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Influence of the Addition of Reclaimed Asphalt Pavement (RAP) on the Performance of Hot Mix Asphalt Mixes

Influencia de la adición de pavimento asfáltico recuperado (RAP) en el comportamiento de las mezclas asfálticas en caliente

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Abstract

The use of recycled asphalt pavements serves as an alternative to reduce the reliance on non-renewable resources. The deteriorated pavement can be recycled as a feasible solution. It is therefore important to study the influence of this material on the behavior of the mixes. In this research, asphalt mixes with 10% and 20% RAP, in the 0-10mm fraction, using two bitumen contents (4.0% and 4.5%) are studied. The mixes with RAP are compared with a conventional asphalt mix. Parameters such as Marshall stability and flow, water sensitivity, permanent deformation, and stiffness modulus were analyzed. The general results show that the behavior of the recycled mixes is similar to or better than the conventional mix. The best results were obtained for the addition of 20% RAP.

Keywords: reclaimed asphalt pavement (RAP), rutting resistance, stability, stiffness modulus.

Resumen

Las mezclas asfálticas recicladas han sido una alternativa para la reducción del empleo de materiales naturales no renovables. El material procedente del fresado o la demolición de los pavimentos deteriorados (RAP) ha sido una solución factible. Por ello es importante estudiar la influencia de este material en el comportamiento de las mezclas. En esta investigación se estudian mezclas asfálticas con empleo de 10 y 20 % de RAP, en la fracción 0-10mm, empleando para su fabricación dos contenidos de asfalto (4,0 y 4,5 %). Las mezclas con RAP son comparadas con una mezcla asfáltica convencional (0 % RAP). Se analizaron parámetros como estabilidad y deformación Marshall, la sensibilidad al agua, la deformación permanente y el módulo de rigidez. Se obtuvo como resultado general que las mezclas recicladas presentan comportamientos similares y superiores a los de la mezcla convencional. Los mejores resultados se obtuvieron para la adición de 20 % de RAP.

Palabras clave: estabilidad, módulo de rigidez, pavimento asfáltico reciclado (RAP), resistencia a la rodadura.

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INTRODUCTION

With the maintenance and rehabilitation of pavements, there is an increase in surface milling operations. It generates materials (aggregates and asphalt) with a high potential for reusing using cold or hot recycling techniques. The use of reclaimed asphalt pavement (RAP) has become relatively common practice in most countries [1], [2], [3] to reduce the negative environmental impact that the construction implies [4], [5], [6], [7], [8] either by the consumption of natural resources [7], energy or by the generation of landfills for the milled material. The idea is that the road integrates, as far as possible, the functions of quarry and landfill [9], [10].

RAP is the aggregate coated with aged asphalt. RAP is the only material that is 100% recyclable [11] but its quality is an important factor in pavement recycling and depends fundamentally on the oxidation of the mix. This leads to differences in the material because the RAP stockpiles do not always come from the same construction site, so there can be significant variations in terms of aggregate quality, content, and type of asphalt [12], [13], [14].

The percentage of RAP to be added to the mixes is established according to the regulations and experiences of each country. In general, the addition of this material in a new mix varies between 10 and 50%. In some countries, it is added in low percentages, due to its quality and influence on road safety. Three types of recycling are established depending on the percentages added. The use of up to 15% is considered as recycling in low percentages, i.e., specialized equipment is not needed because the RAP is taken as another aggregate since the aged asphalt present in the aggregates is not considered. Between 15% and 30% is considered conventional recycling because the pavement performs similarly to conventional mixes, where special equipment and techniques must be applied, although it is technically solved and presents no difficulties. Incorporations of RAP up to a proportion of 10 - 30% do not have any detrimental effect on pavement performance [15], [16]. Finally, percentages higher than 30% of RAP are considered high percentages of RAP, which requires specific studies and special characteristics of the material to be used or the equipment to be used [17].

According to scientific literature, asphalt mixes with low percentages of RAP (< 15%) present low water sensitivity, showing that there are no significant changes with the increase of the RAP percentage [18], [19]. Other research indicated that, in case of low content of RAP, adding reclaimed asphalt leads to increasing the fatigue cracking resistance [20], [21] and rising rutting resistance [22], [23], [24], enhancing moisture damage potential of the mixes [5], [25], [26], [27], [28], [29], increasing tensile strength ratio [5], [25], [30], [31], [32], [33], [34]. Similar investigations suggest that the stiffness modulus of asphalt mixes increases with the presence of RAP [19], [5]. Other studies show that the rise of RAP percentage (>15%) causes higher water sensitivity decreasing the moisture resistance, higher rutting resistance, and resilient modulus [35]. Despite the aforementioned benefits, there are some problems associated with the use of high contents of RAP material in asphalt mixtures such as a reduction in cracking resistance [7], [36].

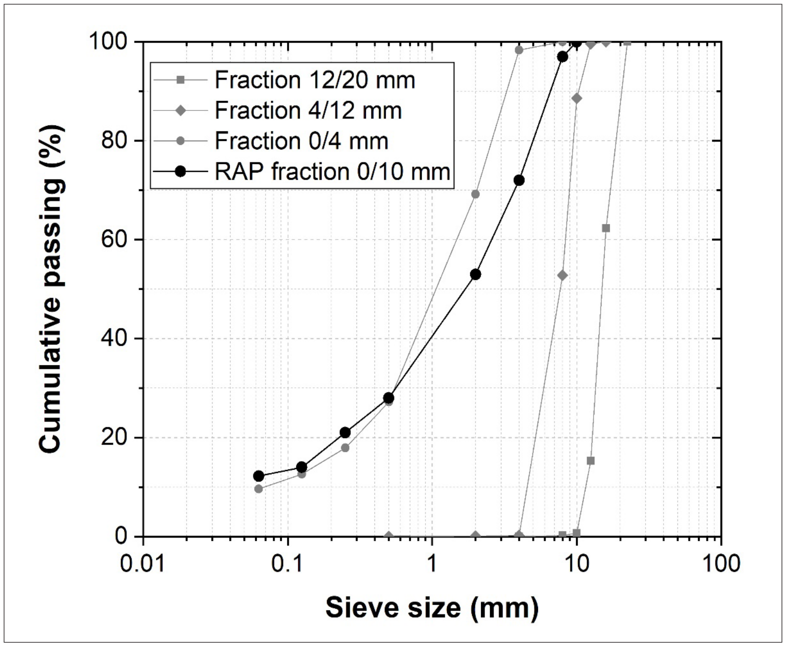
Due to the varied outcomes and the understanding that the performance of asphalt mixes containing recycled asphalt pavement (RAP) can be affected by multiple factors, this research aims to evaluate the behavior of hot mix asphalt containing RAP in proportions ranging from 10% to 20%. This material will be analyzed as an aggregate, without additional treatment. For this purpose, the results will be compared with a conventional mix and with the requirements established in the standards.

MATERIALS AND METHODS

Materials

Three fractions of natural aggregates, one fraction of RAP recovered and bitumen penetration grade 50/70 were used for the asphalt mix design. The natural aggregates used were limestone from the Fontcalent quarry located in the province of Alicante, Spain, as same the fraction of RAP. The fractions used as a coarse aggregate were natural limestone (4/12 mm and 12/20 mm). As a fine aggregate a limestone, the fraction 0/4 mm was used. Limestone filler was used in all the mixes manufactured.

Figure 1 illustrates the particle size gradations, while Table 1 presents the physical properties of natural aggregates, as obtained according to the UNE EN 933-1 standard [37]. The RAP granulometry used corresponds to the “black curve”, there is no shredding procedure was used.



Source: own elaboration.

Figure 1. Particle size gradations of natural and RAP aggregates

Table 1. Natural aggregate characterization

Properties	Standard	Fraction 12/20 mm	Fraction 4/12 mm	Fraction 0/4 mm
Apparent density (g/cm3)	UNE EN 1097-6 [38]	2.68	2.69	2.65
Water absorption 24 h (%)	UNE EN 1097-6 [38]	0.5	0.4	1.02
Abrasion test (%)	UNE EN 1097-2 [39]	28	28	-
Flakiness index (%)	UNE EN 933-3 [40]	16	18	-
Sand equivalent (%)	UNE EN 933-8 [41]España</pub-location><publisher>Asociación Española de Normalización y Certificación</publisher><urls></urls></record></Cite></EndNote>	-	-	67

Source: own elaboration.

The binder used in the present work is classified as 50/70 according to the PG-3 [42] from the REPSOL company. Table 2 shows the characterization of the bitumen used in the manufacture of the mixes.

Table 2. Bitumen properties

Properties	Standard	Results	Requirement in PG-3 [42]
Penetration (1/10 mm)	UNE EN 1426 [43]	58	50-70
Softening point (°C)	UNE EN 1427 [44]	50.8	46-54

Source: own elaboration.

The RAP was obtained from the milling of the pavements and was subjected to a homogenization and screening process and then stockpiled at the Fontcalent asphalt plant of PAVASAL company (Alicante, Spain).

For this research, the RAP was used in percentages of 10% and 20% of the mixing aggregate weight in the fraction 0/10 mm. It is considered a low percentage and conventional recycling of recycled material. In the mixes with RAP will be considered both the effect of RAP as aggregate and the percentage of aged bitumen. The percentage of aged bitumen was determined to calculate the percentage of natural bitumen to add in the mixes.

The components of the RAP (recovered aggregate and aged bitumen) were also characterized. For the separation of the asphalt, the solvent perchloroethylene was used and then cold extraction was performed using the continuous flow centrifuge to separate the aggregate and the solvent with the aged bitumen. After the separation of the materials, the aged bitumen was recovered with a vacuum pump (Figure 2), according to UNE-EN 12697-1 standard [45].

Source: own elaboration.

Figure 2. Vacuum system for extracting bitumen

The RAP characterization is shown in Table 3, where the results obtained were also compared with the recommended ranges for each of the properties and were found to be within the recommended limits.

As can be seen in Table 3, the penetration of the aged bitumen is lower than the recommended values. For this reason, the combination of aged-new bitumen should be accomplished with the bitumen grade 50-70 mm, and it does not vary with the addition of the different percentages of RAP.

Table 3. RAP characteristics

Properties	Standard	Results	Recommended values [46], [15], [19]
RAP Bitumen content (%)	UNE EN 12697-1 [45]	4.8	Standard: 4.5 – 6 Maximum: 3 – 7
RAP Moisture (%)	UNE EN 12697-14 [47]	3.4	Standard: ≤ 5 Maximum: 7 – 8
Aged bitumen Penetration (1/10mm)	UNE EN 1426 [43]	5	10-80

Source: own elaboration.

To characterize the aged bitumen extracted from the RAP and new bitumen, both were mixed in the three percentages selected for the research (0%, 10%, and 20%) and the penetration of these combinations was determined. As shown in Table 4, the combinations of aged-new bitumen for 10% and 20% addition of RAP did not modify penetration bitumen value, remaining within the required range of 50-70 [42]. The results are according to other research [46], where the authors state that for additions between 15% and 30% of RAP, there are no variations in the properties of the materials and procedures for the mixes.

Table 4. Penetration values obtained for different percentages of aged-new bitumen mixed

RAP percentage	Penetration (1/10 mm)	Requirement (/1/10 mm)
0% RAP	58	50-70
10% RAP	57.5	
20% RAP	56	

Source: own elaboration.

Asphalt Mixes Design

Three dense asphalt mixes with a 16 mm aggregate maximum size were designed (AC 16D) [42]. A conventional mix without RAP (0% RAP) was used as a control asphalt mix to compare with the mixes with RAP. Two asphalt mixes with 10% and 20% of RAP were designed. In each case, two bitumen contents (4.0% and 4.5%) were used. Table 5 shows the sieve size distribution combining RAP and natural aggregates of each asphalt mix with the upper and lower limits established in PG-3 [42] for AC 16D.

Table 5. Mix aggregate proportions of each asphalt mix

Asphalt mix	12/20 mm	4/12 mm	0/4 mm	Filler	RAP 0/10 mm
0% RAP	15	30 30 29	53,5	1,5	-
10% RAP	15		44	1	10
20% RAP	15		35,2	0,8	20

Source: own elaboration.

Figure 3 shows the aggregate combination of each of the mixes designed.

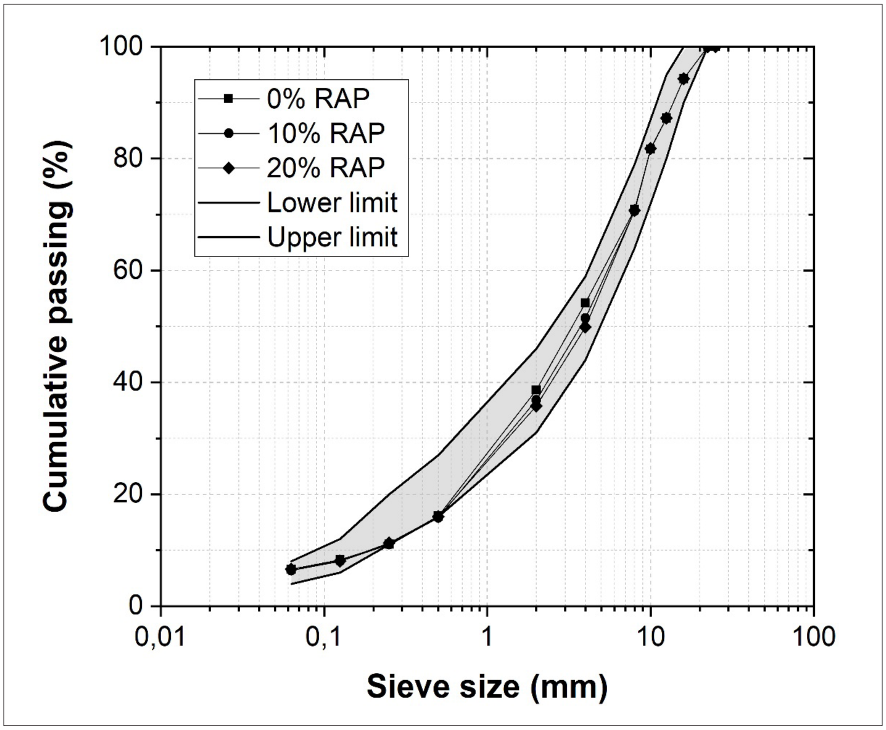


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Figure 3. Particle size gradations of the designed asphalt mixes including the lower and upper limits required in PG-3 for dense mixes AC 16D [42]

For the addition of new bitumen to be used in the mixes designed, the aged bitumen content contained in the RAP is computed, which was determined by Equation [1].

$$Pr = Pc - (Pa * Pp) \qquad [1]$$

Where Pr is the percentage of new bitumen to be added; Pc is the total percentage to be added; Pa is the percentage of bitumen in the RAP and; Pp is the percentage of RAP in the mixes designed. Table 6 shows the content of new bitumen to be added in each asphalt mix designed obtained by Equation [1].

Table 6. Bitumen content to be added in each mix designed

Asphalt mix	Aged bitumen content in the RAP (%)	Total bitumen contained in the mix (%)	New asphalt to be added (%)
0% RAP	4.8	4.0	4.0
		4.5	4.5
10% RAP		4.0	3.52
		4.5	4.02
20% RAP		4.0	3.04
		4.5	3.54

Source: own elaboration.

Experimental Procedure

The Marshall method according to the standard UNE EN 12697-34 [48] was used for the manufacture of asphalt mixes. The parameters established therein (density, voids in the mix, in the aggregate, stability, and Marshall deformation) were determined. In addition, the long-term behavior properties such as dry and wet indirect tensile strength, moisture susceptibility, stiffness modulus, and permanent deformation were analyzed. The results were compared with the control mix and with the specifications established in Spanish standards [42].

To evaluate the indirect tensile strength (ITS) of the mixes, the standard UNE EN 12697-23 [49] was used. The indirect tensile test consists in breaking cylindrical specimens by applying a compressive load along the vertical diameter and ITS was determined by the Equation [2].

$$ITS = \frac{2 \cdot P}{\pi \cdot D \cdot h} \qquad [2]$$

where ITS is the indirect tensile strength (MPa); P is the applied load (N); D is the specimen diameter (mm); and h is the specimen thickness (mm).

The water damage resistance test evaluated with the indirect tensile strength ratio (ITSR) by dividing a set of specimens for testing to ITS in dry condition (ITS_d) and another set for determining ITS in wet condition (ITS_w), as indicates the standard UNE EN 12697-12 [50]. The ITSR water damage resistance was determined based on Equation [3].

$$ITSR = \frac{ITS_w}{ITS_d} \times 100 \qquad [3]$$

For determining the permanent deformation, the wheel tracking test was carried out according to the standard UNE EN 12697-22 (small-size device air) [51]. A moving wheel stresses a pavement slab at 60 °C for 10 000 cycles and the permanent deformation is recorded. The wheel tracking slope (WTS_{air} - in mm/103 load cycles) was determined based on the rut depth between 5,000 and 10,000 cycles (Equation [4]).

$$WTS_{air} = \frac{d_{10\,000} - d_{5\,000}}{5} \qquad [4]$$

The stiffness modulus was determined according to the standard UNE EN 12697-26 [52] at different temperatures (20, 30, and 50°C) following the Equation [5].

$$Sm = \frac{F(\nu + 0.27)}{z \cdot h} \qquad [5]$$

where the stiffness modulus in MPa is Sm; F is the maximum value of applied vertical load (N); ν is the Poisson coefficient; h is the thickness of the specimen in mm; z is the horizontal displacement (mm).

RESULTS AND DISCUSSION

Volumetric Parameters of the Mixes

Figure 4a shows the density of the mixes obtained, and Figure 4b represents the air voids content (Va) and the voids in the mineral aggregates (VMA).

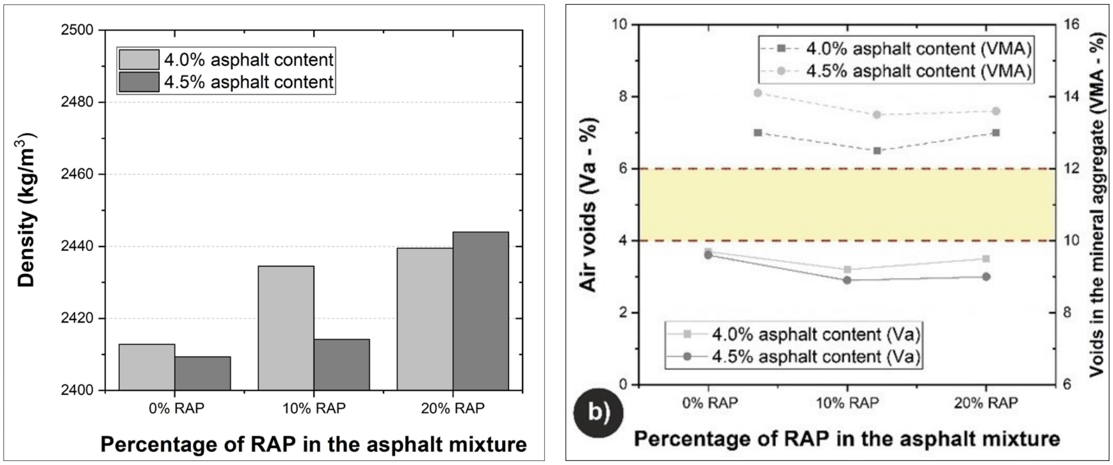

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Figure 4. a) Density of asphalt mixes produced with varying amounts of RAP and different bitumen content and; b) air voids and voids in the mineral aggregate of those mixes. Red dotted lines indicates the limits of Va established for designing dense mixes AC 16D [42]

As can be seen in Figure 4, the recycled asphalt mixes (manufactured with RAP) show higher density than the mixes without RAP for the two bitumen contents studied (4% and 4.5%). The results indicated an increase in the density with a higher content of RAP in the mixes manufactured.

The void values were similar for all mixes. Va and VMA showed a slight decrease regarding the control mix with 0% RAP and a slight increase with a higher percentage of RAP. The control mix with 0% RAP and 4.5% asphalt meets the recommendations indicated in PG-3 for VMA (>14%). As can be seen, the samples with RAP presented lower values of voids, highlighting the low values of Va exhibited by the mixes with RAP according to other researchers reported [53], [54].

Marshall Stability and Flow

The results obtained in the stability and flow Marshall tests are shown in Figure 5. The results are by several authors that stated an increase of Marshall stability with higher RAP content in the mix compared with the control mixes (0% RAP) [55]. Furthermore, it can be noted that the values obtained meet the specifications outlined in PG-3 [42], except for the control mix (0% RAP), which exhibited lower stability than the requirements (≤ 12.5 kN).

As shown in Figure 5 when the percentage of RAP was higher in the mix, the deformation also increased. All the values obtained in the mixes were according to the recommendations specified in PG-3 (2-3.5 mm). It can be said that the behavior according to the Marshall tests of the mixes manufactured with RAP was better than the control mix, obtaining the best results for the mixes with higher RAP content (20%).

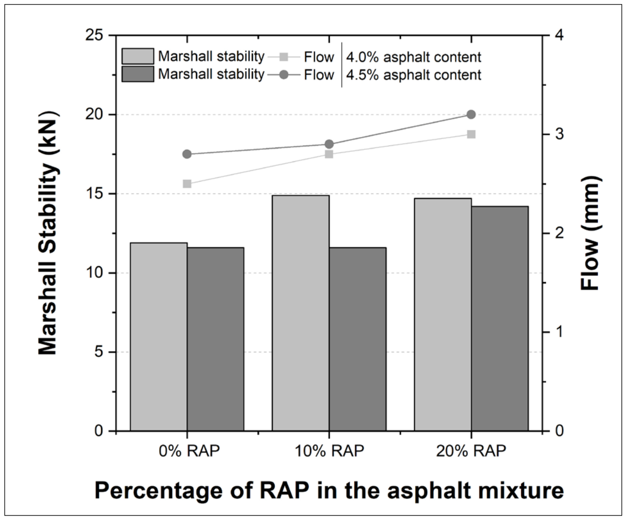

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Figure 5. Results of the Marshall stability and flow test

Water Damage Resistance

Figure 6 shows higher indirect tensile strengths in both states (dry and wet) than the 0% RAP mixes. It can be observed that the water damage resistance did not show considerable differences with 4% or 4.5% of bitumen content. However, it can be seen higher ITS when RAP content increases.

ITSR, for 4% bitumen content, was higher in the mixes that were manufactured with RAP than the control mix without RAP. However, for mixes with 4.5% of asphalt content, better behavior was determined in the control mixes. Nevertheless, the results confirmed that all the mixes complied with the established Spanish standards (>80%).

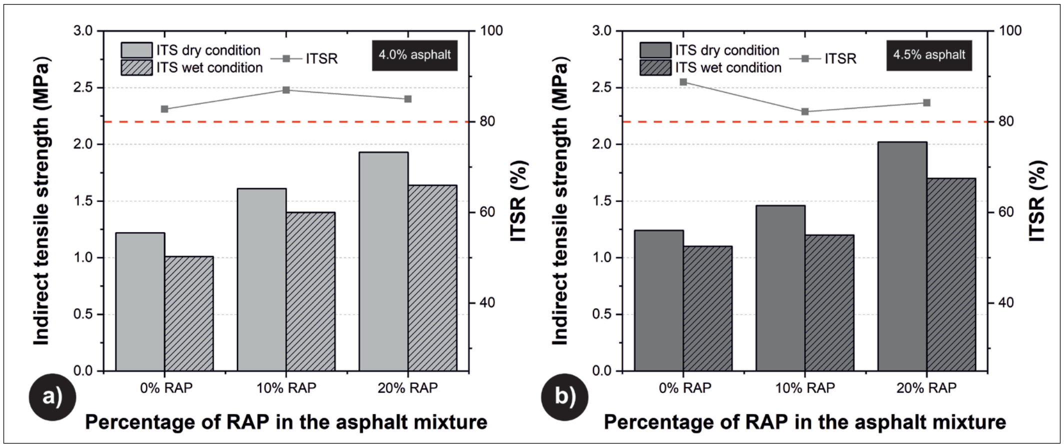

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Figure 6. Results obtained of indirect tensile strength (ITS) in dry and wet conditions and indirect tensile strength ratio (ITSR) of a) mixes with 4.0% of asphalt content and; b) mixes with 4.5% of bitumen content. Red dotted lines indicate the minimum value (>80%) established for designing dense mixes AC 16D [42]

Permanent Deformation

The results of the permanent deformations (WTSair) are shown in Figure 7. As usual, the deformations obtained according to the wheel tracking test increased for higher percentages of asphalt content, while with the increase in the percentage of RAP, they decreased. This corroborates the results obtained in other research [18], where it is stated that the increase in the percentage of RAP in the asphalt mixes favors their stiffness causing a decrease in the permanent deformations.

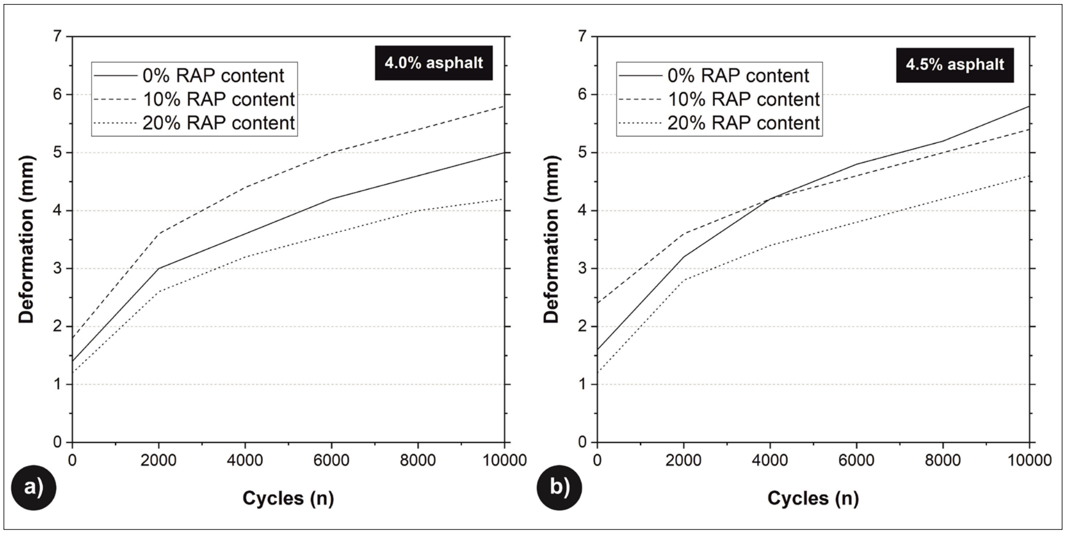

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Figure 7. Results obtained of permanent deformation with wheel tracking test for a) mixes with 4.0% of bitumen content; b) mixes with 4.5% of bitumen content

In addition, Table 7 shows that the results obtained in the slope (WTSair) and the depth of rut (PRDair) were higher than the maximum limits established in Spanish standard which limited WTSair ≤ 0.07 mm/103 cycles and PRDair ≤ 5%.

Table 7. Wheel tracking test results

Asphalt mix	Total asphalt contained in the mix (%)	WTSair (mm/103 cycles)	PRDair (%)
0% RAP	4.0	0.23	12.56
	4.5	0.25	13.87
10% RAP	4.0	0.25	13.72
	4.5	0.18	13.06
20% RAP	4.0	0.16	9.56
	4.5	0.19	10.78

Source: own elaboration.

Stiffness Modulus

The stiffness modulus of asphalt mixes at different temperatures (20, 30, and 50 °C) was determined by the IT-CY method according to UNE EN 12697-26 [52].

Figure 8 shows that the stiffness modulus of the asphalt mixes increased with higher RAP content when the test was done at 20 °C and 30 °C. As can be seen a different behavior was observed at a temperature of 50 °C, since when the percentage of bitumen increases, the modulus decreases for the mixes with RAP. It can be noted that the stiffness modulus decreases with increasing temperature, showing the susceptibility of the mixes to high temperatures. Spanish recommendations establish that the stiffness modulus at 20 °C for dense mixes should be between 3500 MPa and 9500 MPa [56]. As can be seen, the mixes manufactured at 20 °C were according to this recommendation. When the temperature was higher (30 °C) asphalt mixes with RAP and 4.5% of bitumen content were still between the recommended values and with 50 °C the stiffness modulus was lower than requirements.

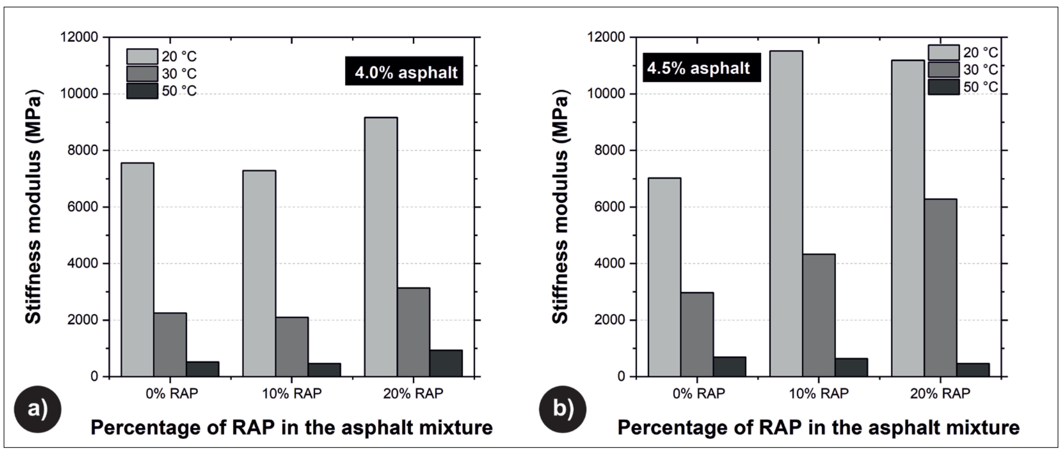

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Figure 8. Results obtained of stiffness modulus of: a) mixes with 4.0% of bitumen content; b) mixes with 4.5% of bitumen content

CONCLUSIONS

The results obtained confirm the viability of using RAP to reduce natural aggregate in dense hot mix asphalt as a solution to minimize the exploitation of raw materials and reduce the impact of waste material. The main conclusions that can be drawn from this work are the following:

The asphalt mixes manufactured with RAP exhibited similar or better behavior than those manufactured without RAP. This corroborates the use of RAP in the asphalt mixes as a substitute for natural aggregate.

When the RAP content increases in asphalt mixes, density, Marshall stability, indirect tensile strength, and stiffness modulus also increase.

Higher RAP in asphalt mixes increases the stiffness modulus of the mixes causing a decrease in the depth of permanent deformations.

It is corroborated that the asphalt mixes manufactured with RAP up to 20% substituting natural aggregates, do not require modifications in the procedure or in the technology to be used, since they do not cause variation contributing to sustainable construction.

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