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PERFORMANCE OF RECYCLED ASPHALT MIXTURES FORMULATED WITH MODIFIED BITUMEN

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Abstract

The maintenance of flexible roads or roads at end of life service generates high quantities of reclaimed asphalt pavement every year. The reuse of these materials, considered for a long time as waste, allows a substantial saving in transport, energy, and maintains dwindling natural resources. Recycling of asphalt also helps to reduce inert waste storage volumes, and conserve valuable landfill space. The applicability of recycled asphalt was tested in laboratory, and asphalt mixtures containing 20%, 40% and 50% of reclaimed asphalt pavement (RAP) were designed. Marshall and Duriez tests have been performed on various formulations using paving grade bitumen and modified bitumen as binders, the latter contains a quantity of Styrene /Butadiene / Styrene (SBS) polymer. This investigation led to the conclusion that the performance of recycled asphalt mixture containing 20% of RAP is significantly closer to those obtained with virgin asphalt mixture without recycled materials. In addition, the use of SBS polymer improves the properties of recycled asphalt mixtures even with high amounts of reclaimed asphalt pavement.

Key words: asphalt, formulation, performance, reclaimed asphalt pavement, recycling

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1. Introduction

In recent years, many companies around the world have committed themselves to develop and generalize the recycling of asphalt, commitments made possible thanks to the development of asphalt recycling techniques. The use of reclaimed asphalt pavement (RAP) in asphalt mixtures contributes to the reduction of construction costs through the saving of aggregates and binder.

Major research axes are being launched around the world in order to increase the RAP proportion in asphalt mixtures and try to obtain similar performances, even better than virgin asphalt, which contains only new materials (Swamy and Das, 2009; Melbouci et al., 2014). The recycling operation consists to incorporate old asphalt with new aggregates and virgin binder in order to produce new asphalt mixture. Several economic and technical factors encourage investment in this field: high cost of asphalt's components, availability of recycling facilities such as cold milling machines, and the existence of large asphalt deposits in road networks. The old asphalt designated under the name of ''Reclaimed Asphalt Pavement'' (RAP), which is a granular material resulting mainly from maintenance and road rehabilitation. It is a mixture of aggregates, binder, additives, and even waste sometimes. Recycled asphalt mixtures are mainly defined by the mass fraction of RAP that they contain. Most laboratory studies have concluded that the properties of recycled asphalt and virgin asphalt mixtures are almost similar when the percentage of RAP is low up to 15% or 20% (Mcdaniel and Anderson, 2001; Mcdaniel et al., 2002). Indeed, a low rate of RAP will not significantly affect the stiffness and strength of the final asphalt mixture in both high and low temperatures. However, above 20% of RAP, stiffness

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and strength of asphalt mixture increase significantly, and thus, resistance to rutting improves (Mcdaniel et al., 2002; Mcdaniel et al., 2007; Pasetto and Baldo, 2018). Therefore, it is not necessary to take into account the composition and the influence of RAP on the asphalt mixture prepared within the limit of 10%; this proportion is increased to 20% in the case of foundation layers. If high amounts of RAP are used (> 20%), analysis of RAP composition becomes necessary due to its influence on the properties of the asphalt mixture (Pieri, 1994). For example, the characteristics of the granular skeleton as well as the properties of the binder of the reclaimed asphalt pavement-RAP-are required.

A bituminous mixture is defined as an amalgam of binder, aggregates, and fines (< 80μm). This mixture is monolithic where the binder adheres perfectly to the aggregates; the consistency of this material is variable with the temperature. There are several types of asphalt mixture such as: very thin asphalt concrete, thin asphalt concrete, and high modulus asphalt. The adequate asphalt mixture is flexible enough at low service temperatures to avoid cracking and sufficiently rigid at high service temperatures to prevent rutting (Crispino et al., 2018; Mouillet et al., 2008).

According to the study carried out by Loizos (2000), the rutting of the superficial layers is the consequence of the accumulation of permanent deformations under the effect of high temperatures. Other studies (Haddadi, 2007; Swamy et al., 2011) have shown that the main cause of these impairments is the poor stability of the wearing layer. During warm periods, rutting is more frequent as the traffic is channeled at low speed in the acceleration or deceleration zones. The most common type of rutting on flexible pavements comes from the creep of bituminous mixture (Proteau and Paquin, 2001; Saoula, 2010).

While the average amount of RAP used in recycled asphalt mixtures in Algeria is almost non-existent, the amount used in the United States (U.S) is estimated at 20 percent, in other countries like Japan; for example, this rate reaches about 47 percent (Hansen and Copeland, 2017; West and Copeland, 2015). Economic and environmental benefits increase with the RAP percentage in asphalt mixture. However, with high amounts, the introduction of these old materials could give mixtures with less workability, difficult to compact, and more prone to cracking during the service life of the pavement because of their stiff and brittle nature (Carvajal Munoz et al., 2015; Kaseer et al., 2017; Mogawer et al., 2012; Nash et al., 2012). To improve the properties of the aged binder in RAP such as stiffness, and provide adequate performance, some adjustments to the recycled asphalt mixtures are required, like the use of virgin binder and/or recycling agents. Due to increased product availability, ease of addition to asphalt mixtures, and their cost-effectiveness, especially when high amounts of recycled materials are used, the use of rejuvenators and/or recycling agents has gained attention of researchers during the last years. Some investigations have shown that the addition of recycling agent can reduce the stiffness, viscosity, and embrittlement of RAP old asphalt binders and improve their ductility (Garcia Cucalon et al., 2018; Kaseer et al., 2018; Menapace et al., 2018). The stiffness of the recycled asphalt mixtures can be significantly reduced by the recycling agents. Moreover, several studies (Carvajal Munoz et al., 2015; Kaseer et al., 2017; Mogawer et al., 2013; Tran et al., 2012) have shown that the stiffness of recycled asphalt mixtures can be equivalent to that of virgin mixture without recycled materials due to the use of suitable recycling agent dosage.

The aim of this paper is to study the influence of high amounts (> 20%) of RAP on the performance of recycled asphalt mixtures using two types of binder. The effects of SBS polymer are also investigated.

2. Materials and methods

2.1. Materials

The materials used in this study are: aggregates, reclaimed asphalt pavement (RAP), bitumen, and Styrene/Butadiene/Styrene (SBS) polymer.

2.1.1. Aggregates

The aggregates used in the present study are the aggregate fractions commonly used in Algeria for the preparation of asphalt concrete for road construction. Three limestone fractions are used: sand 0/5 mm and two fractions of gravel 3/8 and 8/15 mm. Their physical and mechanical characteristics are given in Table 1. From the results, it can be deduced that the intrinsic physical and mechanical properties of the aggregates meet the requirements of the standards.

Table 1. Results of tests on aggregates

Tests	***Standard***	***Fractions (mm)***			***Spécifications***
		0/5	3/8	8/15	
Los Angeles (%)	NF P18-573	-	24.7	21.19	≤ 25
Micro Deval (%)	NF P18-572	-	13.20	12.86	≤ 20
Flattening coefficient (%)	NF EN 933-3	-	8.83	10.64	≤ 20
Cleanliness (%)	NF P18-591	-	1.59	0.90	≤ 2
Sand equivalent (%)	NF EN 933-8	66	-	-	≥ 60
Methylene blue value	NFP 94-068	0.16	-	-	≤ 2
Density	NFEN 1097-6	2.69	2.70	2.69	>2.60

2.1.2. Bitumens

Two types of bitumen were used, (paving grade bitumen (40/50) and modified bitumen (20/30)). They are provided by NAFTAL Company. It is worth noting that the modified bitumen is composed of paving grade bitumen and 4.5% of Styrene/Butadiene/Styrene (SBS) polymer.The characteristics of binders used such as penetration at 25°C, Ring and Ball Temperature (TBA), and relative density are summarized in Table 2. The results of the tests recorded are the average of three tests carried out on three samples.

2.1.3. Reclaimed asphalt pavement (RAP)

The reclaimed asphalt pavement (RAP) used in this investigation is originated from the rehabilitation of an old semi-rigid pavement of a national road (RN) in the city of ‘’Baraki’’ (Algiers). This aged material was crushed and screened before use. The binder content is estimated at 4.45%; it was evaluated by the method of KUMAGAWA (NF T66-001). The percentage of fines is about 7.64%.

2.1.4. Styrene/Butadiene/Styrene (SBS)

The SBS polymer used was Kraton D-1101 supplied by the NAFTAL Company. Kraton D-1101 is a linear SBS polymer in powder form that consists of different combinations made from blocks polystyrene (31%) and polybutadiene of a very precise molecular weight. These blocks are either sequentially polymerized from styrene and butadiene and/or coupled to produce a mixture of these chained blocks. The SBS polymer used has the following characteristics: specific gravity of 0.94; tensile strength at break of 31.8 MPa and elongation at break equal to 875%.

2.2. Formulation of mixtures

Recycled asphalt mixtures are composed of RAP, new aggregates, and binder. The purpose of the formulation is to determine optimal mass percentage of RAP to achieve the performance of virgin asphalt mixture without recycled materials. The method of formulation followed is divided into two main stages:

- Formulation of virgin asphalt mixture which is a Semi-Dense Bituminous Concrete (BBSG 0/14) without RAP;
- Formulation of recycled asphalt mixtures at 20%, 40% and 50 % of RAP proportions, according to Algerian recommendations (CTTP, 2004).

Following the determination of the properties of the materials used in this study and preparation of the samples; Marshall and Duriez tests were conducted on each of the specimens. The targeted performances are: stability, compactness, resistance to water, and creep.

2.2.1. Composition of mixtures

The preparation of asphalt mixtures in the laboratory was conducted in accordance with standard norm NFP 98-250-1. The virgin asphalt mixture designated by the letter (A) represent a semi-dense bituminous concrete (BBSG 0/14), It is composed of three fractions of aggregates and binder; the mass proportion of each constituent is given in Table 3

The mixture (A), composed of new asphalt without recycled materials is considered as a reference sample.The granulometric curve of the virgin asphalt mixture is given in Fig. 1. It fits perfectly in the upper and lower limits of the gradation curve of a semi-dense bituminous concrete (0/14 mm).

Depending on the type of binder used, two major series are distinguished: the first series includes asphalt mixtures dosed with base bitumen and the second series represents mixtures formulated with modified bitumen. Codes are assigned to these two series:

- MIX-PGB: asphalt mixtures dosed with paving grade bitumen
- MIX-MB: asphalt mixtures formulated with modified bitumen.

Table 2. Characteristics of binders

Characteristic	*Paving grade bitumen*	*CTTP Specifications*	*Modified bitumen*	*CTTP Specifications*
Penetration at 25 °C (1/10 mm)	42.1	[40 ÷ 50.1]	26	[20 ÷ 30]
Ring and Ball Temperature(TBA) (°C)	54	[47 ÷ 60]	79	-
Density	1.02	[1.00 ÷ 1.10]	1.06	-

Table 3. Composition of the reference asphalt mixture

Materials	*Mass content (%)*
Sand 0/5 (mm)	45
Gravel 3/8 (mm)	15
Gravel 8/15 (mm)	40
Binder	5.44

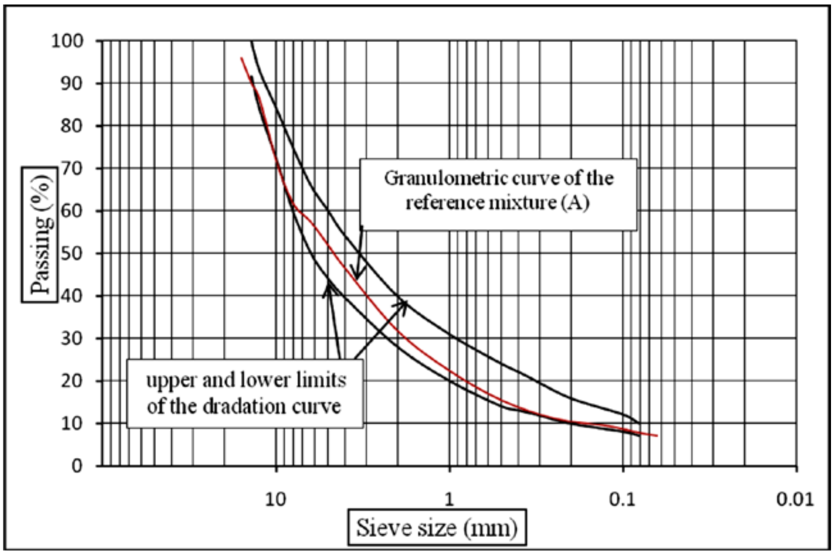

Fig. 1. Granulometric curve of the virgin asphalt mixture (A)

According to the percentage variation of RAP, eight (8) formulations were established. The implementation was carried out at a temperature of 160 °C. The eight formulations retained in this study are summarized in Table 4.

2.3. Preparation of test specimens

Marshall and Duriez test specimens are prepared according to the following experimental protocol:

- Put in the oven the granular mixture (virgin aggregates + RAP), bitumen, Marshall and Duriez molds at 160 °C for 2 hours;
- Laying granular mixture and bitumen on a hot plate,
- Mixing the granular mixture with the necessary amount of bitumen of adequate grade for 2 to 5 minutes;
- Filling the molds at 1200 g for Marshall and 1000 g for Duriez;
- Compacting under a Duriez press with a load of 60 kN for 5 minutes;
- Compaction using Marshall Impact compactor.

3. Results and discussions

The virgin and recycled asphalt mixtures are subjected to Marshall and Duriez mechanical tests to evaluate their behavior under different solicitations.

3.1. MARSHALL test

The purpose of this test is to determine, for a given temperature and compaction energy, the "stability" and "creep" of an asphalt mixture. The Marshall test is the recommended method for the analysis and control of asphalts. In the laboratory, it measures the resistance of a specimen to the deformation in the loading phase. Marshall test results for the different prepared mixtures are summarized in Table 5. The result mentioned represents the average value of three samples.For more visibility and clarity, these results (compactness, stability, creep and quotient) were highlighted in the form of curves. Indeed, the variation of the compactness of mixtures according to the percentage of RAP is represented in Fig. 2.

From the results obtained, we notice that the compactness of asphalt mixtures decreases with the increase of RAP amount. It is also noted that the introduction of SBS into the binder helps to reduce the difficulty of samples compaction.

Recycled asphalt mixtures formulated based on paving grade bitumen with RAP contents of 20% and 40% give satisfactory results compared to the specifications (NF EN 13108-1). With a percentage of 50%, the value of the compactness does not meet the requirements of the standard.

Table 4. Composition of asphalt mixtures with RAP variation

Mixtures	***Series MIX-PGB***		
	New aggregates (%)	***RAP (%)***	***Temperature***
Mixture (A)	100	0	160 °C
Mixture (B)	80	20	
Mixture (C)	60	40	
Mixture (D)	50	50	
	Series MIX-MB		
Mixture (E)	100	0	160 °C
Mixture (F)	80	20	
Mixture (G)	60	40	
Mixture (H)	50	50	

Table 5. Results of the MARSHALL tests of the different mixtures

Properties	***Series MIX-PGB***				***Series MIX-MB***				***Specifications***
	(A)	***(B)***	***(C)***	***(D)***	***(E)***	***(F)***	***(G)***	***(H)***	
Compactness (%)	94.69	94.45	93.59	91.17	95.10	94.62	94.12	93.50	92 à 96
Stability (kN)	19.45	17.58	12.97	10.67	22.81	17.86	15.63	14.37	>10.50
Creep (mm)	2.91	3.10	3.86	4.12	2.61	2.95	3.54	3.75	≤ 4
Marshall Quotient (kN/mm)	6.68	5.67	3.36	2.59	8.74	6.05	4.42	3.83	-

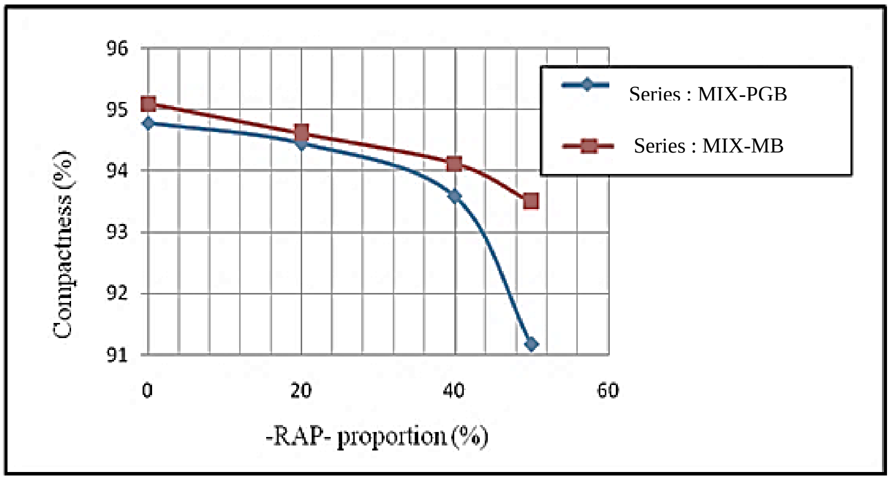

Fig. 2. Variation of the compactness based on the percentage of RAP

Marshall Stability is the maximum force that the sample can withstand. It assesses the sensitivity of the mixture to deterioration of the coating or accelerated aging. The evolution of the stability of samples according to the RAP proportion is shown in Fig. 3.

As for compactness, the stability of samples decreases with the percentage of RAP in the mixtures, the decrease is more significantly with mixtures formulated with paving grade bitumen. This decrease can be explained by the aged materials of the RAP (especially bitumen) of bituminous concrete, which induced the modification of their mechanical and chemical characteristics.

However, the stability results obtained are very satisfactory and meet the requirements for all asphalt mixtures. Overall, the stability results obtained with modified bitumen are much better than those of paving grade bitumen. It can be concluded that the introduction of SBS polymer improves the stability of the samples.

Fig. 4 illustrates the creep variation as a function of RAP proportion. Creep is the shortening of the diameter of the specimen at the time of its rupture. According to the results obtained, a gradual increase in creep is observed with the RAP proportion. This increase is due to the old bitumen rigidity. The values obtained mean that the creep resistance decreases with the increase of RAP, which is probably due to the aging of the materials that become stiffer (road traffic and climatic conditions). We can also note that the results obtained with modified bitumen are much better than those of paving grade bitumen. Moreover, it can be seen that at 20% of RAP, the creep is rather low and is not far from the value of the virgin asphalt mixture (without recycled materials) but beyond this RAP rate, the deformation is more important, therefore, this rate could be considered as a transition point. These results are supported by those of the bibliography (Hajj et al., 2009) which stipulate that the properties of recycled asphalt mixtures containing up to 20% of RAP are not influenced by the composition of RAP (binder and aggregates) and require no particular study.

On the other hand, beyond this percentage of RAP, the composition of the RAP must be taken into account because of its influence on the properties of the recycled asphalt mixture.

The Marshall quotient is an indicator of the resistance to permanent deformation, shear stress and rutting of asphalt mixtures. Higher quotient values indicate that the asphalts are more resistant to permanent deformation, since they are considered to be the main cause of hot asphalt degradation (Masad et al., 2008). The Marshall Quotient (QM) as a function of RAP proportion is shown in Fig. 5. We distinguish that the Marshall Quotient values obtained decrease with the increase of RAP.

This means that the cohesion of the constituents of the asphalt mixtures decreases with the increase of RAP. It can also be deduced that the addition of SBS improves the resistance to rutting. Moreover, the value of the quotient of the virgin asphalt mixture increases from 6.68 kN/mm, without SBS, to 8.74 kN/mm with the presence of this polymer.

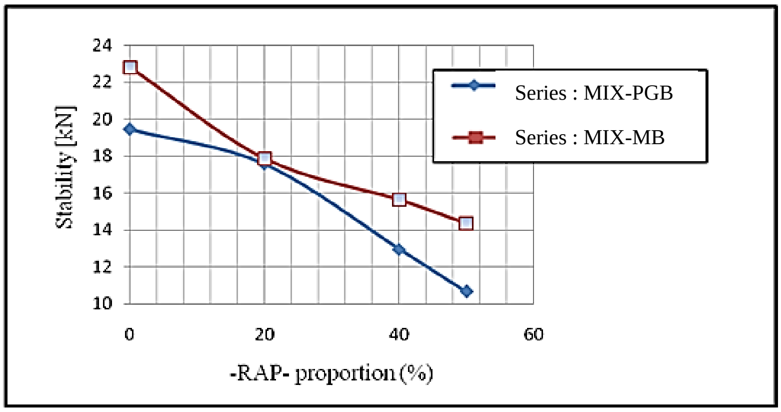

Fig. 3. Variation of the stability of the samples according to the percentage of RAP

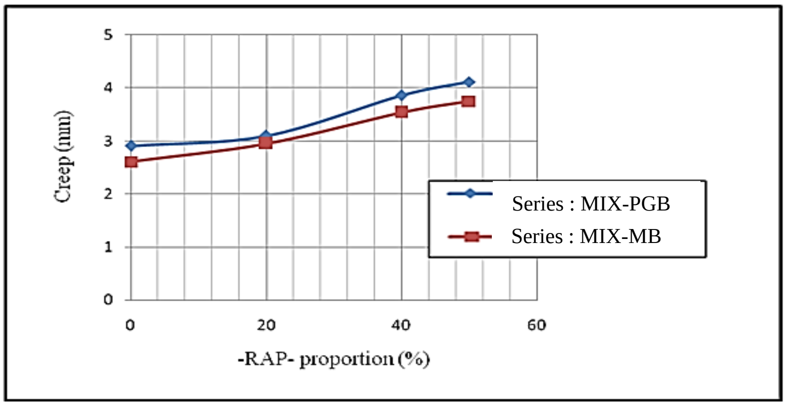

Fig. 4. Creep variation as a function of RAP proportion

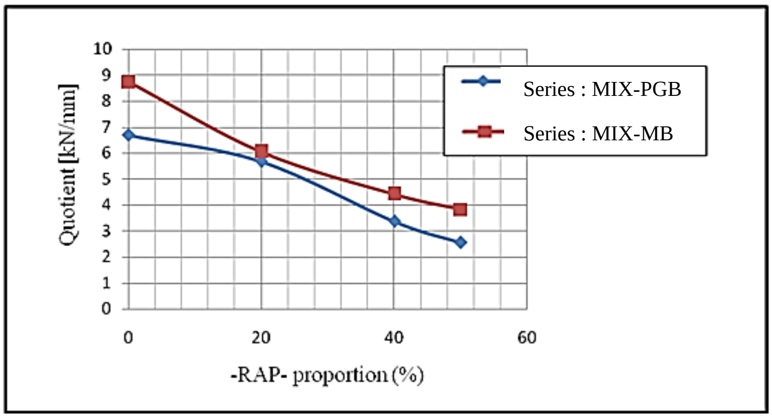

Fig. 5. Marshall Quotient variation based on the percentage of RAP

3.2. DURIEZ test - Water sensitivity

The purpose of Duriez test is to determine, for a given temperature and compaction, the resistance to water of an asphalt mixture from the ratio of the compressive strengths with and without immersion of the specimens. Indeed, some specimens are kept immersed in water for seven days at 18 °C and others are stored in a dry room at 18 °C with 50% relative humidity. Resistance tests are performed after seven (7) days. (R) and (r) respectively represent the average values of the compressive strength of dry and immersed samples.

The results of Duriez tests for the different mixtures are summarized in Table 6. The evolution of the compressive strength (R) of the dry specimens according to RAP proportion is shown in Fig. 6. The compressive strength of the dry specimens (R) decreases as the percentage of RAP increases. On the other hand, the compressive strength values are acceptable compared to the specifications (NF EN 13108-1). This decrease can be justified by the loss of mechanical performance of old materials (aggregates and bitumen) caused by the service life (road traffic, wear, rain ... etc). It can also be noted that the resistance values of recycled asphalt mixtures are almost identical between those of the mixtures dosed with paving grade bitumen and those formulated with the modified bitumen while there is a significant difference in the resistance values for the two virgin asphalt mixtures. In other words, SBS improves resistances, especially in virgin asphalt mixtures without recycled materials.

The variation of the compressive strength of the specimens immersed in water (r) according to the percentage of RAP is illustrated in Fig. 7. Through Fig. 7, we note that the two curves have the same shape, the compressive strength of the immersed specimens decrease with the increase of RAP for all recycled asphalt mixtures. It is practically the same behavior as for the dry samples but with lower values. The lowest value is estimated at 6.81 MPa with 50 % of RAP recorded for samples using paving grade bitumen.

Water sensitivity is the resistance to stripping under the effect of water. This property can be expressed by the ratio of the two resistances (r) and (R). In order to highlight the appearance of the reduction of the resistance, the ratio (r/R) as a function of the RAP proportion is shown in Fig. 8. Following the curves, we note that the ratio (r/R) decreases with the increase of RAP percentage, and this is valid for all the recycled asphalt mixtures (paving grade bitumen and modified bitumen).

Table 6. Results of Duriez tests of the different mixtures

Mixtures	*Series MIX-PGB*				*Series MIX-MB*				*Spécifications*
	(A)	*(B)*	*(C)*	*(D)*	*(E)*	*(F)*	*(G)*	*(H)*	
Resistance R (MPa)	12.22	11.70	10.50	8.58	15.41	11.82	10.78	8.65	> 7
Resistance r (MPa)	11.20	10.07	8.65	6.81	13.97	10.29	9.12	7.07	-
Ratio (r/R)	0.92	0.86	0.82	0.79	0.89	0.87	0.85	0.81	>0.8

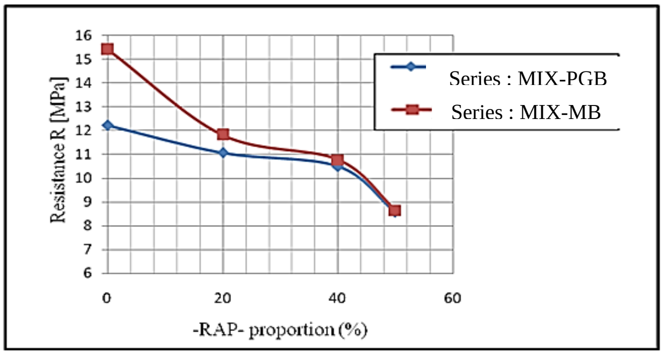

Fig. 6. Evolution of the compressive strength (R) of dry samples as a function of RAP proportion

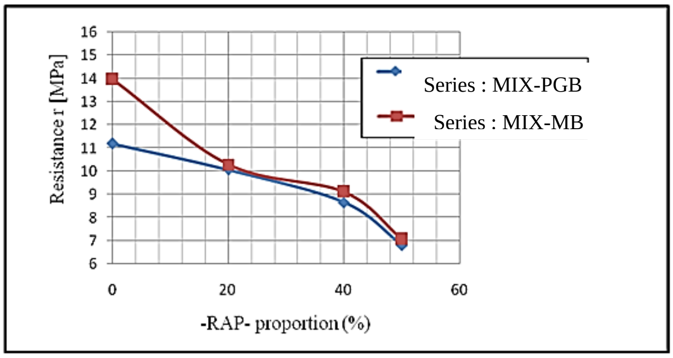

Fig. 7. Evolution of the compressive strength (r) of immersed specimens as a function of RAP proportion

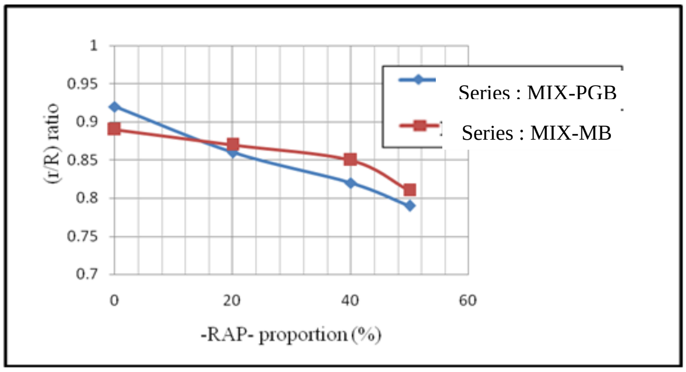

Fig. 8. Evolution of the (r/R) ratio according to RAP proportion

This reduction in compressive strengths is mainly related to the loss of the mechanical properties of the recycled aggregates as well as to the aging of the bitumen, which presumably has lower physicochemical characteristics compared to the virgin bitumen (Dieter et al, 2014). However, it can be clearly seen that the resistance ratio decreases almost linearly, thus forming a straight line (especially up to 40% of RAP). Nevertheless, the slope is slightly more important for asphalt mixtures formulated with paving grade bitumen. At a proportion of 16%, the value of the strength ratio is equivalent (intersection point of the two lines). Depending on the results obtained, a fairly precise relationship can be developed linking the resistances and the RAP proportion.

4. Conclusions

The recycling of asphalt has many advantages (technical, environmental, and economic). The possibility of recycling asphalt with high amounts (>20%) of recovered material has been evaluated in this paper. The effect of incorporating a recycling agent on the properties of virgin and recycled asphalt mixtures was also investigated. From the results of this experimental research, it could be concluded that:

- Pavement recycling can be performed without restrictions up to 40% of reclaimed asphalt pavement (RAP) without the use of recycling agents.

- Increasing the RAP percentage decreases the performance of the recycled asphalt mixtures especially the stability, creep, and rutting.

- Asphalt mixtures dosed with modified bitumen (4.5% of Styrene/Butadiene/Styrene) give better results than those formulated with paving grade bitumen. Indeed, the results of the performance tests carried out with different RAP proportions clearly show that pavement recycling can be carried out without restrictions up to 40% of RAP for recycled asphalt mixtures dosed with paving grade bitumen, and up to 50% of RAP for recycled asphalt mixtures formulated with modified bitumen.

- The performances of recycled asphalt mixtures obtained with 20% of RAP are significantly closer to those obtained with the virgin asphalt mixture without recycled materials.

- The introduction of SBS polymer significantly improves the properties of asphalt mixtures, especially virgin asphalt mixtures without recycled materials. Its effect decreases with the presence of RAP.

- As a perspective, the measurement of the influence of RAP proportion should be coupled with the measurement of the influence of the manufacturing parameters temperature and mixing time. Measurement of stiffness modulus, and fatigue strength should complement these investigations.

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