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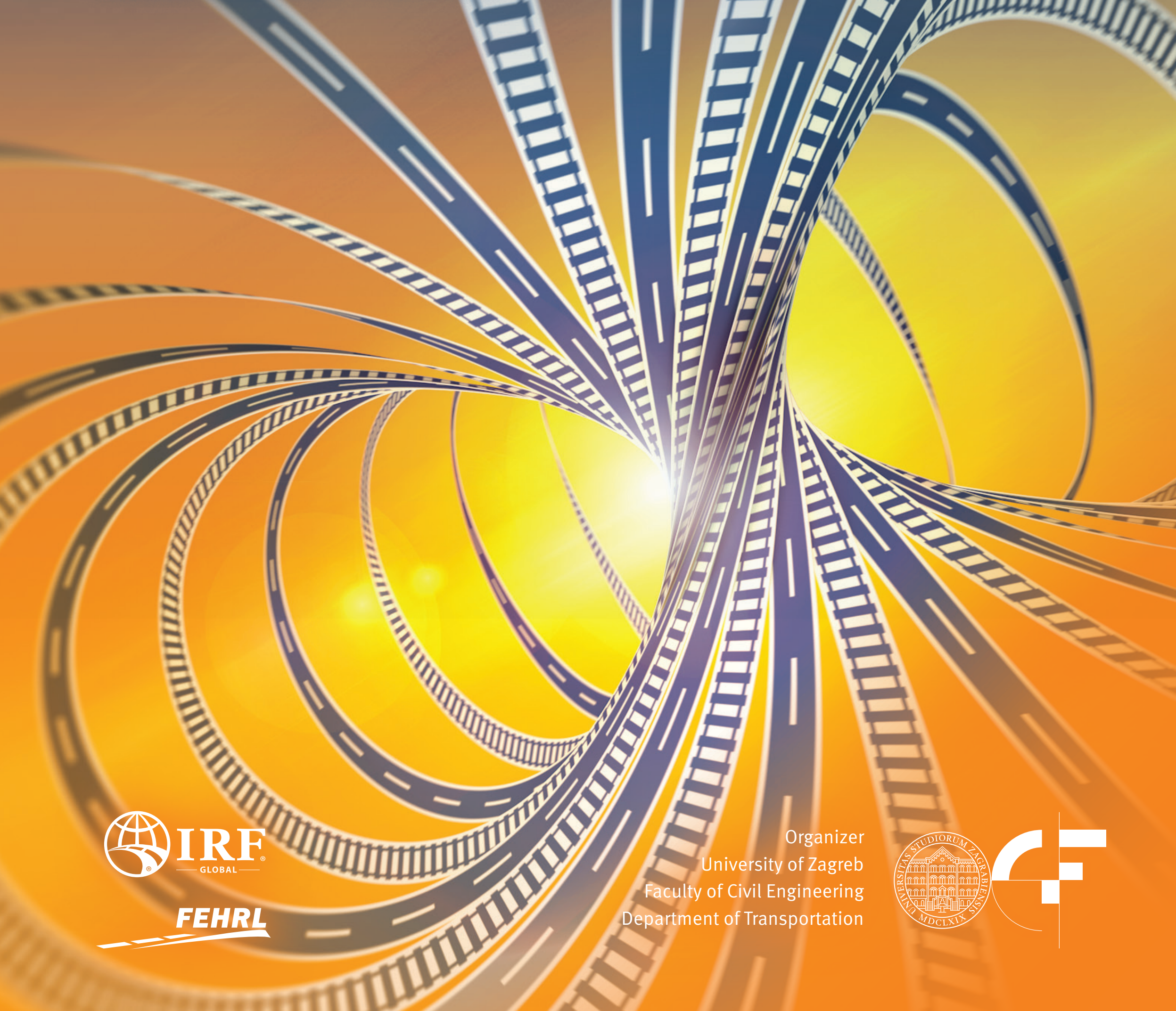
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR



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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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LABORATORY PERFORMANCE-BASED APPRAISAL OF HALF-WARM MIX RECYCLED ASPHALT MIXTURES CONTAINING UP TO 50 % OF RECLAIMED ASPHALT PAVEMENT

José Manuel Lizárraga[1], Antonio Ramírez[2], José R. Marcobal[3], Juan Gallego[1]
[1] *Technical University of Madrid (UPM), Department of Civil Engineering-Transport, Madrid, Spain*
[2] *Department of Research, Development and Innovation, Sacyr Construction, Madrid, Spain*
[3] *Department of Pavements, Sacyr Construction, Madrid, Spain*

Abstract

The use of greener paving technologies involving recycling material and emulsified bitumen is gaining momentum in the recent years as a way to improve environmental performance, reduce pollutant emissions and energy consumption. Thus, one of the leading objective of this research paper is to present the main performance outcomes obtained of an extensive laboratory study to account for, and determine the volumetric and mechanical performance properties of both half–warm mixes (HWMA) and half–warm mix recycled asphalt (HWMRA) mixtures containing two different rates of reclaimed asphalt pavement (25 % and 50 % RAP), with an over-stabilized bituminous emulsion, and, thereafter, compared them with that of a conventional HMA mixture. To do so, both HWMA and HWMRA mixes were designed in the laboratory using the Duriez mix design method in order to calculate the optimal binder film thickness required to achieve a high level of performance and durability of the mixes based on the specific surface area (SSA) of aggregates. Posteriorly, the mixture performance was studied and tested in the laboratory in order to determine the apparent density, air voids, water susceptibility, indirect tensile strength (ITS), at 15 °C, stiffness modulus at 20 °C, and rutting performance, at 60 °C. The results of laboratory showed that the performance of the HWMRA mixtures containing a high RAP content (50 %), and a 50/70 pen-grade bitumen, exhibited an equivalent permanent deformation and moisture damage resistance to the conventional HMA mixture.These findings encourage and strengthen greater confidence in promoting the use of these types of sustainable asphalt mixes.

Keywords: half-warm mix recycled asphalt, overstabilized emulsion, laboratory performance, rutting, moisture damage

1 Introduction

Nowadays, the rising attention to new disruptive asphalt paving technologies has emerged in the wake of the increasing global awareness of the environmental damages arising from the greenhouse gas (GHG) emissions and the consumption of scarce and non-renewable resources.This fact have instigated the researchers to push and move towards more sustainable management practices as a way to to improve environmental performance stewardship, increase construction efficiency, reduce energy consumption and pollutant emissions. One example of a technology that has the potential to get over these issues is the use of half-warm mix asphalt

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(HWMA) mixtures with reclaimed asphalt pavement (RAP). They are manufactured, laid and compacted in the workable temperature range of 65-100 °C.
Despite the environmental, social, technical, and economic advantages of using the HWMRA mix, there still remain a large number of questions to be addressed and answered regarding the long-term performance and durability of these mixes. One of the concerns is (1) due to the often unknown-nature, stocking, and variability in the physical binder properties of the RAP [1]; (2) the lack of current well-established technical specifications, and legislation limitations, in the EN code; and (3) the fact that the use of high RAP contents can lead to increased stiffness modulus and lower durability. However, the inclusion of high contents of RAP into virgin mixes is crucial to improve the bearing capacity and hence the resistance to permanent deformations. In this consonance, McDaniel and Anderson, [2] reported that the inclusion, either low or high contents, of RAP into new mixtures lead to an increase in resistance to permanent deformations because of the hardening of the asphalt binder. However, the results reported by other authors are less conclusive, in the sense that mixtures, manufactured at lower temperatures, containing high RAP contents showed a low rutting resistance, likely as a result of lowering mixing and compaction temperatures [3]. Likewise, Button et al. [4] claimed that the mixes fabricated at low temperatures and emulsified bitumen are typically characterized by having a lower bearing capacity and rutting performance than the HMA mixtures.
These facts have instigated researchers to look into new strategies that enable to enhance mixture's mechanical performance and durability, and reduce at the same time manufacturing and constructing pavement costs. For this reason, an innovative research project entitled "Research and Development of Sustainable asphalt pavements fabricated at low temperatures and Recycled" – (PASOS), was launched in order to promote a new environmental performance approach based on the use of two virgin half-warm mixes (HWMA) and three half-warm mix recycled asphalt (HWMRA) mixtures containing two different rates (25 % and 50 %) of RAP, and an over-stabilized emulsion, for their use in binder and wearing courses of road pavements. In this regard, one of the leading objective of this paper is to determine the mix design compactive effort with the gyratory compactor to posteriorly account for, and calculate the volumetric and mechanical performance properties of these mixes, and, hence, compared them with that of a corresponding HMA mixture.

2 Materials

In this study, six asphalt mixes were studied and tested in the laboratory as follows: (1) a virgin HWMA mix with a 35/50 pen-grade for binder course (HWMAbinder 35/50); (2) a HWMA mix – 35/50 pen-grade, for wearing course (HWMAsurf 35/50); (3) a HWMRA mix containing up to 25 % RAP – 35/50 pen-grade (HWMRA 25 % RAPsurf 35/50); (4) a HWMRA mix with a high RAP content of up to 50 % and a 50/70 pen-grade (HWMRA 50 % RAPbinder 50/70); (5) a HWMRA with a RAP content of 25 % and a 50/70 pen-grade (HWMRA 25 % RAPbinder 50/70); and (6) a dense-graded hot mix asphalt concrete mixture (AC16 D) with a 50/70 pen-grade.

2.1 RAP

The reclaimed asphalt pavement (RAP) was homogenized, treated and classified in two fractions: fine (0/5 mm) and coarse (5/25 mm). This was done in order to guarantee (1) the final binder contents in the final mix design, (2) ensuring the consistency of grading curves and (3) avoiding at the same time excessive mix heterogeneity in the final mixture design. Both fractions of RAP were then characterized in terms of binder content (EN 12697-1), binder recovery (EN 12697-3), and black and white curves. The characterization of the asphalt binder was conducted in terms of bitumen consistency (i.e., penetration and softening point), see Table 1. The black and white grading curves were found to meet the minimum requirements of regularity according to Spanish regulations in Art. 20.2.2.2 – PG-4.

Table 1 Physical characteristics of the aged RAP binder

Characteristics	0/5 mm	5/25 mm	RAP
Binder (%,b/m)	6.40	4.27	5.41
Binder (%,b/a)	6.84	4.46	5.72
Penetration, at 25ºC (dmm)	18	15	16
Softening point, R&B (ºC)	71	74	72

2.2 Virgin aggregates

The virgin aggregates selected and used in this research study were the siliceous and limestone aggregates in which the siliceous aggregates were used for the coarse fraction (12/18 and 6/12 mm), whilst the fine fraction (0/6 mm) is made-up of the limestone aggregates. Table 2 shows the main physical and mechanical characteristics of the different virgin aggregate fractions.

Table 2 Virgin aggregates and the particle size distribution

Test Method	Sieve size (mm)	12/18 mm	6/12 mm	0/6 mm	Filler
Particle grain size distribution (UNE-EN 933-1)	20 (3/4”)	100	100	100	100
	12.5 (1/2”)	33	100	100	100
	10 (3/8”)	2	84	100	100
	5 (Nº4)	–	0.7	96	100
	2.5 (Nº8)	–	0.3	70	100
	0.63 (Nº30)	–	–	36	100
	0.315 (Nº50)	–	–	23	98
	0.16 (Nº100)	–	–	15	96
	0.08 (Nº200)	–	–	9	75
Flakiness index, (EN 933-3), %		10	10	–	–

2.3 Conventional asphalt binder

Two conventional asphalt binders were selected and used according to their penetration grade, that is, a 35/50 pen-grade was selected and used in the wearing course mixture based on the principle that former bitumen (35/50) should present a good coating with the recycled aggregates, good water sensitivity values, and preventing at the same time rutting distresses when compared to 50/70 pen-grade. For the binder course mixture,a 50/70 pen-grade was used to obtain a less stiff and brittle mixture by enabling greater deformations before its fatigue cracking failure occurs in the field. Table 3 shows the physical properties of the asphalt binders.

Table 3 Physical properties of the residual asphalt binder

Properties	Test method	Unit	penetration grade	
			35/50	50/70
Penetration, at 25ºC	EN 1426	0.1 mm	40	61
Softening point, (R&B)	EN 1427	ºC	48.6	52.6
Fragility fraass	EN 12593	ºC	-10	-13

2.4 Bituminous emulsion characterization

Two cationic slow-setting bituminous emulsions (C69B3-EXPORTEM) have been formulated through the use of proprietary emulsifiers, which allowed to further stabilize the emulsion for long-distance transport, and preventing at the same time sedimentation tendency, coalescence, and phase separation of the emulsion at high storage temperatures.Thus, the residual asphalt binder was formulated with a high residue asphalt binder content of roughly 69 % (by weight of the emulsion), to guarantee thick asphalt emulsion film coating on the RAP and virgin aggregates. Table 4 shows the physical and chemical properties of the over-stabilized emulsion.

Table 4 Physical and chemical characteristics of the bituminous emulsion

Characteristics		Test method	Unit	C69B3 35/50	C69B3 50/70
Binder content (from water content)		EN 1428	%	68.95	69.01
Breaking value		EN 13075-1	–	75	73
Efflux time, 4 mm at 40°C		EN 12846	S	10	11
Residue on sieving for 0.5 mm		EN 1429	%	0.05	0.05
Settling tendency at 7 days		EN 12847	%	0.05	0.05
Saybolt-Furol Viscosity	25°C	ASTM D	S	128	106
	50°C	7496-11		70	60
Recovery binder from emulsion. Part 1: Recovery by evaporation (EN-13074)					
Penetration at 25°C		EN 1426	0.1mm	50	69
Softening point		EN 1427	°C	51.8	48.8
Fragility fraass point		EN 12593	°C	–10	–11
Force ductility, at 25°C, 5 cm/min		EN 13589	cm	>100	>100
Solubility in Trichloroethylene		ASTM D 2442	%	99.1	99.1

3 Mix design method

3.1 Half-warm mix recycled asphalt mixtures

In order to define the optimal binder film thickness required to achieve a high level of performance, coating, and proper bonding of the mineral aggregate surface with the mixture, the Duriez mix design method was selected and used based on the specific surface area (SSA) of aggregates. In which the mean apparent density of the virgin aggregates was calculated (ρ = 2.750 g/cm^3), together with the specific gravity of the residual asphalt binder (γ = 1.03 g/cm^3), according to EN 15326. Once those properties had been calculated, the SSA (m^2/kg) of aggregates of each type of mixture was determined applying Eq. (1) introduced by Duriez and Arrambide [5]:

$$SSA = 0.237g + 1.60S + 12.85s + 117.8f \tag{1}$$

Where SSA is the specific surface area of aggregates expressed in terms of m^2/kg; g is the percentage of gravel by weight above 5 mm sieve (3/4” and No. 4); S is the percentage of coarse sand between 0.315 and 5 mm sieves (No. 4 and 40); s is the percentage of fine sand by weight grains between 0.080 and 0.315 mm sieves (No. 4 and 200); f is the percentage of filler by weight of grains below 80 µm (No. 200).

Posteriorly, the half-warm mixes were manufactured in the laboratory by heating the RAP at 100 °C, virgin aggregates at 110-115 °C, and bituminous emulsion at 60 °C. The laboratory compaction system selected and employed to assess the mixes was the shear gyratory compactor (SGC), at 80 °C, according to EN 12697-31. These mixes were then prepared and tested in the laboratory applying four different compaction energies with the gyratory compactor (45, 90, 135 and 180 gyros), at 45 gyration increments, where the number of gyros applied to each RAP mixture was adapted in order to achieve air voids in the value range of 4-6 %. Thus, the gyratory compaction began using the following standard conditions (1) Rotation internal angle speed: 1.20°; (2) Static contact load pressure: 600 kPa; (3) Speed of rotation: 30 gyros/min; and (4) Mold diameter: 150 mm. The Marshall mix design was used to design and compute the optimal binder content of the HMA mixture (EN 12697-34). The specimens were compacted with a Marshall hammer applying 75 blows on each face, at 150 °C (EN 12697-30). The target void content was the same as that for the rest of the mixes, in order to reliably compare their mechanical properties. Table 5 shows the final compositions of the mixtures studied.

Table 5 Final composition of the mixtures

Materials	Fraction (mm)	Wearing course			Binder course		
		HWMA	HWMRA 25 % RAP	HMA AC16 D	HWMA	HWMRA 25 % RAP	HWMRA 50 % RAP
Virgin Aggregates	12/18	15	15	10	24.8	20	18
	6/12	30.2	28	29	34.2	30	36.8
	0/6	54.8	32	–	40	6	20
	Filler	0	0	–	1	21	12.2
	0/5 *	–	–	37	–	–	–
	0/5 **	–	–	25	–	–	–
RAP	0/5	–	12.2	–	–	23	12.8
	5/25	–	12.8	–	–	0	0.2
Aged binder (%,b/a)		4.95	4.95	0	4.60	4.60	4.60
Emulsion/ binder		3.54	3.54	5.0	3.0	3.0	3.0
Final binder (%,b/a)		7.17	5.13	5.0	6.67	6.67	6.67

*Note: %b/a – percentage of binder by mass of aggregates. * Siliceous; ** Limestone*

4 Test results and discussion

In order to assess the volumetric and mechanical performance properties of the mixtures studied, in-laboratory samples were studied and tested for air voids, stiffness modulus, at 20 °C, water sensitivity, ITS at 15 °C, and rutting resistance, at 60 °C. Looking at the air void content values, it can be said that the air voids targeted were successfully achieved for both HWMA and HWMRA mixtures, as they were found to fall within the values range of 5 ±1 % when applying the optimal compaction energy (OCE), that is to say, 135 gyros for the HWMRA 25 % RAPbinder mixture, whilst for the remaining mixtures studied this number was 180. The bearing capacity of the mixtures was evaluated through the stiffness modulus test, at 20 °C, according to EN 12697-26. For the HWMRA 50 % RAPbinder (50/70) mixture, the average stiffness modulus value of 3762 MPa was obtained, while for the HWMAsurf (35/50) mixture this number was 2493 MPa. Thus, it is worth noting that the difference in the stiffness modulus values, between HWMA and HWMRA mixtures, is likely due to the ageing of the recycled binder added into the new mixture as well as it may be also attributted to the differences in binder consistency.

4.1 Moisture damage

The moisture damage resistance was assessed by conducting the water sensitivity test (EN 12697-12). Thus, in-laboratory samples were compacted with the gyratory compactor applying two-thirds of the total compaction energy used for laboratory specimen preparation. Figure 1 shows the indirect tensile strength (ITS) values, at 15 °C, in-wet and in-dry conditions, and the retained strength (ITSR) value results.

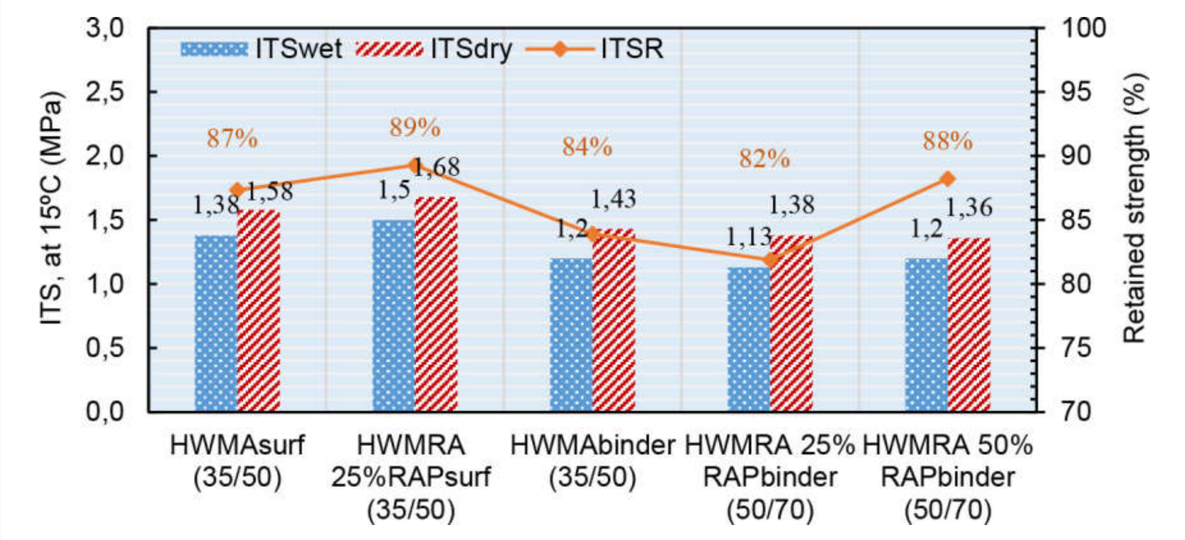

Figure 1 Indirect tensile strength, at 15 °C, and retained water strength values

Looking at the moisture damage values, the HWMRA 25 % RAPsurf (35/50) mixture showed the highest resistance to moisture damage value (89 %), whilst for the conventional HMA mixture the average retained water strength value was 87 %. Similar outcomes have been found and contrasted by Karlsson and Isacsson [6], who claimed that mixtures containing a high RAP content exhibit similar moisture damage resistance values to that of HMA mixtures, since the recycled aggregates are covered with a thin-film of asphalt binder, which prevents the water penetration into the particles [7]. Thus, one can say that the HWMRA mixtures meet the minimal percentage required for base, binder (≥ 80 %) and wearing (≥ 85 %) course mixtures of road pavements, according to Spanish regulations – Art. 542.5.1.4 – PG-3.

4.2 Rutting

In order to complete the laboratory study of the mechanical performance of the mixtures studied, the resistance to permanent deformation was assessed by conducting the wheel tracking test, at 60 °C, according to EN 12697-22. Among all the mixtures studied, the HWMRA mixture containing up to 25 % RAPsurf (35/50) showed the lowest deformation slope value of 0.074 (mm/1000 load cycles), between 5000 and 10.000 load cycles, and average proportional rut depth (PRD) value equal to 5 %. In this regard, the slope of the rut depth (RDair) curves depicted in this Figure showed that both HWMRA (25 % RAPsurf -35/50 and 50 % RAPbinder -50/70) mixtures exhibited equivalent resistance to permanent deformation to the HMA mixture. Similar outcomes were reported by Hajj et al. [8], who reported that mixtures containing a high RAP content present better, or similar, resistance to permanent deformations than that of the HMA mixtures. Based on the rutting values obtained, and according to Spanish regulations in Art. 542.5.1.3 – PG-3, one can say that both HWMRA mixtures were found to meet the minimum rutting performance values for use in base, binder and wearing course mixtures of road pavements subject to any heavy traffic load category and thermal zone in Spain.

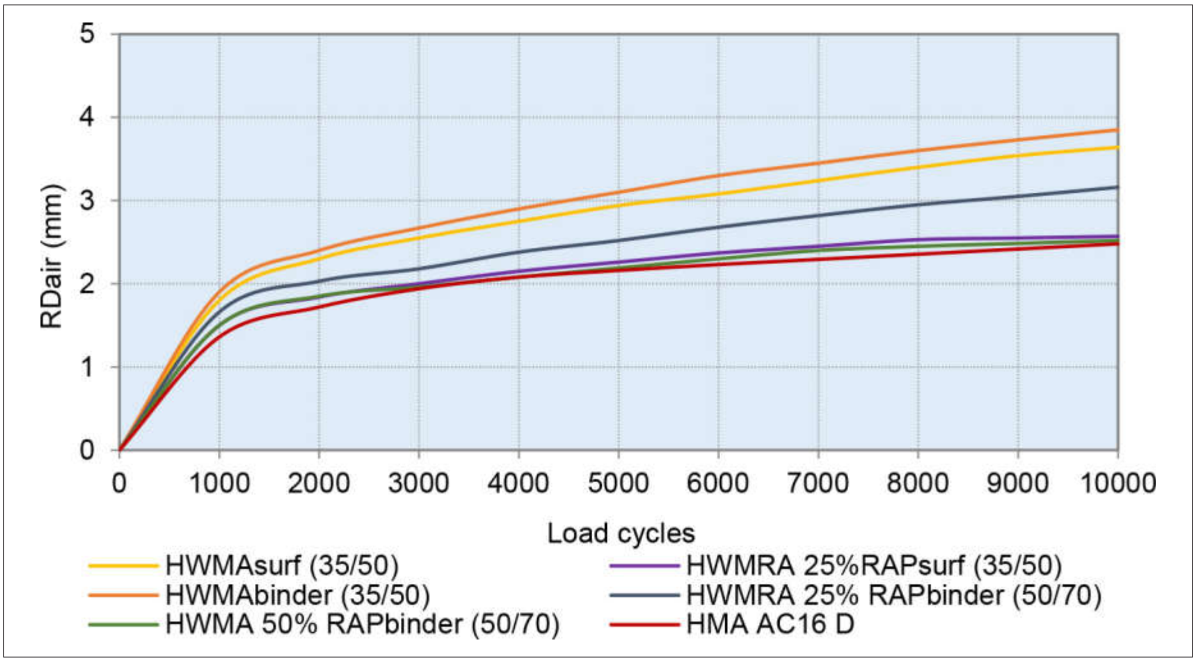

Figure 2 Wheel tracking test value results, at 60 °C

5 Conclusions

This research presents the main performance outcomes of a research study aimed at accounting for, assessing, and determining the volumetric and mechanical performance properties, in- laboratory, of two virgin half-warm mix asphalt (HWMA) and three half-warm mix recycled asphalt (HWMRA) mixtures containing two RAP contents (25 % and 50 %), and, thereafter, compared with that of a HMA mixture. Based upon the results obtained in this research study the following conclusions can be drawn; (1) the air voids were successfully achieved in the value range of 4-6 %, applying the optimal compaction energy with the gyratory compactor; (2) Both HWMA and HWMRA mixtures met the minimum moisture damage resistance values allowed for base, binder (≥ 80 %) and wearing course (≥ 85 %) mixtures; (3) The HWMRAbinder 50 % RAP mixture showed higher stiffness modulus values (at 180 gyros) than the rest of mixtures studied, due to the hardening and ageing of the asphalt binder added into this mixture; (4) In particular, the HWMRA mixtures showed good resistance to permanent deformations below 0.076 (mm/1000 load cycles) and mean rut depth values below 5 %. Finally, one can say that the HWMRA mixtures containing high rates of RAP, and an over-stabilized emulsion, can be regarded as an environmentally sound alternative to conventional HMA mixtures.

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