# Investigation of performance properties of laboratory and plant produced bituminous mixture containing high rates of reclaimed asphalt

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## ABSTRACT

*The use of reclaimed asphalt pavement (RAP) has gained considerable importance due to increasing environmental concerns and economical aspects. There is interest in using higher RAP contents and in using RAP in more mixtures.*
*Although a large amount of asphalt from damaged roads are reclaimed each year, only a small part of it can be up-cycled into a higher value. The efforts have been towards increasing the RAP content by using rejuvenator and efficient plant processes to comply with the requirements. The proper mix between old and new materials, especially blending of binders is very important in the mechanical performances of recycled asphalt mixture. In the framework, there is a need for investigation of performance characteristics of laboratory and plant- produced recycled asphalt mixtures.*
*This paper presents an experimental study to evaluate the performance properties of laboratory and plant-produced bituminous mixtures containing high rates of reclaimed asphalt pavement (RAP). The laboratory mixtures will be compared to plant produced mixtures to evaluate the degree of blending between the virgin materials and RAP. The results of the study will be also evaluated the performance of recycled mixture in comparison to virgin bituminous mixtures in accordance with the requirements of the different asphalt pavement layers.*
*The study is carried out into three stages. In the first stage, dense graded bituminous mixture containing 50 % RAP and special rejuvenator will be designed based on performance characteristics of mixture in terms of permanent deformation, fatigue cracking and moisture susceptibility. Additionally the properties of the binders (virgin, RAP and recovered) such as penetration, softening point will be examined. In second part of the study, recycled asphalt will be produced in the double drum batch type plant by hot recycling method and paved as a surface course. In the last stage, quality control and performance tests will be performed on the samples taken from the plant and the layer. As a result, the properties of plant produced recycled asphalt will be compared with that of laboratory produced recycled asphalt.*

**Keywords:** Mechanical Properties, Performance testing, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

## 1. INTRODUCTION

Recycled asphalt mixtures are increasingly used by highway agencies all over the world. Besides general saving cost and energy consumption, it also saves natural resources and environment. Although a large amount of asphalt from damaged roads are reclaimed in each year, only a small part of it can be recycled in the production of bituminous mixtures for asphalt layers. Additionally, since owing to the shift in road construction activities from new construction to maintenance, the need for asphalt base course is going to fall, whilst recycling for the purpose of obtaining asphalt binder and surface course mixtures will increase significantly. In this framework, it is required to investigate the effects of high quantities of reclaimed asphalt (RAP) in asphalt surface and binder courses.

Because of long term aging of asphalt mixtures, the binder of reclaimed asphalt is stiffer, less ductile and with lower temperature susceptibility than conventional paving grade bitumen. Therefore RAP binder could be inert as a black rock and its residual properties could influence the final binder characteristic. It is difficult to obtain the proper mix between old and new binders. Especially blending of binders is very important in the mechanical performances of recycled asphalt mixture. It is required to soften the oxidized bitumen in RAP to provide thorough blending at lower temperature [1,2]**.**

In accordance to the current specification based on research prescribes that up to 15% RAP of mix can be added without changing the virgin binder grade. At RAP contents between 15% to 25 %, the virgin binder grade must be adjusted one grade softer to account for the stiffening effect of the hardened RAP binder. At RAP contents above 25%, a special design, rejuvenator and the special production process is necessary [2,3 ]. Rejuvenators are used to promote addition of more RAP to mixtures, to soften the oxidize binder in RAP to provide thorough blending with fresh bitumen and lower mixing and compaction temperature to offset the reduced stiffness and also to eliminate the need of lower binder grade. The rejuvenator makes the binder softer and mixture is more resistant to cracking [1,2,3,4].

In Turkey, recycled asphalt base courses have been constructed with the mixtures containing 10% to 35% reclaimed asphalt pavement (RAP) material, but there is no experience for the construction of surface course with recycled asphalt. Especially the high quantity of reclaimed asphalt in asphalt surface course is required more stringent investigation to evaluate the performance of recycled asphalt in comparison to virgin bituminous mixtures.

In this context, this paper presents a case study on producing recycled asphalt with 50% reclaimed asphalt and 3% rejuvenator.

***The primary objectives of this study:***

- To evaluate the performance properties of laboratory produced recycled asphalt concrete- RAC versus conventional asphalt concrete as reference mixture for surface course and to compare the results.
- To produce recycled asphalt in the plant by hot recycling method having pre-heating unit for RAP and to pave and to compact as a surface course. To carry out and evaluate the production and quality control tests.
- To compare the properties of plant produced recycled asphalt with that of laboratory produced recycled asphalt.

***This study was carried out into three stages:***

- ***In the first stage:*** Dense graded bituminous mixture for surface course containing 50% RAP and also 3% rejuvenator (specified by supplier) by the weight of bitumen contained in the RAP. The mixture was designed based on Marshall Method and determined performance characteristics in terms of permanent deformation, fatigue resistance and moisture susceptibility. Same tests were performed on the reference mixture. Since the production of RAC containing 50 % RAP without using soft virgin bitumen or rejuvenator or special production techniques such as warm mix asphalt is impossible in practice **[**2,3,4,5]. RAC without rejuvenator hasn't been included in this study.
- ***In second stage:*** 100 tons of recycled asphalt was produced in a batch type plant equipped with two parallel drums. One of the drum is for heating the RAP and the other for heating and drying the virgin aggregates. The mixture is laid and compacted with conventional equipment.
- ***In the third stage:*** The same initial tests defined in the first stage were performed on plant produced recycled asphalt mixture with rejuvenator. Compaction degree of the layer was determined on core samples.

## 2. RECLAIMED ASPHALT

In this study, it was used reclaimed asphalt excavated by milling machine or excavator from damaged asphalt surface courses. Since the reclaimed asphalt could contain coarse particles, they were crushed by impact type crusher, separated into 2 sizes; 0-10 mm and 10-20 mm and stored at 2-3 m height on the plant production site. The particle sizes distributions of RAP fractions were determined on 10 samples taken from every stocks and the average gradations of the fractions are given in Table 3. Since the maximum ranges of grading envelopes are ± 5 % , the feed stocks of RAP are evaluated quite homogeneous . The RAP stocks were visually inspected during storing and loading to the feed bin of the plant not observed any foreign matters



## 3. LABORATORY STUDIES

### 3.1-Materials properties of reference asphalt mixture and recycled asphalt

#### 3.1.1- Virgin aggregate properties

Crushed calcareous aggregates derived from same quarry are used for reference mixture and also for recycled asphalt. The properties of the aggregate and the limits of Turkish Highways Technical Specification are given in Table- 1. To produce recycled asphalt, 50% of virgin aggregate at the size of 12-5 mm was added in the recycled asphalt mixture. The gradation of virgin aggregate fraction is given in Table 2.

**Table 1- Aggregate properties**

| Properties | Unit | Method | Specification | Result |
|---|---|---|---|---|
| Flakiness index | % | TS EN 933-3 | - | 14 |
| Abrasion value (LA) | % | TS EN 1097-2 | Max. 30 | 22 |
| Water absorption | % | TS EN 1097-6 | Max. 2,0 | 1,16 |
| Soundness ,MgSO4 | % | TS EN 1367-2 | Max. 16 | 4,2 |
| Stripping strength | % | TS EN 12697-11 | Min. 60 | 65-75 |
| Coarse aggregate unit weight | g/cm$^3$ | TS EN 1097-6 | - | 2,74 |

**Table 2- The gradation of the fraction - 12- 5 mm prepared from virgin aggregate**

| Sieve seize, mm | 19,1 | 12,7 | 9,52 | 4,75 | 2,0 | 0,42 | 0,177 | 0,074 |
|---|---|---|---|---|---|---|---|---|
| 12-5 mm % passing | 100 | 98 | 75 | 15,5 | 1,3 | 1,1 | 0,9 | 0,5 |

#### 3.1.2- Reclaimed asphalt fractions and gradations

Crushed RAP was separated in two different sizes: 20-10 mm and 0-10 mm. The gradations of the fractions are given in Table 3.

**Table 3- The gradations of RAP fractions**

| Sieve seize, mm | 19,1 | 12,7 | 9,52 | 4,75 | 2,0 | 0,42 | 0,177 | 0,074 |
|---|---|---|---|---|---|---|---|---|
| 10-20 mm RAP % passing | 100 | 75 | 39* | 19 | 16 | 11 | 7,7 | 5,4 |
| 0-10 mm RAP % passing | | | 100 | 84 | 58 | 28 | 18,3 | 13,1 |

** It was difficult to sieve the crushed RAP from 10 mm sieve properly in practice, the percentage of the passing material from 10 mm sieve was quite high.*

**3.1.3 -Binders properties**

**3.1.3.1 Added bitumen properties**

In this study, B 50/70 grade bitumen supplied by TUPRAS refinery was used. The properties of bitumen and the specification limits are given in Table-4.

**Table 4- Properties of virgin bitumen- B 50/70**

| Properties | Unit | Test Method | Specification | Result |
|---|---|---|---|---|
| Penetration | 0.1mm | TS EN 1426 | 50 - 70 | 56,4 |
| Softening Point | ºC | TS EN 1427 | 46 - 54 | 49,0 |
| Frass Breaking point | ºC | TS EN 12593 | Max. -8 | -12 |
| Flashing point | ºC | TS EN 2592 | Min. 230 | 332 |
| Specific gravity | g/cm$^3$ | TS EN 15326 | - | 1,021 |
| Resistance to aging (RTFOT)<br>- Mass change<br>- Retained penetration<br>- Increase softening point | <br>%<br>%<br>°C | <br>TS EN 12607-1<br>TS EN 1426<br>TS EN 1427 | <br>Max.0,5<br>Min.50<br>Max. 9.0 | <br>0,03<br>57<br>6 |
| Solubility | % | TS EN 12592 | Min. 99.0 | 99,9 |

**3.1.3.2- Bitumen content of the RAP and properties of the recovered binder**

Soluble binder content test in according to EN 12697-1 was conducted on the samples taken from stocks. The binder content and properties of recovered bitumen from RAP by using rolling vaporizer method - EN 12697-3 are given Table-5 .

**Table 5- Bitumen content and properties of recovered binder**

| Bitumen content in the RAP , % | Properties | Test Method | Recovered binder |
|---|---|---|---|
| 3,48 | Penetration | TS EN 1426 | 31,1 |
| | Softening Point | TS EN 1427 | 56,8 |

**3.1.4- Rejuvenator agent**

Since the high amount of RAP in the mixture, rejuvenator named Evoflex® was used to improve the properties of aged bitumen and to comply with the binder target properties. In accordance to the instruction of the producer, the rate of the rejuvenator is 3 % by weight of the bitumen content in the RAP. The properties of the additive is given in Table-6

**Table 6- The properties of rejuvenator**

| Properties | Unit | Result |
|---|---|---|
| Appearance | - | Liquid |
| Specific gravity | g /cm3 | 0,94 |
| Flashing point | ºC | 194 * |

***** *Since the temperature of the mixture was around 150 ºC, the flashing points of the rejuvenator was higher than the mixture temperature.*

### 3.2- Mixture design

In accordance to National Highways Technical Specification, Marshall Design method is used to design the reference mixture and Recycled Asphalt Concrete - RAC. Same type of virgin aggregate was used for both of the mixtures. Recycled asphalt mixture contained 50% RAP and the rejuvenator rate was 3% by the weight of binder in the RAP. The mixtures were designed to meet the requirements of asphalt concrete for surface course. All asphalt was prepared in accordance with EN 12697-30 in the laboratory. RAP and virgin aggregate were heated respectively at 130 °C and 180 ºC. Added binder was heated at 150°C. All of the components were added at the specified rates in the mixer and blended homogeneously. The loose mixtures were compacted to the specified density and air voids at 150°C. Basic tests - void content, bulk density, maximal density and water sensitivity by indirect tensile test, rutting resistance by wheel tracking test by small device test and fatigue test by four point bending were carried out on these asphalt mixtures Mix formula, the gradations, properties of the mixtures and the specification limits are given in Table 7. Both of the mixture are identified as AC 20 surf 50/70 in accordance with EN 13108-1.

**Table 7- The mix formula and gradation of the reference mixture and recycled asphalt mixture**

| | **Reference mixture AC 20 surf 50/70** | **RAC AC 20 surf 50/70 ( 50% RAP with rejuvenator)** | **Spec. Limits** |
|---|---|---|---|
| Virgin Aggregate / RA Mix formula | Virgin 19-12 mm - 8 %<br>Virgin 12- 5 mm - 42%<br>Virgin 5- 0 mm - 50% | RAP 20-10 mm- 5%<br>Virgin 12-5 mm- 50 %<br>RAP 10-0mm - 45 % | |
| Rejuvenator | - | 3% by the weight of RAP binder | |
| Gradation- Sieve size, mm | % Passing | % Passing | Passing % |
| 19,0<br>12,5<br>9,5<br>4,75<br>2,00<br>0,425<br>0,180<br>0,075 | 100<br>92<br>80<br>49<br>27<br>13<br>10<br>5,5 | 100<br>98<br>85<br>46<br>27<br>14<br>9<br>6,4 | 100<br>88-100<br>72-90<br>42-52<br>25-35<br>10-20<br>7-14<br>3-8 |
| Optimum total bitumen content % by weight | 4,65 | 4, 65= 1, 74 RAP binder.<br>+ 2,91 added bitumen | 4,0 -7,0 |
| Density t/m$^3$ TS EN 12697-6 | 2,420 | 2,405 | |
| Void content , %<br>Void filled with bitumen, %<br>Void between mineral aggregates %<br>TS EN 12697-8 | 4,0<br>71,0<br>14,1 | 4,28<br>69,7<br>14,1 | 3-5<br>65-75<br>14-16 |
| Marshall - TS EN 12697-34<br>Stability, kg<br>Flow, mm | 1220<br>3,28 | 1440<br>3,38 | > 900<br>2-4 |
| Filler /Bitumen rate | 1,2 | 1,37 | Max. 1,5 |
| Indirect tensile strength ratio %<br>AASHTO T 283 | 81,2 | 87,0 | Min.80 |
| Wheel tracking small size device<br>EN 12697-22, PRD %<br>(30000 cycle at 60 °C) | 6,1 | 5,2 | Max. 8 |

### 3.2.1- Recovered binder properties of RAC mixtures - The effect of rejuvenator

The effect of rejuvenator on recovered binder was determined on laboratory prepared samples with and without rejuvenator by using rolling vaporizer method - EN 12697-3. Results are given in Table-8 and Figure 1.

Penetration and softening point of the recovered binder from RAC without rejuvenator have been also calculated by the following formulas given in EN 13108-1 Annex A to check the results.

Penetration : $a \log pen_1 + b \log pen_2 = (a+b) \log pen_{mix}$

$pen_{mix}$ : Calculated penetration of the binder in the mixture
$pen_1$ : Penetration of the binder recovered from RAP
$pen_2$ : Penetration of the added binder
a and b : The portion by mass of the binder from RAP (a) and from the added binder (b) in the mixture
$a + b = 1$ .

Softening Point: $T_{R\&B}$ mix $= a \times T_{R\&B1} + b \times T_{R\&B2}$

$T_{R\&Bmix}$ : Calculated softening point of the binder in **in the mixture**
$T_{R\&B1}$ : Softening point of the binder recovered from RAP
$T_{R\&B2}$ : Softening point of the added binder
a and b : The portion by mass of the binder from RAP (a) and from the added binder (b) in the mixture
$a + b = 1$ .

Calculated values are:
Penetration = 45 Softening point =52ºC. The calculated values are almost same as the tests results.

**Table 8- Properties of virgin bitumen, RAP binder and recovered binders from laboratory produced RAC with and without rejuvenator**

| Properties | Test Method | AC 50/70 virgin | RAP binder | RAC binder without rejuvenator | RAC binder with rejuvenator | Specification |
|---|---|---|---|---|---|---|
| Penetration | TS EN 1426 | 56,4 | 31,1 | 44,0 | 53,0 | 50-70 |
| Softening point | TS EN 1427 | 49,0 | 56,8 | 54 | 51,0 | 46-54 |

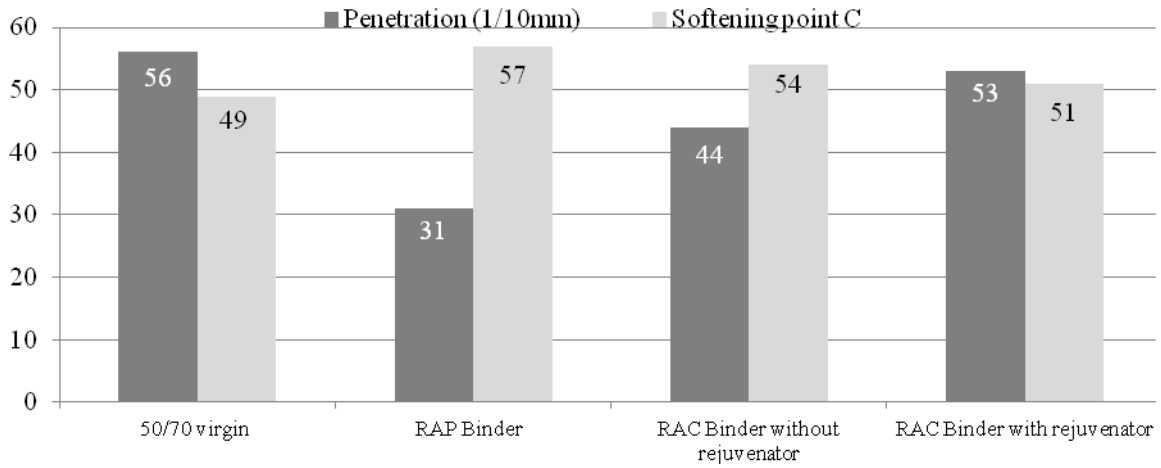


**Figure 1- Penetration and softening point of the binders**

In accordance to the results, the rejuvenator increased the penetration and decreased the softening point.

### 3.2.2 Resistance to fatigue

Resistance to fatigue was determined in accordance to EN 12697-24 Procedure D - Four-point bending test on prismatic shape specimens. The test is conducted at 20°C temperature and 10 Hz frequency. To compare the resistance to fatigue, the test was performed either the mixtures contained 50% RAP and reference mixture. The average results of the tests are given in Table 9. Based on the results of stiffness, the stiffness of RAC with rejuvenator is almost two times higher than that of reference mixture.

**Table 9- The results of four point bending test**

| Laboratory produced | Micro strain | Freq. Hz | Temp. °C | Average Initial Stiffness, Mpa | Average Total dissipated energy, MJ/m3 | Average Load cycles |
|---|---|---|---|---|---|---|
| Reference Mixture | 150 | 10 | 20 | 4745 | 20,7 | 170.855 |
| | 250 | 10 | 20 | 4421 | 8,4 | 27.345 |
| | 350 | 10 | 20 | 4074 | 5,3 | 9.031 |
| RAC with 50% RAP + rejuvenator | 150 | 10 | 20 | 9034 | 84,2 | 624.723 |
| | 250 | 10 | 20 | 9193 | 14,3 | 32.595 |
| | 350 | 10 | 20 | 7494 | 2,3 | 3.508 |

## 4. TRIAL SECTION CONSTRUCTION - PRODUCTION AND PAVING OF RECYCLED ASPHALT

Trial section was constructed on the urban road. Recycled asphalt was produced in the parallel double drum dryer batch type asphalt plant having capacity, 240 t /h. The plant is designed for reclaimed asphalt by heating, a separate, inflow large volume drying drum equipped with a special designed burner to preclude direct contact between the flame and reclaimed material. The RAP fractions having about 2,5 % moisture were feed separately to the drum from different silos at the defined proportional rates .The drum for RAP is located at the top of the plant .The virgin aggregate sized 5-12 mm was feed directly to the second drum located at the bottom like normal plants. RAP fractions and virgin aggregate were dried and heated respectively at about 130 °C and 190 °C. If the mixture containing 50% RAP isn't produced in the special plant having pre-heating system and not contained rejuvenator, it is required to heat the virgin aggregate at the temperature over 200° C [7,8] .After heating, the RAP is stored in an insulated buffer silo from where it is batch weighed and introduced to the mixer In this plant, the mixer is installed under the parallel drum to allow RAP to follow a straight way thought the entire system to avoid the sticking of RAP particles. The virgin aggregate is feed to mixer at the same time. After dry mixing operation, the fresh bitumen and rejuvenator at the specified rates were added into mixer then mixed thoroughly to obtain homogenous mixture at the temperature of 150ºC. The mixing time was the same as the normal bituminous mixture. Total amount of produced recycled asphalt was 110 ton for trial section. The Figure 2 shows a schematic of double drum dryer batch type asphalt plant.

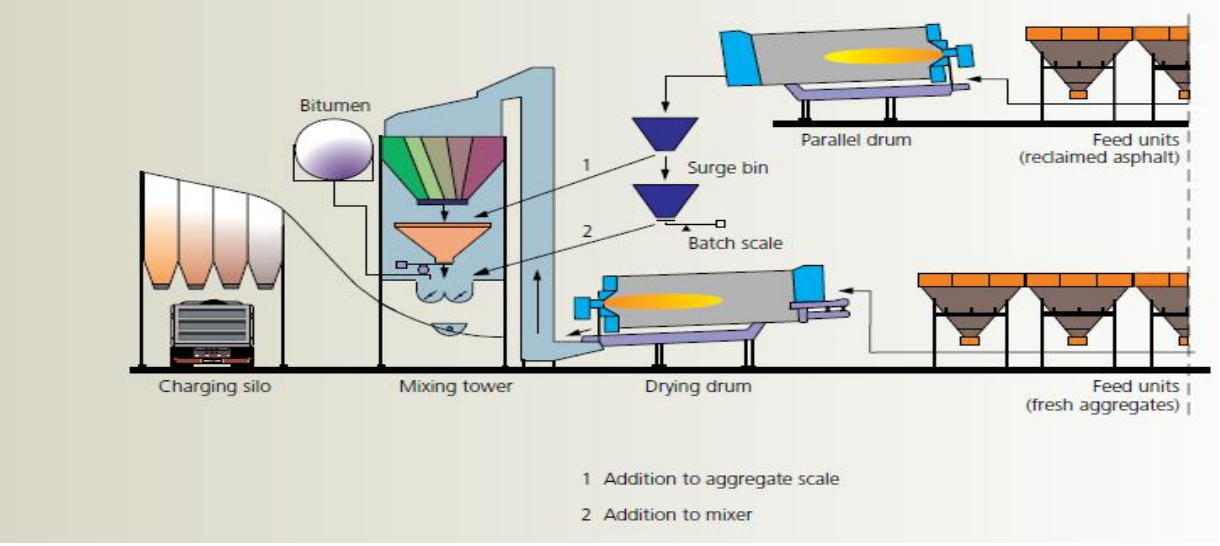


**Figure 2- Batch mixing plant - Heating of reclaimed asphalt in separate parallel drum [7]**

The mixture discharged from the mixer was homogenous and shiny in appearance with the aggregate completely coated with binder and there were no balling of RAP materials .The mixture was transferred to the site by trucks. During paving, the ambitious temperature was about 35 ºC and the weather was sunny. The mixture was paved with finisher and compacted by vibrating roller. Since the workability of the mixture was apparently better than conventional asphalt concrete, it was compacted easily at 5 passes of roller. Joints and manual works was also better and easier



**4.1. Tests conducted on the samples taken from plant and trial section**

Although recycled asphalt characteristics determined in a lab mix design are complying with the specification criteria, there may be differences between laboratory produced mixture and what is actually produced by mixing plant. Then plant production process and weather conditions have an effect on RAC mixture properties . For those reason, specimens were prepared from plant produced asphalt mixture to verify the properties. The samples were taken on the truck to carry out the same tests conducted on laboratory produced samples. The results of gradation, bituminous content, Marshall Tests, wheel tracking and indirect tensile strength test are given in Table 10. Fatigue test result is given separately in Clause 4.1.1. The tests results of laboratory produced RAC is also given in Table 10 for comparison.

**Table 10- Test results of laboratory and plant produced recycled asphalt mixtures with 50% RAP + Rejuvenator**

| | **RAC- Laboratory produced** | **RAC - Plant produced** | **Specification** |
|---|---|---|---|
| Gradation<br>Sieve size, mm | **% Passing** | **% Passing** | **% Passing** |
| 19,0<br>12,5<br>9,5<br>4,75<br>2,00<br>0,425<br>0,180<br>0,075 | 100<br>98<br>85<br>46<br>27<br>14<br>9<br>6,4 | 100<br>99<br>88<br>46<br>25<br>15<br>12<br>7,8 | 100<br>88-100<br>72-90<br>42-52<br>25-35<br>10-20<br>7-14<br>3-8 |
| Optimum total bitumen content<br>% by weight TS EN 12697-1 | 4,65= 1,74 RAP binder +<br>2,91 Virgin Bitumen | 5,2 | 4,0 -7,0 |
| Bulk Density t/m$^3$<br>TS EN 12697-6 * | 2,405 | 2,403 | |
| Void content , %<br>Void filled with bitumen, %<br>Void between mineral aggregates %<br>TS EN 12697-8 | 4,28<br>69,7<br>14,1 | 4,0<br>72,2<br>14,4 | 3-5<br>65-75<br>14-16 |
| Marshall - TS EN 12697-34<br>Stability, kg<br>Flow, mm | 1440<br>3,38 | 1457<br>3,08 | > 900<br>2-4 |
| Filler /Bitumen rate | 1,37 | | Max. 1,5 |
| Indirect tensile strength ratio %<br>AASHTO T 283 | 87 | 88 | Min.80 |
| Wheel tracking with small size device<br>EN 12697-22<br>Proportional rut depth, %<br>(30000 cycle at 60 °C) | 5,2 | 5,4 | Max. 8 |

All properties of plant produced RAC are within the specified limits and compatible with the properties of laboratory produced RAC.

The in-place density, compaction degree and the thickness of the layer were determined on the 4 core samples taken from the trial section in accordance with EN 12697-6 and the average results are given in Table 11.

**Table 11- Average results of compaction degree and the thickness of the layer**

| Core thickness, mm | Compaction degree % |
|---|---|
| 48 | 98 |

### 4.1.1- Recovered binder properties from the plant produced RAC mixture

Table 12 shows the recovered binder properties of laboratory with and without rejuvenator and plant produced mixture with rejuvenator.

**Table 12- Properties of recovered binder from laboratory produced and plant produced RAC**

| Properties | Test Method | Laboratory produced RAC binder without rejuvenator | Laboratory produced RAC binder with rejuvenator | Plant produced RAC binder with rejuvenator |
|---|---|---|---|---|
| Penetration | TS EN 1426 | 44,0 | 53,0 | 52 |
| Softening Point | TS EN 1427 | 54,0 | 51,0 | 50 |

### 4.1.2- Resistance to fatigue

Resistance to fatigue of plant produced mixture was determined at the same test conditions of that of laboratory produced mixture. The results of the tests of plant and laboratory produced RAC with rejuvenator are given Table 13.

**Table 13 - The results of four point bending test of plant and laboratory produced recycled asphalt mixtures with rejuvenator**

| | Micro strain | Freq. Hz | Temp. °C | Average Initial Stiffness, Mpa | Average Total dissipated energy, MJ/m3 | Average Number of load, cycles |
|---|---|---|---|---|---|---|
| RAC plant produced | 150 | 10 | 20 | 11088 | 84,8 | 460081 |
| | 250 | 10 | 20 | 10206 | 10,9 | 23482 |
| | 350 | 10 | 20 | 9382 | 5,7 | 6314 |
| RAC laboratory produced | 150 | 10 | 20 | 9034 | 84,2 | 624723 |
| | 250 | 10 | 20 | 9193 | 14,3 | 32595 |
| | 350 | 10 | 20 | 7494 | 2,3 | 3508 |

The stiffness results of RAC with rejuvenator produced in laboratory is compatible with the results of plant produced mixture.

## 5- EVALUATION OF MECHANICAL TEST RESULTS

In accordance to the results of the tests conducted on the samples of reference mixture and RAC produced in the laboratory and RAC produced in the plant, all of them have shown a good compliance with the national highways specification.

The rutting depth ratio of the mixtures are given in Figure 3. The rutting ratio of laboratory produced RAC with rejuvenator is 17 % lower than that of reference mixture. The rutting results of laboratory produced and plant produced recycled asphalt mixture are very close to each other.

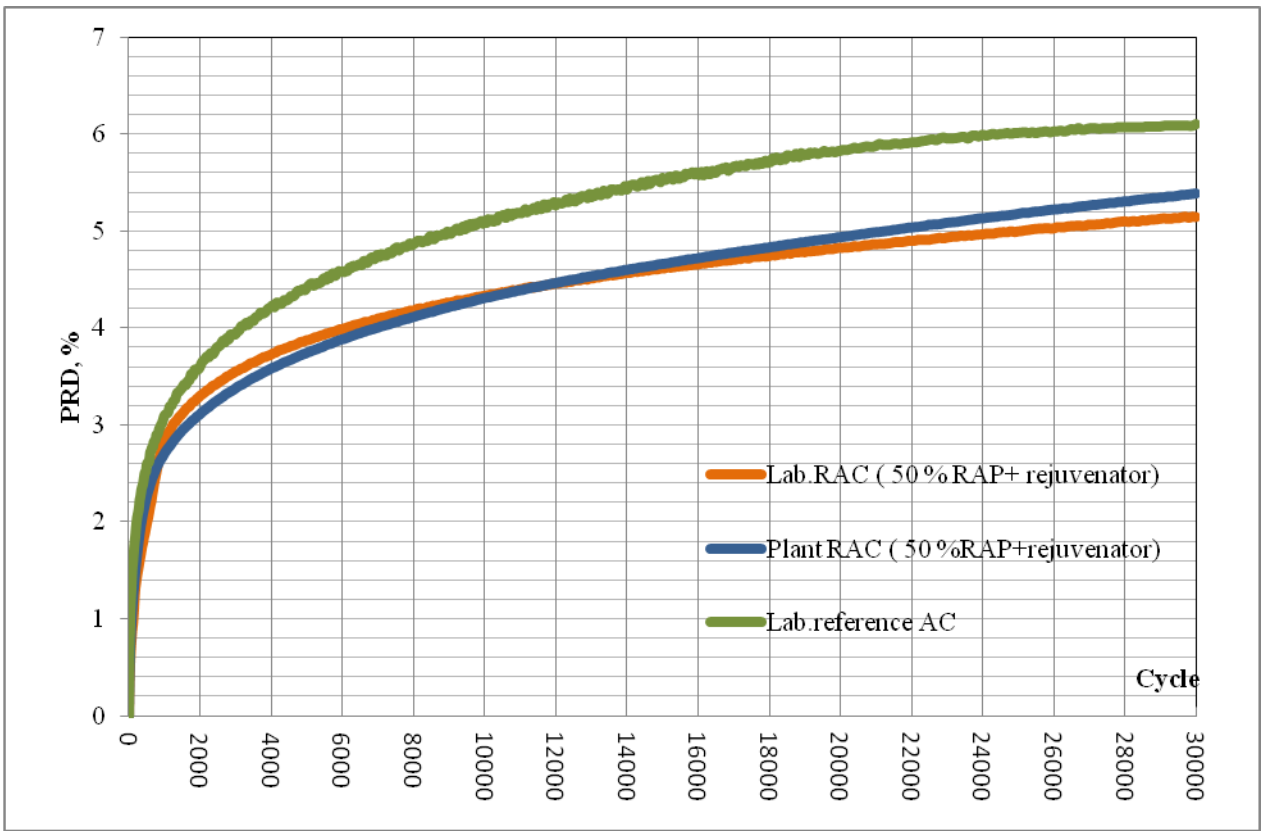


**Figure 3- Rutting resistance of laboratory produced AC and RAC and plant produced RAC**

Indirect tensile strength ratio of the mixtures is given in Figure 4. ITSR value of the RAC is 8 % higher than that of the reference mixture .The results of laboratory and plant produced RAC are almost same.

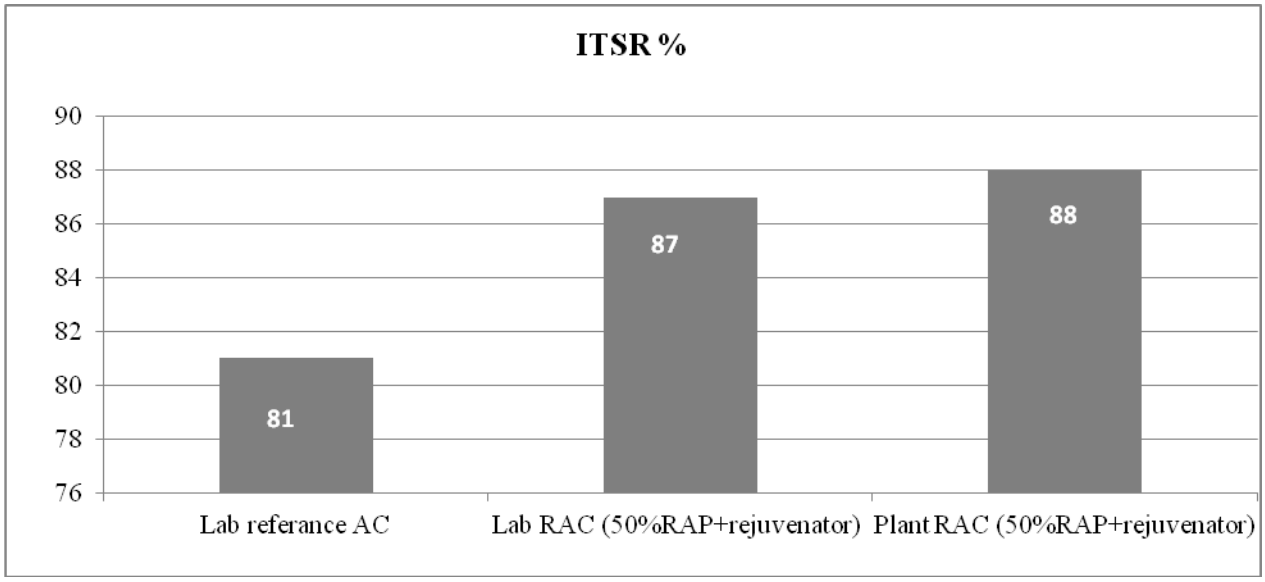


**Figure 4- Indirect tensile strength ratio of the mixtures**

Fatigue test results are shown in Figure 5 and Figure 6. Fatigue resistance test result in terms of micro strain at 1000.000 cycles [8,10,11], $\varepsilon_6$ for laboratory produced RAC (142 μs) is 56 % higher than that of reference mixture (91 μs). The strain, $\varepsilon_6$ of the plant produced RAC ( 125 μs) is 12 % lower than the result of laboratory produced RAC (142 μs) but higher than that of reference mixture (91 μs)

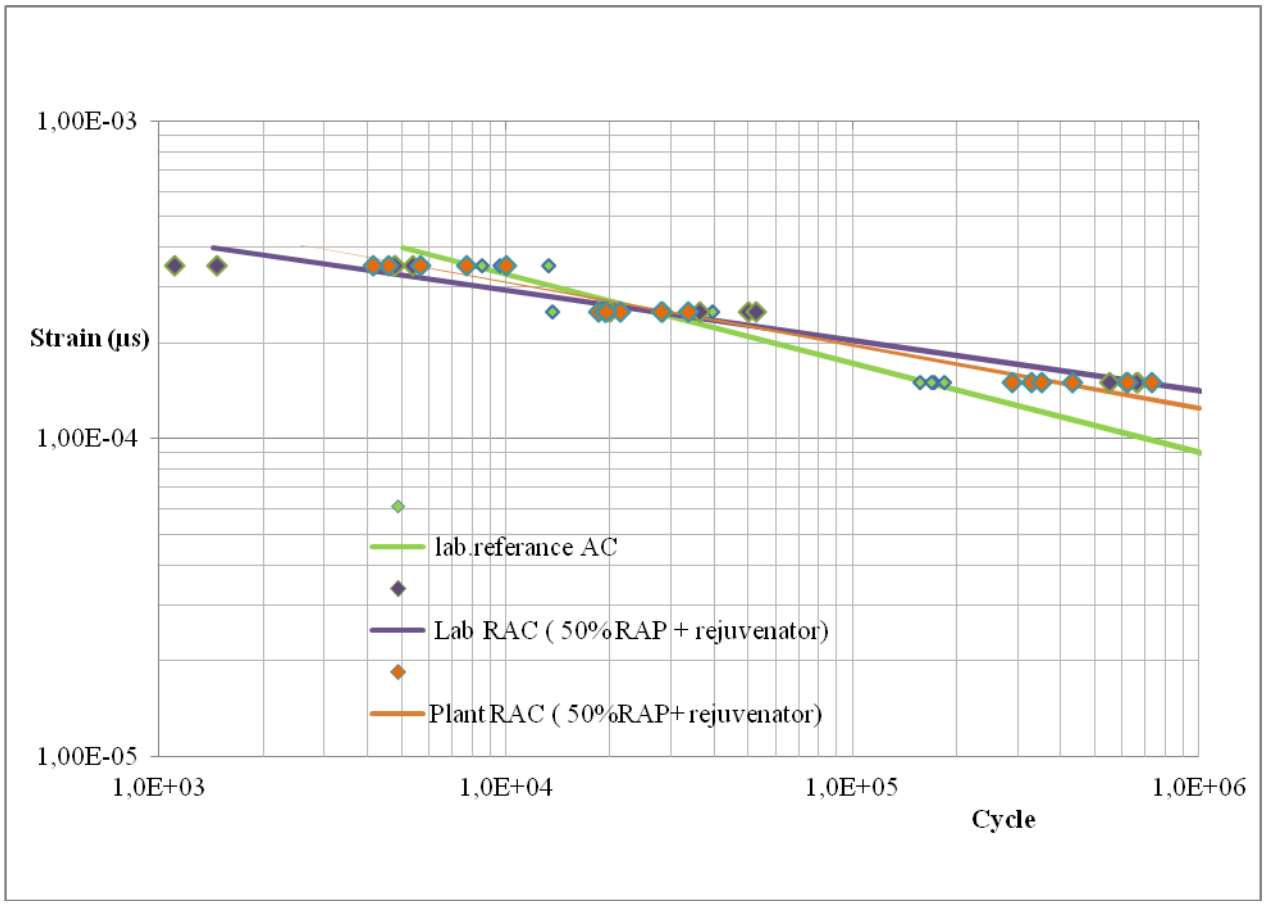


**Figure 5- Number of load cycles and micro strain lines of the mixtures**

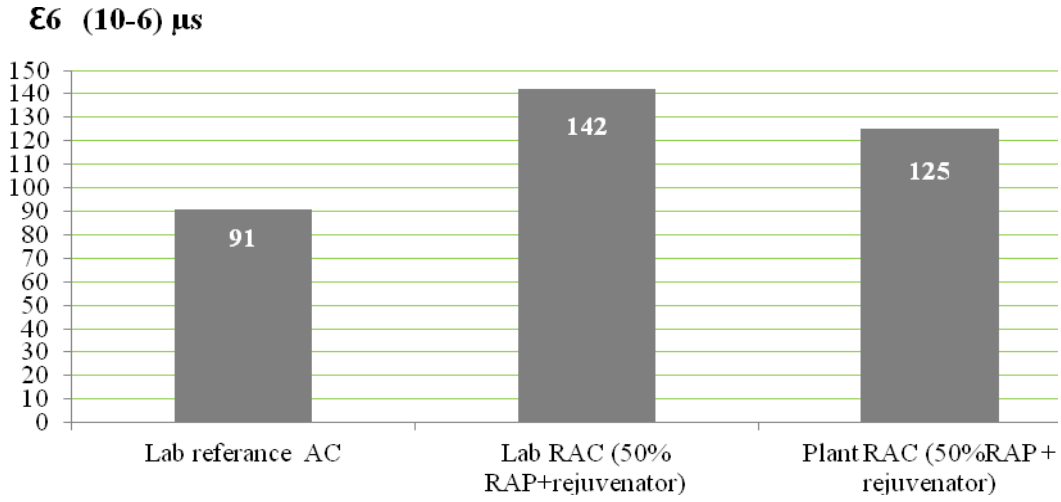


**Figure 6- Fatigue resistance deviations**

## 6. CONCLUSION

Recycled asphalt concrete mixture for wearing course incorporating 50 % RAP with rejuvenator were tested and demostrated improved mechanical properties relative to the reference mixture.

The followings conclusions can be drawn from this study:

- Since the penetration and softening point of the binder in reclaimed asphalt is too hard for usage 50% RAP in the mixture, new binder and rejuvenator was added to comply with the specified grade of bitumen. In this study, it is used 3% rejuvenator by the weight of binder in RAP to eliminate the need of soft binder. It is found that the rejuvenator increased the penetration and decreased the softening point of the RAC mixture. Therefore binder properties of the mixture comply with the specification limits. The rejuvenator soften oxidized bitumen in RAP and makes the mixture more resistance to cracking. On the other hand decreased softening point makes the binder

less aged and more resistance to low temperature. It is also provide thorough blending during mixing operation by improving workability. [1,2,3,4,5]

- Volumetric properties of recycled mixtures with rejuvenator produced in laboratory and plant are complied with the specification .
- Since the rutting ratio ( 5,2 %) of laboratory produced RAC with rejuvenator is less than the criteria for the specification ( 8% ) and 15 % lower than that of reference mixture (6,1 %). Therefore it is evaluated that the RAC mixture has shown better resistance to permanent deformation.
- Indirect Tensile Strength -ITS results of the recycled mixture with rejuvenator were within the requirements and ITSR value is 8 % higher than that of the reference mixture, resulting less sensitive to water.
  The RAC mixture containing 50% RAP and rejuvenator displayed 56 % increase in strain level at $10^6$ load cycles in four point bending test when compared to the reference mixture.
- In spite of 50% RAP content of the mixture and 2,5 % moisture content of RAP , recycled asphalt mixture with rejuvenator was produced at conventional asphalt mixing temperature (150 º C ) by heating virgin aggregate at around 190 º C which was lower than the required temperature ( over 200 º C ) [7].Therefore during the production of RAC contained high amount of RAP, the lower temperature of the aggregate means lower energy consumption and thus reduced greenhouse gas emissions.
- Although the facilities available in laboratory cannot be compared with an industrial scale mixing plant, the results on recycled asphalt mixture produced in the plant confirmed the results from laboratory produced mixture. The results show that the high efficiency of the plant fit to high rate of recycling is very important.
- Recycled asphalt trial section was paved and compacted satisfactory in regard to compaction degree and void contents. Additionally based on visual inspection, there was better workability of recycled mixtures with rejuvenator compared to the conventional mixture.
- All of the tests results show that asphalt mixture containing 50% RA with rejuvenator fulfilled the specifications and the obtained mechanical performance regarding to rutting resistance, water sensitivity and fatigue resistance is in most cases even better than the reference mixture.

As a result, the mechanical test results demonstrated that 50% RAP with rejuvenator can be used as a viable alternative mixture for surface course. The main keys of success are the homogeneity of RAP, proper laboratory design of RAC by using rejuvenator and mixing plant with two separate drums where one is especially dedicated to the preheating of RAP.

It is required to assess the trial section and take samples after a specific service time to determine short and long term performance of the mixture.

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