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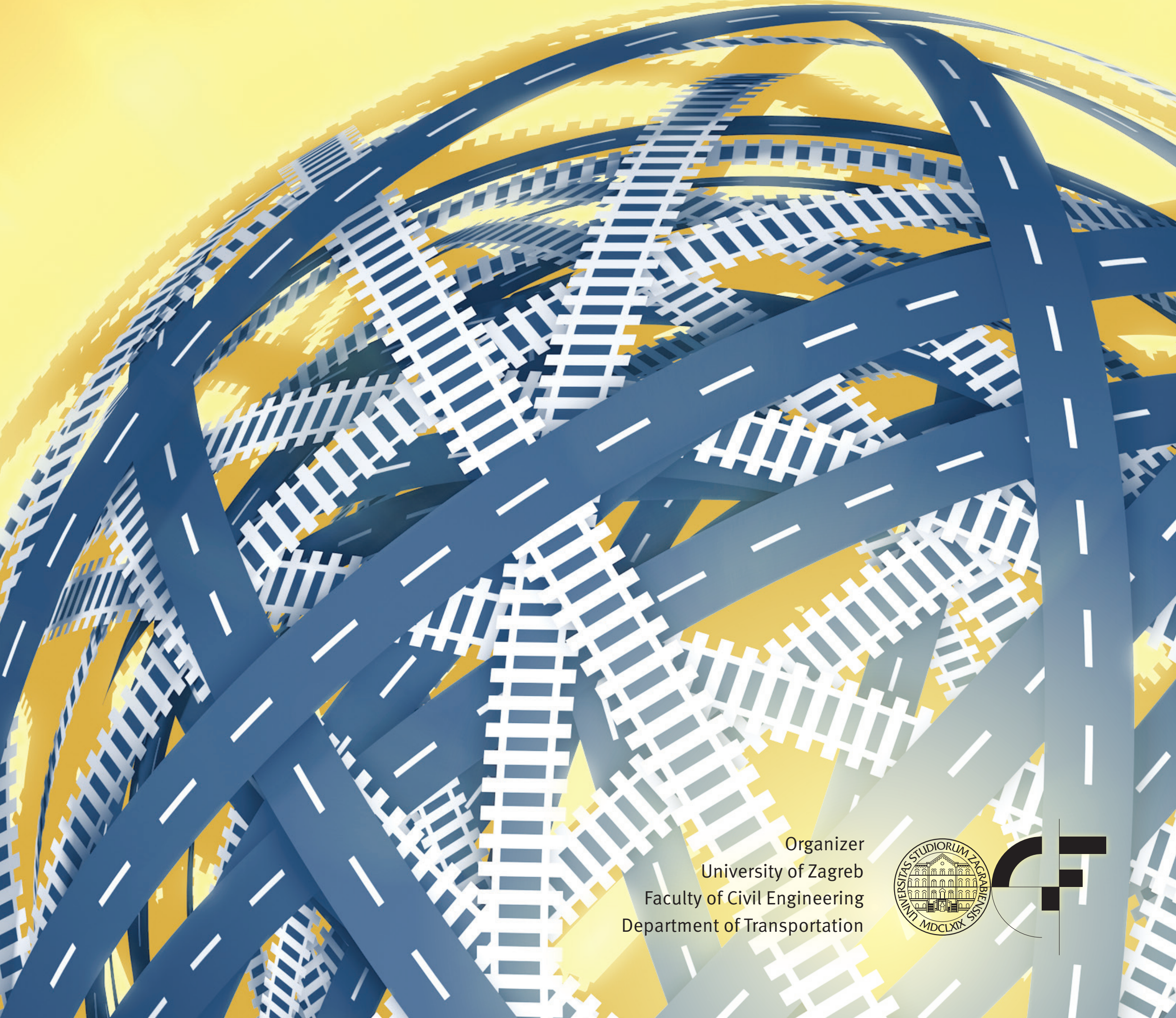
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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IMPACT OF WASTE ENGINE OIL AS REJUVENATOR ON UTILIZATION OF RECLAIMED ASPHALT PAVEMENT IN BITUMINOUS MIXTURES

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Abstract

Demand for sustainable pavements increases day by day in asphalt paving industry. Efficient utilization of raw materials along with the economic issues is the main reason to increase the amount of Reclaimed Asphalt Pavement (RAP) in bituminous mixtures. Since RAP is essentially aged material, it is considered not to behave like a fresh pavement. Hence, many researchers have tried to seek for innovative technologies in order to enhance RAP characteristics to utilize it over again. The objective of this study is to investigate the influence of Waste Engine Oil (WEO) on properties of RAP and therefore to determine the optimum amount of RAP in order to achieve desired characteristics of mixture. In this study the mixtures including various contents of RAP, modified with optimum WEO content, were prepared together with control mixtures. Mixture characteristics such as air void contents and Marshall Stability and Flow values were determined to be checked with specification requirements. Indirect Tensile Strength (ITS) values were accordingly measured for mixtures containing high possible amounts of RAP modified with WEO and control specimens. Based on the developed evaluation indices (as the ratio of ITS results of RAP containing specimens modified with WEO to ITS results of control specimens) comparisons were made. The results showed that the use of WEO, as a rejuvenator for mixtures containing RAP, enhanced the amount of RAP used in bituminous mixtures.

Keywords: asphalt recycling, reclaimed asphalt pavement, rejuvenator, waste engine oil, indirect tensile strength

1 Introduction

Recycling of bituminous materials has generated considerable discussion and development during the last decades. Although it is not a new idea, recent studies appear to be in response to the need of many countries to reduce their dependency on imported crude oil and the derivative product known as bitumen.

Many recent technologies introduce innovative methods for recycling of Reclaimed Asphalt Pavement (RAP). There are many fields of use for RAP from using it as backfill materials to implementation it within pavement superstructure courses. It is important to designate the most valuable field of recycling for RAP. Many studies have addressed many areas of utilization for RAP beside the optimum amount within the mentioned area [1]. Worldwide in addition to science world, within the high petroleum prices period, private sector has developed many methods in order to use RAP with high possible amounts [2]. Although private sector technologies are controlled and confirmed by authorities in accordance with specifications, these technologies are not accessible to the public due to know-how excuses.

Allegedly the United States of America and many other countries have led the technological development of modern recycling methods for RAP. While recycling is not practiced nationwide in USA, now it has become a common practice in many states. Other countries which seem to be interested in developing of recycling processes include Germany, France, Finland, India, South Africa and Turkey [3].

RAP contains both aggregates and bitumen, and hence it saves natural resources while it is and eco-friendly technology [4]. The use of RAP provides an economical solution for paving since it helps saving of both aggregates and bitumen within the new flexible pavement [4]. Therefore, the more the implementation of RAP, the more economical and sustainable pavements are achievable.

Recycling methods can generally been categorized as Cold and Hot recycling [1]. Cold recycling of bituminous mixtures involves RAP, water and a recycling agent in place without applying heat generally by use of emulsions since hot recycling implements heat and generally recycling agents in presence of heat. Both methods can be conducted in production plant or in-place. The common point in most recycling methods is the presence of a recycling agent which paves the way for easier application.

Use of rejuvenators also called recycling agent is one of the most famous methods introduced to facilitate the use of RAP especially within the upper surfaces of flexible pavements such as binder and surface courses [3]. Various kinds of rejuvenators have been introduced to asphalt recycling field so far, some commercialized and some still remained within the literature. These kinds of rejuvenators mostly are used within hot recycling applications. Many of rejuvenators have oily base, since it is believed that aged asphalt lacks the oily component of bitumen during the service life of bituminous pavements [5]. The bitumen is generally defined as a colloid system in which asphaltenes take role as the dispersed phase and maltenes as the continuous phase [6]. The evaporation and removal of oily constituents (mainly as maltenes) plays an important role in aging process of bitumen [7]. It is known that without using of rejuvenators, recycling results in a stiffer and accordingly brittle pavement [8].

Shen et al. (2007) evaluated the using of rejuvenating agents on Superpave mixtures containing RAP. It is reported that the mechanical properties of mixtures involving RAP and rejuvenating agent were improved. Additionally, more amount of RAP could be included within the Superpave mixtures by use of oily based rejuvenators [9].

Asli et al. (2012) investigated the feasibility of waste cooking oil as rejuvenator for recycled mixtures. Authors indicated that the use of waste cooking oil rehabilitated the properties of aged bitumen. It is said that the rejuvenated binder behaved similar to virgin binder in terms of penetration and softening point. The researchers also claimed more amount of RAP within the recycled mixture could be available by implementation of waste cooking oil [10].

Yu et al. (2014) implemented waste vegetable oil and an aromatic extract in order to rejuvenate the aged bitumen. The rejuvenator was used to enhance the rheological properties of the aged binder. It is reported that the use of these agents could modify the chemical structure of the aged binder and thus the mechanical behaviour as well. The researchers evaluated the samples at both macro- and micro-scales and found out that characterization of rejuvenating impact on aged binders could gain the advantage of improved recycling of bituminous materials [11].

In another study, high temperature properties of rejuvenating recovered binder with waste cooking and cotton seed oils was examined [12]. Authors employed the waste cooking and cotton seed oils for rejuvenation of RAP. They reported that use of these rejuvenators could reduce the viscosity value and fail temperature of aged binders. Besides, the rheological studies unveiled an increase of phase angle in rejuvenated binders. The results also proved that, selecting the optimum dosage of rejuvenator can recover the rutting performance of aged binder substantially [12].

Ongel and Hugener (2015) also discovered that the use of rejuvenators can recover the original rheological properties of aged binders to a large extent. The authors claimed that 100% recycling can be a solution for environmental problems under favour of rejuvenators [13].
Nayak and Sahoo (2015) tried two kinds of local oil for rejuvenating aged binders. Panogamia oil and composite castor oil were employed within this study. The rheological evaluation of effect of these rejuvenators on aged binder represented that, these oils are capable of enhancing both rutting and fatigue properties of aged binders [14].
When it comes to Waste Engine Oil (WEO), what literature survey brings to light is that WEO is also amongst the addressed oily based rejuvenators [15], [16]. Zaumanis et al. investigated the performance properties of RAP binder and 100% recycled asphalt mixtures with six different rejuvenators. WEO was employed in order to enhance RAP binder within the scope of this study as well. The authors reported improvement in many aspects such as reducing the performance grade of rejuvenated RAP binder to the level of virgin binder, passing rutting requirement, enhancing of mixture cracking resistance and improved workability for rejuvenated mixtures [15].
WEO was similarly employed within another study conducted by Jia et al. (2015) in order to investigate its influence on the rheological properties of RAP binder as well as fatigue properties of HMA containing RAP. It was reported that the use of WEO within HMA involving RAP can offset the increase of stiffness imposed by aged RAP binder. The authors claimed limited enhancements on fatigue properties of the mixtures containing RAP by use of WEO [16].
The utilization of WEO and it efficiency as stated in literature is the keystone to perform this study so as to investigate its employability with RAP. The objective of this study is to evaluate and establish the rejuvenating effect of WEO, as well as determining the optimum dosage and accordingly utilizing WEO in rejuvenation of RAP to take advantage of high RAP contents within the recycled bituminous mixtures.

2 Experimental

2.1 Materials

50/70 penetration grade virgin binder provided from Aliağa/Izmir petroleum refinery was used within the scope of this study. This penetration grade is used in the area in accordance with Turkish specifications. In order to characterize the properties of the virgin binder, conventional tests such as: penetration test, softening point test, Rolling Thin Film Oven Test (RTFOT) and etc. were conducted. These tests were performed in conformity with the relevant standards. Results are presented in Table 1.

Table 1 Properties of virgin binder

Test	Specification	Results	Specification limits
Penetration (25 °C; 0.1 mm)	TS EN 1426	63	50–70
Softening point (°C)	TS EN 1427	49.7	46–54
Viscosity at (135 °C)-Pa.s	ASTM D4402	0.425	–
Viscosity at (165 °C)-Pa.s	ASTM D4402	0.1	–
Rolling Thin Film Oven (163 °C)	TS EN 12607-1		
Change of mass (%)		0.05	0.5 (max)
Retained penetration after RTFO (%)	TS EN 1426	74	50 (min)
Softening point rise after RTFO (°C)	TS EN 1427	4.5	7 (max)
Specific gravity	ASTM D70	1.038	–
Flash point (°C)	TS EN 22592	+260	230 (min)

Limestone aggregates provided from Dere Madencilik / Izmir quarry were employed in mixture tests. The properties of the limestone aggregate specifications such as specific gravity, Los Angeles abrasion resistance, sodium sulphate soundness, fine aggregate angularity and flat and elongated particles are presented in Table 2. Gradation of aggregate was chosen in conformity with the Type I wearing course of Turkish Specifications. Table 3 presents the final gradation table chosen for mixture.

Table 2 Properties of limestone aggregate

Test	Specification	Result	Specification limits
Specific gravity (Coarse Agg.)	ASTM C 127		–
Bulk		2.704	–
SSD		2.717	–
Apparent		2.741	–
Specific gravity (Fine Agg.)	ASTM C 128		
Bulk		2.691	–
SSD		2.709	–
Apparent		2.739	–
Specific gravity (Filler)		2.732	–
Los Angeles abrasion (%)	ASTM C 131	22.6	max. 30
Flat and elongated particles (%)	ASTM D 4791	7.5	max. 10
Sodium sulphate soundness (%)	ASTM C 88	1.47	max. 10–20
Fine aggregate angularity	ASTM C 1252	47.85	min. 40

Table 3 Gradation table

Sieve size/No.	Gradation [%]	Specification	Specification limits [%]
19 mm.	100	Type I wearing course (Turkish Specification)	100
12.5 mm.	92		83–100
9.5 mm.	73		70–90
No.4	44.2		40–55
No.10	31		25–38
No.40	12		10–20
No.80	8		6–15
No.200	5.3		4–10

RAP was provided from a reclaimed type I wearing surface course subjected to regular and heavy traffic loads for a period of 12 years. 16 x 1000 gr. batch samples were selected randomly by a random separator and tested for determination of binder content and gradation. Based on the extraction test results, the binder content was found as 4.30 % within the available RAP. RAP binder was extracted by means of a centrifuge extractor and distilled by a distillatory setting to obtain RAP binder. Following the determination of the RAP binder content, sieve analysis was performed on the extracted aggregates. The gradation table for RAP is given in Table 4. The conventional binder test results for extracted RAP binder are presented within the Table 5.

Table 4 Sieve analysis of RAP

Sieve No	Retained [%]	Passing [%]	Spec. limits [%]
19 mm	0	100	100
12.5 mm	1.6	98.4	83–100
9.5 mm	10.1	89.9	70–90
No.4	45.9	54.1	40–55
No.10	69.8	30.2	25–38
No.40	86.5	13.5	10–20
No.80	91.18	8.82	6–15
No.200	94.17	5.83	4–10

Table 5 Properties of RAP binder

Test	Specification	Results
Penetration (25 °C; 0.1 mm)	TS EN 1426	38
Softening point (°C)	TS EN 1427	61
Viscosity at (135 °C)-Pa.s	ASTM D4402	0.538
Viscosity at (165 °C)-Pa.s	ASTM D4402	0.188

The rejuvenator employed within this study was provided from a waste and residual oil wholesale trader company who owns the licence for collection of waste oils. In order to obtain a homogenous product, the samples were directly obtained from batch tank which is supposed to be a blend of all waste engine oil brands and types. The wholesaler claims a firm homogeneity for the mentioned tank. WEO is in liquid form at ambient temperature and has a dark brown colour.

2.2 Methodology

In this study, the mixtures containing various amounts of non-rejuvenated RAP and rejuvenated RAP (treated with WEO), respectively representing control and rejuvenated specimens were prepared using Marshall compactor. The mechanical performances of the samples were evaluated by Marshall stability and flow test. Besides, volumetric analysis was done and taken into consideration in selection of highest RAP content. Turkish specification limits were taken into account as the main indicator in determination of highest RAP content for both control and rejuvenating samples. Following the determination of highest RAP content; the specimens containing highest RAP content were prepared and tested for Indirect Tensile Strength (ITS) test. Based on ITS values; aging indices were calculated for these specimens and compared to each other. The primary steps in the design of Hot Mix Asphalt (HMA) include the determination of material properties of RAP and virgin materials, the selection of an appropriate percentage of RAP and virgin aggregate to meet gradation, the selection of appropriate binder content to satisfy viscosity and penetration requirements in terms of workability, and to meet the specification requirements in terms of stability, flow and air voids.

2.2.1 Determination of target mixtures contents

Marshall mix design method was employed to design virgin bituminous mixtures. The optimum bitumen content was determined 4.76 % by weight of aggregates. In order to implement various contents of RAP within the final mixture, the target bitumen amount supposed to be added to the total mixture was calculated separately for different RAP content. The Eq. (1) was used to determine the amount of virgin binder to be added to the target mixture.

$$Pr = Pc - (Pa * Pp) \tag{1}$$

Where:
Pr – Percent of virgin binder to be added in the mix containing RAP;
Pa – Percent of RAP binder in the mix;
Pc – Percent of total binder in the mix;
Pp – Percentage of RAP in the mix.

Following the determination of virgin binder amounts to be added into the target mixtures with respect to the values given in Table 6, the asphalt concrete samples including various contents of non-rejuvenated and rejuvenated RAP respectively representing control and rejuvenated specimens were prepared taking the mixing and compaction temperatures into consideration. The mixing and compaction temperatures were calculated using equiviscous temperature charts for virgin, RAP and rejuvenated binders plotted according to viscosity values determined at 135 °C and 165 °C. Viscosity values were measured by means of a Brookfield viscometer.

Table 6 Binder contents to be added into the target mixes

RAP Content [%]	Pc [%]	Pa [%]	Pr [%]
10	4.76	4.30	4.33
20			3.9
30			3.47
40			3.04
50			2.61
60	4.76	4.30	2.18
70			1.75
80			1.32
90			0.89
100			0.46

2.2.2 Determining optimum rejuvenator content and rejuvenation process

Based on the literature review; considering the conventional bitumen test results of virgin and RAP binder, the objective was defined as to rejuvenate RAP binder in order to obtain a binder similar to virgin binder in terms of specifications. Rejuvenator is supposed to enhance and cure the RAP binder. Many studies have addressed the penetration value as an indicator for determining the optimum rejuvenator content [10], [17-19]. Therefore, the optimum content of WEO within the modified RAP binder was determined as the target content to obtain a rejuvenated binder having the same penetration value of virgin binder. In other words, when the RAP binder is modified with this WEO content, the acquired binder will have the same penetration value of virgin binder. In order to perform this task, RAP binder was modified with various dosages of WEO. The range was chosen based on literature review and preliminary studies [16]. Modification was processed for 5 minutes at 140°C using a laboratory blender at normal shear rates (700 rpm) to obtain a homogenous rejuvenated binder. Table 6 consists of penetration test results of rejuvenated binders with various WEO contents. The optimum WEO content was determined as 5.4% by weight of RAP binder corresponding target penetration value of 63.
Following the determination of optimum WEO content; RAP mixtures were rejuvenated and stored. In order to perform the rejuvenation process, 4000 gr batches of RAP were heated to 140°C the same temperature in which binder blending took place. The bitumen content of RAP were calculated and taken into account in rejuvenation process. Within the process, the optimum amount of WEO was gradually sprayed into the mixture while mixing was in process

inside a laboratory mixer for 5 minutes. The derived rejuvenated RAP had a shining dark brown colour compared to non-rejuvenated RAP as seen in Fig. 1.

Figure 1 RAP before and after rejuvenation with WEO

Table 7 Penetration values for rejuvenated binders by various WEO content

WEO Content [%] by weight of RAP binder	Specification	Penetration (25 °C; 0.1 mm)
0	TS EN 1426	38
2		44.5
3		49
4		53.5
5		59.5
6		68

2.2.3 Indirect tensile strengths and aging evaluation of mixtures

Following the determination of high possible RAP contents for rejuvenated mixtures, specimens were prepared with this RAP content for both rejuvenated and non-rejuvenated mixtures and tested for Indirect Tensile Strength (ITS). To perform this task, ASTM D6931 -the standard test method for indirect tensile strength of bituminous mixtures was taken into account. The ITS test was conducted by Marshall stability and flow apparatus. The loading rate was set to 51(mm/min) in case for ITS.

Fig. 2 illustrates the true assembly of a specimen between loading strips. To be adequate and unbiased, three specimens for both non-rejuvenated and rejuvenated RAP involving mixtures and also control specimens with no RAP content were prepared and tested. The ITS results give the evaluation keys in terms of low temperature and fatigue cracking of asphalt pavements. Some studies introduce ITS result as a good indicator in predicting laboratory rutting potential of asphalt mixtures [20]. This test is widely used in investigation of moisture induced damages of bituminous mixtures.

It is known that, aged binder is more brittle and stiffer. In order to evaluate the aging characteristics of non-rejuvenated and rejuvenated RAP involving mixtures, the ITS results of RAP involving mixtures were compared to the results of control mixtures with no RAP. This comparison simply provides aging indices to investigate the aging characteristics of asphalt mixtures.

Şengoz (2003) implemented ITS results of mixtures with various air voids, to assess aging and moisture susceptibility characteristics of HMA mixtures [21]. Another study on short- and long-term aging behaviour of rubber modified asphalts conducted by Liang and Lee (1996) claimed that the short-term and long-term aging increased the measured tensile strengths [22]. Şengoz and Topal (2008) investigated the effects of SBS polymer modified bitumen on the ageing properties of asphalt mixtures using ITS results [23]. They calculated aging indices as the ratio of short- and long-term aged specimen's ITS values to the values of un-aged control specimens prepared with the same additive content. Hurley and Prowell (2005) used ITS results to check the rutting potential after application and the short- and long-term aging characterization of WMA mixtures [24].

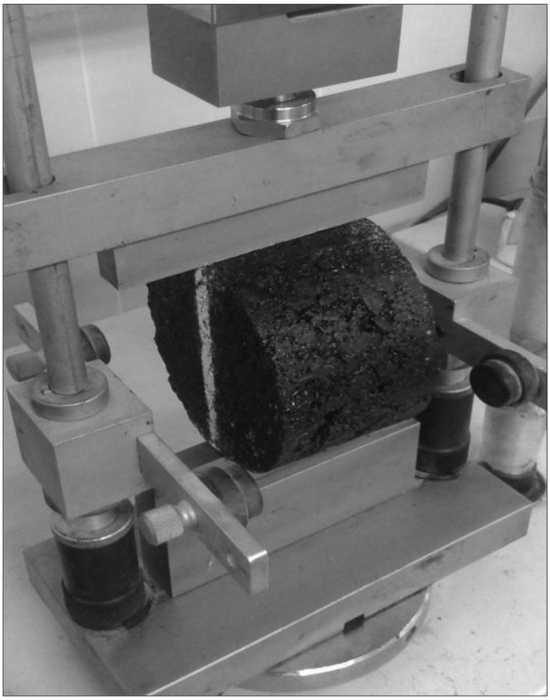

Figure 2 Specimen prepared for ITS test

The raw data recorded from the test device should be processed using the following Eq. (2) to obtain indirect tensile stresses:

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \tag{2}$$

Where:
St – Indirect tensile strength (ITS), [kPa]
P – Maximum load, [N]
t – Specimen height immediately before test, [mm]
D – Specimen diameter, [mm]

Following the determination of ITS values, aging indices were calculated for non-rejuvenated and rejuvenated mixtures respectively as the ratio of ITS value of non-rejuvenated mixture over control mixture and the ratio of ITS value of rejuvenated mixture over control mixture. The results were then compared to each other.

3 Results and Discussions

3.1 Binder test results

Results for rejuvenated binder with optimum WEO content are presented in Table 8. WEO additive was capable of increasing penetration and also decreasing the softening point values both to the required specification limits. Fig 3. represents the penetration values for various contents of WEO. As aforementioned, the optimum WEO content was derived from this chart choosing the WEO content corresponding the same penetration value of the virgin binder. As seen on the Fig. 3, the penetration values track an increasing polynomial trend-line as WEO content increases. It is possible to gain a desired penetration by adding adequate content of WEO to RAP binder. Softening point should be controlled following the addition of WEO. Besides, considering viscosity values, it can be said that the workability of rejuvenated RAP mixtures improved significantly. Mixing and compaction of rejuvenated mixtures can be made with a regular effort. Softening point of rejuvenated binder was determined more than softening point of virgin binder. Although this value is a borderline value in terms of specifications, it is realised that rejuvenated binder will endure higher temperatures during hot seasons. The rejuvenated binder behaves similar to air-blown asphalts in this case. RTFO test results unveiled that the rejuvenated binder is more sensitive to short term aging than virgin binder. This can be attributed to volatilization of oily WEO during heating process of RTFO test. The test results after RTFO still remained within the specification limits. Overall the binder test results are matching with literature [15], [16].

Table 8 Properties of rejuvenated RAP binder modified with optimum WEO content

Test	Specification	Results	Specification limits
Penetration (25 °C; 0.1 mm)	TS EN 1426	63	50–70
Softening point (°C)	TS EN 1427	54	46–54
Viscosity at (135 °C)-Pa.s	ASTM D4402	0.412	–
Viscosity at (165 °C)-Pa.s	ASTM D4402	0.087	–
Rolling Thin Film Oven (163 °C)	TS EN 12607-1		
Change of mass (%)		0.12	0.5 (max)
Retained penetration after RTFO (%)	TS EN 1426	53	50 (min)
Softening point rise after RTFO (°C)	TS EN 1427	6	7 (max)

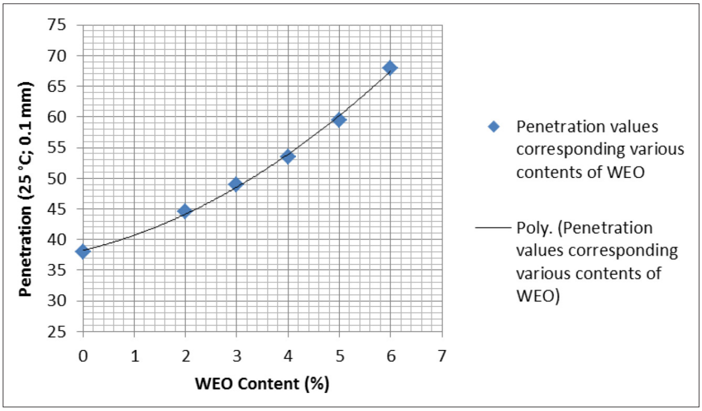

Figure 3 Penetration values corresponding various contents of WEO

3.2 Mixture test results

As mentioned before, the highest RAP contents were determined for mixture containing non-rejuvenated and rejuvenated RAP in order to compare the highest potential of RAP to be employed within a type I wearing course.

3.2.1 Marshall stability and flow results

Volumetric analysis together with Marshall stability and flow values were base criteria in selection of maximum possible RAP content for both mixture involving non-rejuvenated and rejuvenated RAP. Results for air void contents, stabilities and flow rates are respectively presented in Fig. 4 to Fig. 6.

As can be seen in the Fig. 4, all mixtures containing rejuvenated RAP could meet volumetric criteria in terms of air voids since mixtures containing non-rejuvenated RAP fail to satisfy desired air voids content for mixtures containing more than 40% non-rejuvenated RAP. The reason that volumetric characteristic of rejuvenated RAP containing mixtures remained within the desired contents is attributed to lower viscosity values of rejuvenated RAP binder and hence improved workability. At standard mixing and compaction temperatures, it is more convenient to process rejuvenated RAP mixtures than non-rejuvenated RAP mixtures. Rejuvenation made compaction fully done by Marshall compactor with same number of blows for RAP mixtures.

When Fig. 5 is analysed, it is seen that all stability values are over specification limit. This result is expected since the bitumen within RAP is considered as an aged binder and thus the mixtures containing RAP are stiffer than virgin bituminous mixtures hence these mixtures recorded high stabilities. In fact, the most concerned issue for RAP recycling technologies is considered as durability rather than stability. Therefore, volumetric characteristics and flow rates (somehow, as an indicator of flexibility) are more determinative for maximum possible RAP content than stability values.

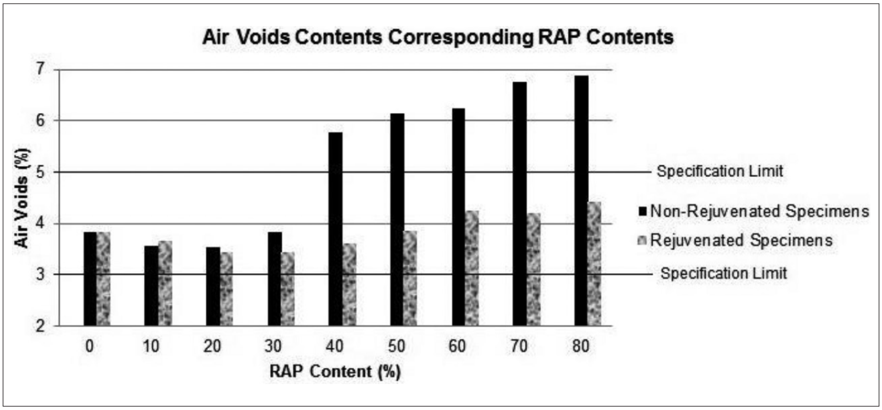

Figure 4 Air void contents

When evaluating flow rates, it is understood that this criteria is determinative for both non-rejuvenated and rejuvenated RAP involving mixtures. It is seen that, mixtures containing over 20% of non-rejuvenated RAP almost fail to meet the flow rate criteria since rejuvenated RAP mixtures flow well under destructive loads before fraction. Flow rates however, has been decisive in determination of maximum possible amount of rejuvenated RAP within type I wearing course. In this sense, 70% of rejuvenated (WEO modified) RAP can be employed within type I wearing course. It is obvious that the amount of maximum RAP which can be implemented without failing to meet all Turkish criteria increases substantially by rejuvenation process with WEO. Evidently, 50% more RAP can be employed by this method.

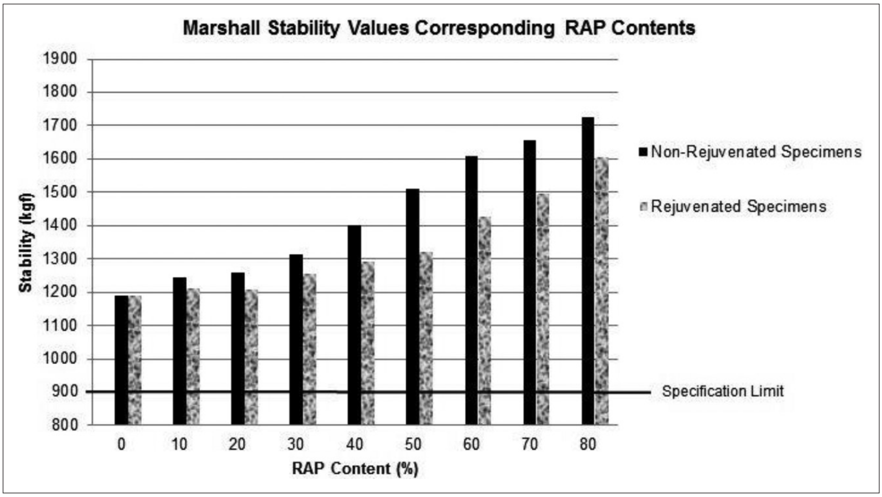

Figure 5 Marshall stability values

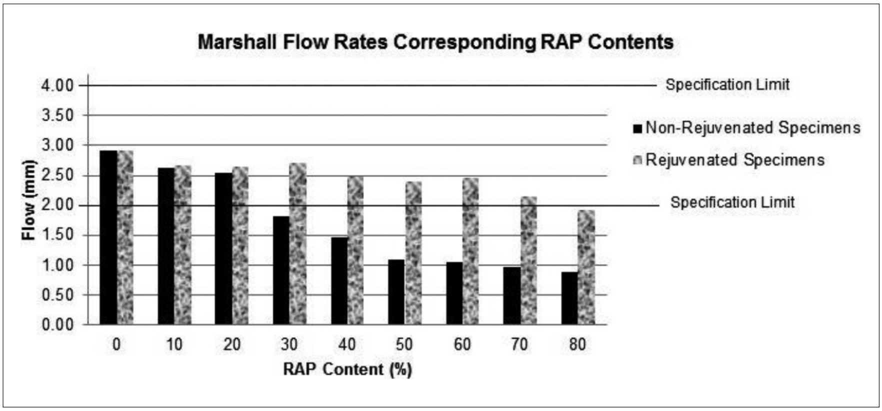

Figure 6 Marshall flow rates

3.2.2 Indirect tensile strength results and aging indices

As aforementioned, specimens were prepared with 70% RAP content (determined as the highest RAP content based on criteria) for both rejuvenated and non-rejuvenated mixtures and tested for ITS. Besides, the same test was conducted on specimens prepared with virgin mixtures with no RAP content as control specimens. The results are shown in Fig. 7.

ITS results provide the insight about mixture stiffness. It is seen that rejuvenated RAP recorded lower ITS than non-rejuvenated RAP. The use of WEO as a rejuvenator for employment of RAP inside HMA can soften the whole mixture and beside better workability, it will result in better flexibility as well. Aging indices have been calculated as 1.39 for non-rejuvenated mixtures and 1.16 for rejuvenated mixtures. The closer the aging index gets to 1, the less the mixture is aged and brittle. Therefore, it can be concluded that WEO modified RAP mixtures will be less brittle.

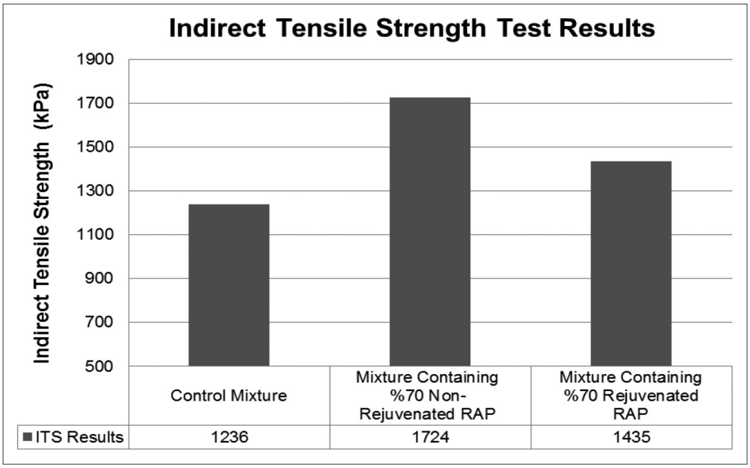

Figure 7 Marshall flow rates.

4 Conclusions and recommendations

Efficient deployment of resources is critical in asphalt paving industry and real attention should be paid to this issue. Aggregate quarries and petroleum industry both consume natural resources to feed asphalt paving industry with raw materials. Sustainability should not come to just study subjects or be confined with economic issues but also it must become a social and institutional responsibility. Recycling is now possible with recent techniques and new technologies are introduced all along the time to industrial world. Reutilizing of aggregates and bitumen will save natural resources and costs to a large extent. In addition, recycling of RAP with WEO will also be in favour of waste management and disposal issues. WEO, as its name suggests is a waste material and should be recycled, reutilized in a proper industry or disposed.

Within the scope of this study, the influence of WEO on properties of RAP was investigated. It was found that, WEO as an oily additive contribute actively as an oily constituent taking the place of previously evaporated and/or separated oil constituents of aged RAP binder. The properties of RAP binder can be enhanced by use of WEO to fulfil specification requirements. Binder penetration and softening point values as well as viscosity of binder can be modified by optimum WEO content. Penetration value is determinant in determination of optimum rejuvenator content. For any kind of WEO available at the market, the selection process can be conducted in order to determine optimum content. In this study, 5.4% of WEO by weight of binder has been found adequate. It is recommended to perform supplementary tests in lights of Superpave standards and specifications. Rheological evaluation of rejuvenated binders can be more interpretive in terms of characterization of rejuvenated binder. Rejuvenated binder not only can fulfil desired properties, it is also capable of meeting after RTFO test requirements. It can be said that WEO is a substantial additive which is efficient in rejuvenation of aged RAP binder.

Implementing WEO as a rejuvenator makes it possible to involve high amounts of RAP within HMA wearing courses. By rejuvenation technology up to 70% of RAP can be utilized without undesirable effects within surface courses. Rejuvenated mixtures are convenient to process in terms of mixing and compaction. WEO helps compaction fully done at standard HMA application temperature ranges. Investigations present that rejuvenated RAP mixtures are less brittle and more durable than non-rejuvenated RAP mixtures. Aging index of rejuvenated mixes are improved compared to non-rejuvenated mixes. It is recommended to evaluate mechanical properties of rejuvenated RAP mixtures in accordance with Superpave criteria. Mixtures should be prepared by means of a gyratory compactor and evaluated for volumetric analysis. Supplementary performance based experiments should be conducted. For RAP mixture tests, rutting and fatigue performance evaluation are recommended.

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