pavement (RAP) was added are (20%, 30%, 40%, and 50%) of total mix weight.

3.2 Durability of hot asphalt mixtures

Durability of an asphalt mixture is defined as its resistance to weathering and the abrasive action of traffic. In terms of its application to asphalt paving materials, durability can be defined as the ability of the materials in the asphalt pavement structure to resist the effects of environmental conditions, such as water, ageing and temperature variations without any significant deterioration for an extended period for a given amount of traffic loading, [13].

To evaluation durability, a mixture is subjected to environmental conditioning, and a mixture property associated with load-related or environmental distress is measured before and after the conditioning process.

Abrasion characteristics of the aggregate in the mixture must also be considered in the evaluation of durability. The greater the protection by asphalt concrete, more durable the mix will be. The fewer air voids in the Total mix, the slower will be the deterioration of the asphalt concrete itself. Theoretical Approach: It's including three steps as following:

a. Marshall Stability

Marshall Stability is calculated from the following equation:

$$S_o = o * R * T \quad (1)$$

Where, S_o = stability numeral, kN

o = stability timepiece reading on Marshall test, kN

R = Proving ring calibration

T = the matter test correction factor

b. Retained Marshall Stability (RMS)

The Retained Marshall Stability is calculated from the following equation:

$$RMS = (S_i / S_o) * 100\% \quad (2)$$

Where: RMS = Retained Marshall Stability (%)

S_i = maximum stability in conditioned set based on times series

S_o = maximum stability in unconditioned set (0 days)

c. Durability Index (DI)

The formula which used to calculate durability index is shown in following equation:

$$DI = \left(\frac{1}{2tn} \right) \sum_{i=1}^{n-1} (S_i - S_{i+1}) * (2tn - (t_{i+1} - t)) \quad (3)$$

Where: S_{i+1} = percent retained strength at time t_{i+1}

S_i = percent retained strength at time t_i

t_i, t_{i+1} = immersion time (from beginning of test).

Durability Index was defined as the average strength loss area enclosed between the durability curves. Figure 2 shows a schematic description of durability curve and Figure 3 shows samples for testing procedure.

Fig 2. Schematic Description of Durability Curve

Fig. 3. Tested Procedure Samples

4 Results

4.1 Marshall stability and flow results

Figure 4 shows the relation between stability and RAP percent heated to 110°C. It can be concluded that stability is increased with increase RAP content. When addition of 30% RAP content, the stability is increased with 21.6% and for addition of 40%; stability is increased with 41.9 %.

Figure 5 shows the relation between flow and RAP percent heated to 110°C. It can be illustrated that the increase in inclusion of the RAP causes a decrease in flow for example the addition of 30% RAP, the flow is decreased with 2.7%, and an addition of 50% RAP, flow is decreased with 8.1%.

Fig.4. Stability with % RAP for 1 day

Fig.5. Stability for RAP heated to 110°C

4.2 Durability test results

The Retained stability (RS) is decreased with increase immersion day for all percent addition. For example, for 20% RAP content the RS value is 98% for one day emersion and is 82.4% for seven days immersion as shown in Table 5. It can be observed that RS is increased with increase RAP content; e.g., the RS for 7 days is 82.4% for 20% addition and is 87.8% for 50% RAP content.

Table 5. Retained stability (%) with days

% RAP	RS for 1 day	RS for 3 day	RS for 7 day
20	98.0	92.6	82.4
30	97.2	93.3	85.6
40	96.4	92.9	88.1
50	95.1	92.7	87.8

Figures 6 and 7 illustrated the relation between stability and immersion day for all percent of RAP additions. It can be noticed that stability for all RAP percent is higher than the control mix. Stability is increased with increase in RAP content until 40% then it decreases for 50% but still above the stability values for 30% RAP content for all immersion days, e.g. the stability value with one day immersion day is increased with (22.3%, 48.7%, 73.5% and 41%) for (20%, 30%, 40% and 50%) RAP content respectively. And the stability value with three immersion days is increases with (26%, 52.1%, 76% and 69.5%) for (20%, 30%, 40% and 50%) RAP content, respectively. While stability value with seven days immersion days is increased with (24.4%, 57%, 88.7% and 83.6%) for (20%, 30%, 40% and 50%) RAP content, respectively.

The addition of RAP that forms from asphalt and aggregates in the "RAP Mix" have developed the Marshall stability and the Retained of Marshall Stability above the "Control Mix". It is confirmed that this can be attributed to the fact that RAP has hardened asphalt, which will cause increased in the stability due to higher asphalt viscosity. The virgin asphalt is having less viscosity than RAP Asphalt "Hardened asphalt" if they have the similarity in grade. For that, when the mixes are subjected to immersion, the stability of the "RAP Mix" will be less affected by hot water than that of the "Control Mix".

Fig. 6. Stability with % RAP for 3 day

Fig. 7. Stability with % RAP for 7 days

4.3 Durability index

Figure 8 illustrates the durability index for RAP heated to 110°C with RAP content, it can be noted that durability index DI decreases with increases RAP content, for example DI decrease with (17.3%) and (45.1%) for 20% and 50% RAP content, respectively as shown in Table 6.

Fig.8. DI for RAP Heated to 110°C

Table 6. Relation Between Durability Index and RAP content

RAP %	DI
0	10.4
20	8.6
30	7.6
40	6.4
50	5.7

4.4 Rutting test results

The resistance to permanent deformation increased with increases of RAP content, e.g. Rut depth is decreased with increase RAP content. Figure 9 illustrated that the Rut depth is decreased by (15.4%) when the

RAP is increases from (20% to 30%) percent, while it is decreased by (31.3%) and (35.3%) when the RAP is increased from (20% to 40%) and up to 50%, respectively. Table 7 illustrates the values of rut depth at end of the test.it can be observed that the rut depth is lower than control mix (0% RAP) for all RAP content, e.g., the rut depth with 20%, 30%, 40% and 50% RAP content is decreased by (8.8%, 22.9%, 37.4% and 41.4%), respectively. Table 8 illustrated the ratio of decreases in rut depth with increases RAP content compared with the original mix. This refer to the addition of Reclaimed Asphalt Pavement is improving the resistance of rutting for the mix. The RAP containing mixes become stiffer compared to the mix without RAP and thus has better resistance to permanent deformation.

Fig. 9. Relation between Cycles number with Rut depth for RAP heated to 110°C

Table 7. Relation between rut depths with % RAP

RAP %	Max rut depth RAP heated to 110°C, mm
20	2.46
30	2.08
40	1.69
50	1.59
20	2.46

Table 8. Decrease Ratio of Rut Depth with RAP

RAP %	Decrease Ratio for RAP heated to 110 °C
20	8.8
30	22.9

40	37.4
50	41.4

5 Conclusions

- Marshal Stability results show that the increasing RAP will increase the stability for RAP heated to 110° C or 140° C. The stability increased by (22.3%) (48.7%), (73.5%) and (69.4%) for (20%), (30%), (40%) and (50%) RAP content respectively for RAP heated to 110°C.
- The Durability results for RAP heated to 110°C show that increase in RAP causes an increasing in resistance to moisture damage for all percent of RAP. The stability increases by (26%), (52%), (76%) and (69.5%) for one day emersion and increases by (24.5%), (52.7%), (77.2%) and (72.7%) for three days and increases by (24.4%) (57.1%) (88.7%) and (83.6%) for seven days; for (20%), (30%), (40%) and (50%) of RAP content, respectively. The DI values are (8.6) (7.6) (6.4) (5.7) for (20%), (30%), (40%) and (50%) RAP content respectively
- Durability Index results decrease with increase in RAP content
- Wheel-Tracking permanent deformation results for asphaltic base course Mixes indicate that increase in RAP will decrease the permanent deformation the rut depth decreased by (8.8%), (22.9%), (37.4%) and (41.1%) for (20%), (30%), (40%) and (50%) RAP content, respectively.

References

1. I. L. Al-Qadi, Q. Aurangzeb, S. H. Carpenter, W. J. Pine, J. Trepanier, ICT R27-37, Champaign (2012)
2. West, R., National center for asphalt technology Report, Auburn University, Alabama (2010)
3. L. Wang, E. Masad, *Proceedings of the Symposium on the Mechanics of Flexible Pavements*, ASCE, **176** (2007)
4. N. Sabahfar, Department of Civil Engineering, Kansas State University (2012).
5. X. Li, M.O. Marasteanu, R.C. Williams, and T.R. Clyne, TRB **2051**, 90–97 (2008)
6. T. A. Pradyumna, A. Mittal, P. Jain, PSBS, **104**, 1149-1157 (2013)
7. V. Winkle, H. Lee, R. C. Williams, S. Schram, TRB **94** (2015)
8. R. Izaks, V. Haritonovs, I. Klasa, M. Zaumanis, PE. **114**, 676-684 (2015)
9. C. Celauro, C. Bernardo, B. Gabriele, J. RCR, 54, 337-347 (2010).
10. SCRB, *General Specification for Roads and Bridges, Section R/9*, Revised Edition, State

- Corporation of Roads and Bridges, Ministry of Housing and Construction, Iraq (2003).
11. K. H Al Helo, Z. I. Qasim, A. D. Majeed, GJESRM, ISSN 2349-4506 (2016).
 12. Z. I. Qasim, A.H. Abed, *the 2nd International Conference on Buildings, Construction and Environmental Engineering (BCEE2)*, Lebanon, (2015).
 13. M. Y. Fattah, Z. I. Qasim, Y. A. Zuhier, GJESRM, ISSN 2349-4506 (2017).