Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 114 (2015) 676 – 684

Procedia Engineering

www.elsevier.com/locate/procedia

1st International Conference on Structural Integrity

Hot Mix Asphalt With High RAP Content

R. Izaks[a], V. Haritonovs[b*], I. Klasa[c], M. Zaumanis[d]

[a, b, c, d.] Riga Technical University, Dept. of Roads and Bridges,
Azenes street 16/20 - 448, 1048 Riga, Latvia

Abstract

Due to increasing cost of asphalt binder, significant economic savings can be realized using high content of reclaimed asphalt pavement (RAP) in the production of new hot mix asphalt (HMA). Moreover, this is an environmentally friendly alternative as it reduces the need for virgin materials. It has to be noted that in Latvia RAP is rarely used in production of HMA and this valuable material is mostly degraded for use in lower value applications. Three mixtures were designed, which were the combination of two different RAP sources and local dolomite aggregates. The RAP binder had significantly aged having penetration of around 38mm, softening point of 56°C and Fraass temperature of -10°C. RAP was added at rates 30% and 50% for each RAP source. A softer binder grade (70/100 versus traditional 50/70) was added to compensate for the aged RAP binder. Hamburg wheel tracking test results demonstrated that all mixtures have high rutting resistance and fatigue test results using four-point bending beam were similar to those of virgin mixture. This demonstrated that mixtures with high RAP content can be successfully designed to meet the local volumetric and performance-specification requirements.

Peer-review under responsibility of INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering

Keywords: reclaimed asphalt pavement; hot mix asphalt; binder; rut resistance; fatigue resistance

[1]Corresponding author: Viktors Haritonovs Tel.:+371 26412568.
E-mail address: viktors.haritonovs@rtu.lv

Peer-review under responsibility of INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering
doi:10.1016/j.proeng.2015.08.009

Introduction

The history of asphalt pavement recycling dates back to the early 1900s. Recycling asphalt pavements first became popular in the U.S. in the 1970s during the oil embargo when the cost of crude oil skyrocketed. Today, the two primary factors that influence the use of reclaimed asphalt pavement (RAP) in asphalt pavements are economic savings and environmental benefits (Newcomb et al. 2007). RAP is a useful alternative to virgin materials because it reduces the use of virgin aggregate and the amount of virgin asphalt binder required in the production of hot mix asphalt (HMA) (Copeland 2011). For higher RAP content (above 25%), design and production takes extra effort, but the savings in using the higher RAP contents significantly outweigh the added costs. Blending to meet gradation and the appropriate binder grade in the final product are keys to successful mix design, production, and performance (Newcomb et al. 2007). The most crucial characteristic of RAP material that affects the properties and performance of recycled mixtures is aging of its binder. The methods for compensating for the aged, stiff binder and ensuring adequate pavement performance include the use of rejuvenating or softening additives, use of softer virgin binder grade and increase in total mixture binder content (Zaumanis 2014). There is no consensus whether HMA which incorporates RAP performs any different compared to HMA without RAP. A number of researchers have pointed out that using RAP increased stiffness (Al-Rousan et al., 2008, McDaniel and Shah, 2002, Tabakovic et al., 2010, Zaumanis 2014, Al-Qadi et al., 2012) while others have reported the opposite (Oliver, 2001, Widyatmoko, 2008). Also, at the time that some studies have revealed improving of fatigue resistance with using RAP (Oliver, 2001, Tabakovic et al., 2006, 2010, Widyatmoko, 2008), other studies have reported some degradation (Al-Rousan et al., 2008, McDaniel and Anderson, 2001, Zaumanis 2014, Al-Qadi et al., 2012).

Objective

The objective of the research is to develop high content recycled mixtures using materials found in Latvia in order to meet the local volumetric and performance-specification requirements for medium and high traffic intensity roads of Latvia and to ensure performance of these mixtures similar to virgin asphalt.

1. Materials and methods

1.1. Aggregate

The aggregates used in this study were fractionated and crushed dolomite. Dolomite is one of the most available sedimentary rocks in the territory of Latvia. According to Latvian Road Specifications 2014, this dolomite can be used for medium and high traffic intensity roads in asphalt base and binder layers.

1.2. RAP materials

The first and most important step in design of recycled HMA is to determine the properties of RAP aggregate and RAP binder. The basic required properties of RAP materials are binder viscosity, bitumen content and particle size distribution of aggregates. Materials from two RAP sources were used in this research. Three mixtures were designed with RAP and one references mixture using only virgin materials. RAP was added at a rate of 30% and 50% for each RAP source. It is important to note, that these percentages were selected based on the Latvian Road Specifications 2014, which define and specify the design requirements of recycled mixtures with RAP. 30 % RAP is within the specified acceptable range while the mixture with 50% RAP is outside this range. Two RAP sources were used. The first source of RAP (A7) was millings from a road rehabilitation project, where an upper layer of an existing pavement was removed. No crushing or screening was done for this material. The second source of RAP (A6) was millings from full-depth road reconstruction project, therefore the resulting RAP was a combination of different asphalt types. Prior to recycling this RAP was crushed and fractionated to size 0/11 mm. This was likely the reason for high dust content (16.2%).

The binder was extracted from both RAP sources according (EN 12697-1 clause B.1.2.) to determine the binder content and aggregate gradation in the RAP sources. The bitumen content is calculated by difference from the weight of extracted aggregates. Table 1 shows the RAP gradation and the bitumen content for both RAP sources. With "A7" and "A6" representing the RAP source.

Table 1 RAP aggregate gradation and bitumen content

RAP source	A6 RAP	A7 RAP
Bitumen content, %	5,12	4,9
Sieve size, mm	passing, %	
22,4	100	100
16	100	99,4
11,2	96,4	92,4
8	89,3	57,1
5,6	81,9	34,4
4	74,7	26,1
2	63,8	21,7
1	52,8	19,3
0,5	41,3	17,4
0,25	29,4	14,9
0,125	20,2	12,5
0,063	16,2	11,1

1.3. Virgin binder

Two types of new bitumen were used. Bitumen 50/70 was used to produce the reference mixture from virgin materials, while for all mixtures having RAP a softer grade bitumen (70/100) was added to compensate for the aged RAP binder and to ensure that the target binder grade is B50/70. The values of these virgin binder properties and requirements are shown in Table 2.

Table 2 Virgin and aged binder properties

Property	Test method	Unit	Requirement B50/70	Requirement B70/100	Virgin binder values		Aged binder values	
					B50/70	B70/100	A6 RAP	A7 RAP
Penetration at 25^0C	EN 1426	0,1 mm	50 -70	70 - 100	64,5	86	38	55
Softening Point R&B	EN 1427	^{0}C	46 -54	43 - 51	47	46	59	50
Fraass Breaking point	EN 12593	^{0}C	≤ -8	≤ -10	-17	-20,8	-9	-11

1.4. RAP binder properties

When using high percentages of RAP (>25%) one needs to know the properties of RAP binder (Kandhal *et al.* 1997). Therefore binder was recovered from both RAP sources by rotary evaporator according (EN 12697-3) to measure penetration, softening point, and Fraass breaking point. Table 2 demonstrates the physical properties of aged binder. Once the desired RAP percentage has been determined, the RAP binder and virgin binder should be combined and put through testing (if the RAP content exceeds 25 percent) to see that it conforms to the target binder grading requirement for the application (Newcomb *et al.* 2007). The penetration can be estimated using Equation 1:

$$a \lg pen_1 + b \lg pen_2 = (a+b) \lg pen_{mix} \quad (1)$$

where pen_{mix} is calculated penetration, pen_1 is penetration of RAP extracted binder, pen_2 is penetration of virgin binder, a and b is proportion of virgin(a) and aged (b) binder: $a + b = 1$. Softening point temperature can be estimated using Equation 2:

$$T_{R\&Bmix} = a \times T_{R\&B1} + b \times T_{R\&B2} \quad (2)$$

where $T_{R\&Bmix}$ is calculated softening temperature, $T_{R\&B1}$ is softening temperature of RAP extracted binder, $T_{R\&B2}$ is softening temperature of virgin binder, a and b is proportion of virgin(a) and aged (a) binder: $a + b = 1$. Fraass Breaking point of blended binder was determined in accordance with EN 12593. Table 3 demonstrates the properties of the combined binder at the demonstrated percentages. Target binder grade is B50/70.

Table 3 Blended binder properties

Property	Test method	Unit	Requirement B50/70	A6 RAP 30%	A7 RAP 30%	A7 RAP 50%
				Percentage binder replacement, %		
				31,8%	36,5%	62,5%
Penetration at 25^0C	EN 1426	0,1 mm	50 -70	66	73	65
Softening Point R&B	EN 1427	^{0}C	46 -54	50	47	49
Fraass Breaking point	EN 12593	^{0}C	≤ -8	-16	-18	-16

1.5. Mix design

Aim of design of recycled HMA is to optimize RAP content and produce a mix with good performance in fatigue, rutting, thermal resistance, and overall durability. Further, the mixture has to meet the required volumetric properties including air voids, voids in mineral aggregates (VMA), voids filled with asphalt (VFA), and dust proportion (AL-Qadi et al. 2007). Mixtures were designed using Marshall method, according to the Latvian Road Specifications 2014. Marshall mix design procedure was used for the determination of the optimal bitumen content for the reference mixture AC-16base/bin, considering the mixture test results for Marshall stability and flow, as well as the volumetric values: air voids (V), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB).

All recycled asphalt mixtures were designed with optimal binder content. To calculate the minimal binder content of mixtures with RAP, it is necessary to know the combined aggregate bulk specific gravity. Calculating the combined bulk specific gravity requires knowing the bulk specific gravity of each aggregate component. The maximum theoretical specific gravity of the RAP was used to backcalculate the bulk specific gravity of the RAP aggregate. To estimate bulk specific gravity of the RAP aggregate Equation 3 and Equation 4 were used (Mc Daniel *et al*. 2001, Al-Qadi et al. 2012).

$$G_{se} = \frac{100 - P_b}{\dfrac{100}{G_{mm}} - \dfrac{P_b}{G_b}} \quad (3)$$

$$G_{sb} = \frac{G_{se}}{\left(\frac{P_{ba} G_{se}}{100 G_b} + 1\right)} \tag{4}$$

where G_{mm} is theoretical maximum specific gravity, $G_{b(RAP)}$ is specific gravity of RAP binder, $P_{b(RAP)}$ the RAP binder content, G_{se} is effective specific gravity of aggregate, G_{sb} is bulk specific gravity of aggregate and P_{ba} are absorbed binder, percent by weight of aggregate. All recycled mixtures were designed with 4.1% binder content, the percentage binder replacement from RAP is shown in Table 4. Test specimens for Marshall Test were prepared using impact compactor according to EN 12697-30 with 2×50 blows of hammer at 145°C temperature. Table 4 presents a summary of the properties of these five mixtures.

Table 4. Summary of asphalt mixture properties

Mix type	Binder	Asphalt content, %	Virgin asphalt content, %	Percentage binder replacement, %	AV, %	VMA, %	VFA, %
					Required value		
					2,5–6,5	≥14	≤80
AC-16 base/bin	50/70	4,7	4,7	0,0	4,5	15,6	71,5
A6 RAP 30%	70/100	3,96	2,7	31,8	6,8	16,1	57,7
A7 RAP 30%	70/100	4,25	2,7	36,5	5,5	15,5	64,4
A7 RAP 50%	70/100	4,26	1,6	62,5	4,5	14,7	69,1

1.6. Methods

Four tests were chosen to assess the mechanical properties of the asphalt mixtures; the four point bending beam test was used to determine the fatigue resistance (EN 12697-24 Annex D) and stiffness modulus (EN 12697-26 Annex B), wheel tracking test was used to determine rutting resistance (EN 12697-22) and Marshall test determine stability and flow according to (EN 12697-34).

1.6.1. Wheel tracking test

Tests were performed according to EN 12697-22 method B (wheel tracking test with small size device in air). Dimensions of wheel tracking test samples were of 305×305 mm and 50 mm high. The samples were compacted in the laboratory by using roller compactor. Resistance to permanent deformation is assessed by the depth of the track and its increments caused by repetitive cycles (26,5 cycles per minute) under constant temperature (60°C). The rut depths are monitored by means of two linear variable displacement transducers (LVDTs), which measure the vertical displacements of each of the two wheel axles independently as rutting progresses (Haritonovs 2013).

1.6.2. Fatigue test

The test was run at 10°C, 10Hz at 115μm and 130μm strain level. The beams were compacted in the laboratory by using roller compactor. They were cut to the required dimensions of 50 mm wide, 50 mm high and 400 mm long. The failure criterion used in the study is the traditional 50% reduction in initial stiffness.

1.6.3. Stiffness test

The test was carried out under the standard conditions of 50μm target horizontal deformation, 10 Hz frequency, at 10°C test temperature. The beams were compacted in the laboratory by using roller compactor.

2. Results and discussion

2.1. Volumetric properties

Volumetric parameters of the different asphalt mixtures at different RAP contents were analyzed. The volumetric result values: air voids (V), voids in mineral aggregate (VMA) and voids filled with bitumen (VFA) are presented in Table 4. For the RAP mixtures, the VMA values decreasing with increase RAP percentage and the VFA values for all of the RAP mixtures are lower than the control mix. Table 4 indicates no significant difference between the air voids in references mix and recycled mixtures. Air voids significantly affect the rate of bitumen content in mixture. The A6 RAP 30% mixture with lowest bitumen content didn`t meet the required value of air voids. Air voids decreasing in recycled mixtures with increase of RAP percentage, because increased the fine aggregate in mixture from RAP.

2.2. Marshall stability and flow test

All mixtures meet the minimum stability criteria of 10 kN for medium and high traffic intensity roads, and satisfy the VMA and VFA requirements. At the same time all mixtures meet Marshall flow criteria of 1-4mm. The flow and stability values for all mixtures are presented in Fig. 1-2. The results show that increasing the A7 RAP content in mixtures also increase Marshall stability and flow.

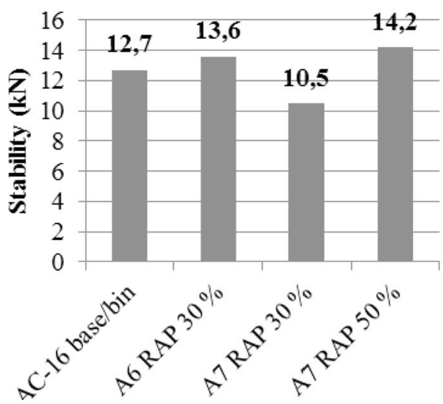

Fig. 1. Marshall stability values.

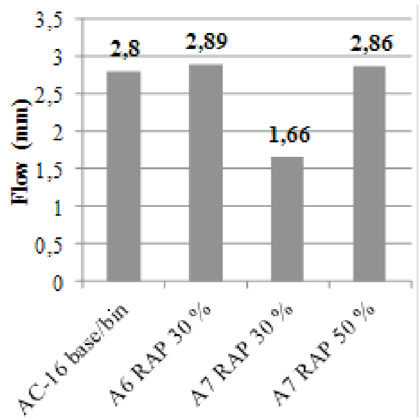

Fig. 2. Marshall flow values.

2.3. Wheel tracking test

Wheel tracking test is used to simulate the effect of traffic and to measure the deformation susceptibility of asphalt samples. The obtained results demonstrate that the largest average rut depth of 3.4 mm and wheel tracking slope of 0.15 mm/1000 cycles appear for the AC-16base/bin references mixture, the potential reason for this might be the highest bitumen content 4.7% for references mixture. A6 RAP 30% mixture with lowest bitumen content shows high resistance to permanent deformations, having an average rut depth value of 1.8 mm and wheel tracking slope of 0.04 mm/1000 cycles (Table 4). Fig. 3 provides a summary of rut resistance properties of the test specimens. Since wheel tracking test results were acceptable for recycled mixtures, it might be possible to redesign the mixture with increased binder content and as a result increase resistance to fatigue.

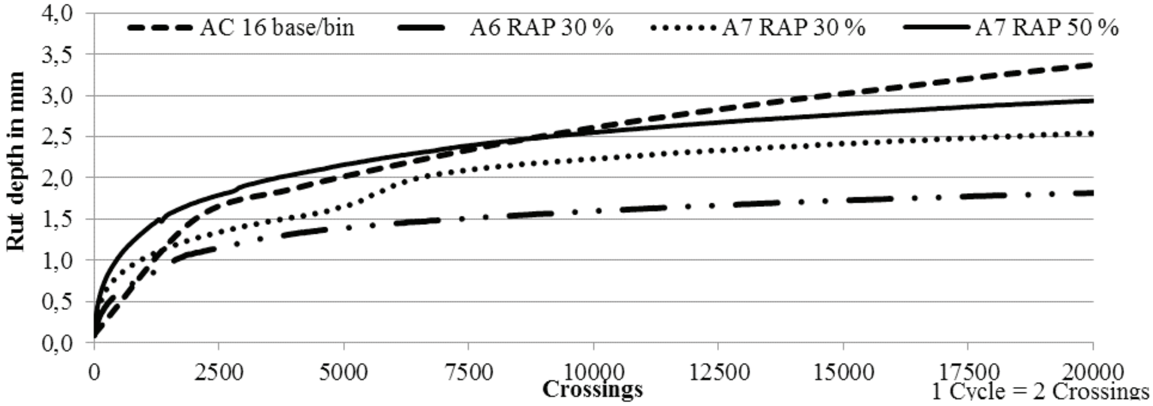

Fig. 3 Wheel tracking test results.

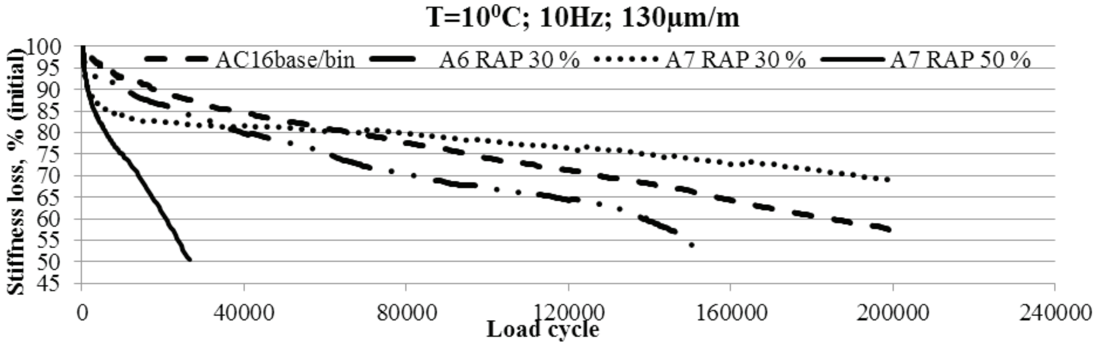

Fig. 4 Fatigue test results.

4.4 Fatigue test

To determine the fatigue life of the prepared asphalt concrete mixes, a four point bending beam test under controlled displacement was conducted. The obtained results indicate that mixture A7 RAP 50% showed far less resistance to fatigue, compared to results for references mixture made with virgin aggregates and mixtures made with RAP content of 30%. The failure criterion, the traditional 50% reduction in initial stiffness A7 RAP 50% mixture reached to 73500 load cycle at 115µm strain level and to 26500 load cycle at 130µm strain level. Using higher virgin binder content in high RAP content mixes can compensate for the decrease in fatigue resistance. Fig. 4 demonstrates stiffness curves.

4.5 Stiffness test

Mixtures containing RAP content of 30% for both RAP sources had lower stiffness than the reference mixture AC-16base/bin B50/70, but these mixtures have similar resistance to rutting. With an increase in A7 RAP content, the stiffness of the mixture increases. The stiffness alone is does not give the full picture however, because the ductility or brittleness of the mixture will also affect its performance with respect to cracking. The 50% RAP mixture contains a large part of aged asphalt binder, which is more brittle than virgin binder, therefore if interaction between the aged and virgin binder completely does not happen, the 50% RAP mixture to be more brittle than the references and 30% RAP mixtures, like in this research. A7 RAP 50% mixture were the similar stiffness result as references mix, but also less resistance to fatigue. The combination of higher stiffness and more brittle behavior will likely result in a shorter fatigue life and a higher probability of thermal cracking occurring in the field. Using small sizes of RAP aggregates leads to an increase in surface area, which in heating of the samples, results in liberating and bleeding more RAP binder into the mixing process. This in turn provides more interaction between the aged and virgin binders and is the likely cause of better virgin and aged binder blending. Fig. 5 demonstrates stiffness modulus values.

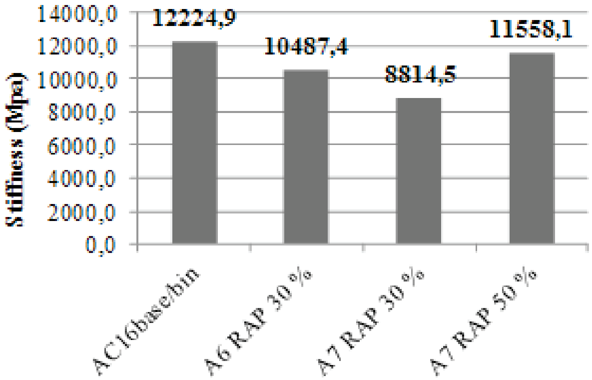

Fig. 5 Stiffness test results.

3. Conclusions

The aim from the design process was to produce recycled mixes with similar properties to the reference mix AC16base/bin (virgin mix made using bitumen B50/70). RAP has no significant effect on volumetric and mechanical properties of the recycled HMA in terms of Marshall stability and flow as well as rut resistance.

Test results also demonstrated that mixtures with RAP showed a little higher resistance to rutting compared to reference mixture, but all of them pass the Specification requirement $WTS_{AIR}<0.3$ mm.

All recycled mixtures (except the A7 RAP 50%) compered to reference mixture showed similar fatigue resistance.

The use of RAP, especially high RAP content, in HMA decreased the fatigue resistance, probably due to the high percentage binder replacement witch stiffens the asphalt mixture. Based on the findings of this study it can be concluded that it is possible to design high-quality HMA with up to 50% RAP that meets the desired volumetric and performance requirements. There are no significant differences in mechanical properties (stiffness and fatigue behavior) between the recycled and virgin mixtures. Increasing the effective asphalt content of the recycled asphalt mixtures will help to increase the durability and fatigue resistance of the asphalt mixtures.

Acknowledgements

The research leading to these results has received the funding from Latvia state research programme under grant agreement "INNOVATIVE MATERIALS AND SMART TECHNOLOGIES FOR ENVIRONMENTAL SAFETY, IMATEH”.

References

[1] Al-Rousan, T., ASI, I., Al-Hattamleh, O. & Al-Qablan, H. 2008. Performance of Asphalt Mixes Containing RAP. Jordan Journal of Civil Engineering volume 2, No. 3.
[2] Al-Qadi, I.L., Elseifi, M. & Carpenter, S.H. 2007. Reclaimed Asphalt Pavement - A Literature Review. Series No. 07-001. Illinois Center for Transportation, University of Illinois.
[3] Al-Qadi, I.L., et al., 2012. Impact of high RAP contents on structural and performance properties of asphalt mixtures. Springfield: Illinois Center for Transportation, Report Number FHWA-ICT-12-002.
[4] Copeland, A., 2011. Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice. FHWA Report No.: FHWA-HRT-11-021.
[5] David E. Newcomb, E. Ray Brown, Jon A. Epps. 2007. Designing HMA Mixtures with High RAP Content. A Practical Guide. Quality Improvement Series 124. National Asphalt Pavement Association, Lanham, MD.
[6] Haritonovs V., Zaumanis M., Tihonovs J., Smirnovs J., 2013. Development of high performance asphalt

concrete using low quality aggregates. Civil Engineering` 13 4th International Scientific Conference Proceedings, Vol. 4 Jelgava, Latvia University of Agriculture, 2013, 371 pages ISSN 2255-7776.
[7] Kandhal, P. S. & FOO, K. Y. 1997. Designing recycled hot mix asphalt mixtures using Superpave technology. ASTM Special Technical Publication, 1322, 101-117.
[8] McDaniel, R.S. and Anderson, R.M., 2001. Recommended use of reclaimed asphalt pavement in the Superpave mix design method: technician's manual. West Lafayette, IN: North Central Superpave Center, Report Number NCHRP 452.
[9] McDaniel, R., Soleymani, H., and Shah, A. 2002. Use of Reclaimed Asphalt Pavement (RAP) Under Superpave Specifications: A Regional Pooled Fund Project, North Central Superpave Center, West Lafayette, IN.
[10] Oliver, J. W. H., 2001. "The Influence of the Binder in RAP on Recycled Asphalt Properties," International Journal of Road Materials and Pavement Design, Vol. 2, No. 3, pp. 311-325.
[11] Tabakovic, A., Gibney, A., Gilchrist, M. & McNally, C. 2006. The influence of recycled asphalt pavement on 20mm binder course mix performance. University College Dublin
[12] Tabakovic, A., Gibney, A., McNally and Michael D. Gilchrist. 2010. Influence of Recycled Asphalt Pavement on Fatigue Performance of Asphalt Concrete Base Courses. DOI:10.1061/(ASCE)MT.1943-5533.0000093
[13] Widyatmoko I. 2008. Mechanistic-empirical mixture design for hot mix asphalt pavement recycling. Construction and Building Materials, Vol. 22, Issue 2, pp. 77-87 doi:10.1016/j.conbuildmat.2006.05.041
[14] Zaumanis M, Mallick RB (2014) Review of very high-content reclaimed asphalt use in plant-produced pavement: state of the art. International Journal of Pavement Engineering, DOI: 10.1080/10298436.2014.893331