

## Evaluation of Characteristics of Recycled Asphalt Pavement (RAP) Materials with and without Using Additive Materials

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### Abstract



Nowadays, reclaimed asphalt pavement is used as hot mix asphalt (HMA) because it has economic and environmental benefits. As an attempt to preserve aggregate resources and save money, this study was done. To evaluate the characteristics of the RAP aggregate, many tests were done that include gradation, specific gravity, Coarse Aggregate Angularity (CAA), Flat and Elongation (F&E), Los Angeles Abrasion (LA), and impact test. Three types of additive materials, which were SBS, CR, and PP, mixed with the reclaimed asphalt blends with three different percentages of 3%, 5%, and 7%. The conventional asphalt binder tests were done for the aged and reclaimed binders. As the percentage of the additive materials increased, the penetration and ductility of the asphalt binder decreased. The elastic recovery of the blends was increased from approximately 7% to 80% when different percentages of SBS additive were used. As the percentage of the additive materials increased, the softening points of the blend increased. The specific gravities of the reclaimed blends were not changed significantly after adding additives. The flash and fire point temperatures increased when the percent of PP additive material was increased to the blends; however, the flash and fire point temperatures decreased when the percent of the SBS and CR additive materials increased. Based on the standard deviation of the RAP asphalt contents, the mixture blend was selected to be 40% RAP and 60% new material. The aged RAP binder was blended with a soft grade virgin asphalt binder that was 60/70 grade. The procedure of Superpave design mixtures was done to find optimum asphalt content and knowing the effects additives on moisture sensitivity of the mixtures. Adding additive materials benefits the

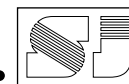
reclaimed mixtures regarding moisture sensitivity. The most beneficial effects of additives on moisture sensitivity of the reclaimed mixtures were 7% SBS, 3% CR, and 5% PP obtaining the ITRR of 99.71%, 97.1%, and 90.7%, respectively. The selected most beneficial blends of the reclaimed asphalt binder with additives were further analyzed using Superpave performance grade tests. The additive materials changed the PG of the blended reclaimed binder with no additive materials from 64 -22 °C to PG of over 88-22 °C for 7% SBS, PG of 76-28 °C for 3% CR, and PG of 82-16 °C for 5% PP. It was recommended to use 7% of SBS in the reclaimed asphalt mixtures for hot climates, and 3% of CR for cold climate conditions.

**Keywords:** RAP, Styrene Butadiene-Styrene (SBS), Crumb Rubber (CR), Recycled Atactic Polypropelene (PP), Performance Grade (PG), Moisture Effect.

### 1. Introduction

The first data on the use of Reclaimed Asphalt Pavement (RAP) were documented in 1915 (Taylor N., 1997). During oil crisis in 1970's the cost of asphalt binder was raised; therefore, using RAP was developed and increased (Sullivan, J., 1996). The National Cooperative Highway Research Program (NCHRP) in 1978 and 1980 published Synthesis of Highway Practice No. 54, Recycling Materials for Highways and Report No. 224, Guidelines for Recycling Pavement Materials (Newcomb D. et al., 2007). After implementing the Kyoto Protocol in 2005, asphalt pavement recycling received major attention and widespread application in the industry of road construction (Ortiz O. R. et al., 2012). As the oil price increases, cost of asphalt





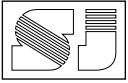
binder increases, too. At the same time availability of crude oil will be decreased, which will make engineers to keep the resources of the earth and using of RAP mixtures will be an evitable. Despite the mentioned economic viewpoint, using RAP benefits environment by conserving petroleum and aggregate resources and saving landfill space. Demolition and construction waste materials have been increased in recent years and have negative effects on the environment. Some municipalities reporting as much as 400,000 tons of recycled materials used in this manner (Bennert, T., et al., 2000). Several methods of recycling of asphalt pavement are available such as hot recycling in plant, hot-recycling "in situ", cold-recycling "in situ". Hot recycling, where virgin materials and RAP are combined, is the most widely techniques used (Ortiz O. R. et al., 2012). The percentage of RAP that can be blended with new asphalt mixture depends on the production process, paving technology and the RAP source and properties (Dondi G. et al.). In 1970s, it was suggested that the amount of RAP to be used in drum mixers and batch plants could be as high as 70% and 50%, respectively. At that time, many problems limited using high RAP percentages. The problems included flammability of recycling agents, emissions due to high temperatures and plants not designed for recycled asphalt, poor control of recycling agent quantities, questions about the variability of the RAP materials, as well as questions concerning the amount of mixing between the recycling agent and old asphalt cement. In many cases, specifications do not allow using high percentages of RAP. Currently, the amount of RAP used is normally not exceed 25% (Newcomb D. et al., 2007).

Nowadays, polymerized asphalt that is a blend of asphalt binder with additive materials are used to improve the fundamental properties of asphalt binders and the performance of asphalt mixtures. Polymer modified binders can be used to improve rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility in HMA. In addition, blending small amounts of polymer dramatically changes the rheological properties of the asphalt binder (Lewandowski L. H., 1994). Among the additive materials, which are used to improve properties of HMA and RAP, are SBS, CR, and PP.

The most commonly used polymer for bitumen modification is SBS, which increase elasticity of bitumen. The researchers at Louisiana State University showed that SBS effects aged and virgin asphalt binder by increasing rutting resistance and decreasing the fatigue resistance of the recycled polymer modified asphalt concrete mixtures (Mohammad L. et.al., 2003). On the other hand, Huang et al. reported that using SBS polymer modified binder in RAP mixture increased resistance to fracture failure from the semi-circular notched fracture test (Huang B. et.al., 2005).

CR, which is beneficial to reduce cost of pavements and to solve of a waste disposal-problem, has been using for paving as an elastic binder additive material. Two techniques can be used for using crumb tire in roads that are dry and wet processes. In a dry process, the CR is mixed with the aggregates of the mixture, while in the wet process the CR is mixed with asphalt cement (Kök, B. V., and Çolak, H., 2011). Navarro et al. investigated that adding ground tire rubber to bitumen results in increasing both the linear viscoelastic modulus and the viscosity at high in-service temperatures (Navarro FJ, 2004). Cao W. concluded that adding of recycled CR to asphalt mixtures using a dry process improved the engineering properties of asphalt mixtures, and the CR content had a significant effect on the performance with respect to resistance to permanent deformation and cracking (Cao W, 2007). Moreover, adding of CR helps increasing the voids in mineral aggregate in Superpave mix design and improving the rutting resistance of asphalt mixtures (Xiao F. et al., 2009). Oliver JWH et al. mentioned some advantages of CR on asphalt pavement such as increasing fatigue life, reducing reflective cracking and low-temperature cracking, and improving tensile strength (Oliver JWH, 2000).

PP is widely used as an appropriate polymer, which has several advantages such as good process ability, low cost, integral hinge property, low density, high softening point and good mechanical properties. The application of using polypropylene is somehow limited because of its relatively moderate fracture performance, especially at sub ambient temperature (Zahedi M., 2014) (Yazdani A., 2012).



## 2. The Objectives of the Study

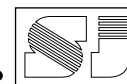
Using RAP materials has several economic and environmental benefits

- Understanding the characteristics of aged asphalt binder and the aggregates of the RAP materials and comparing them to specification to be used in new hot mix asphalt.
- Evaluating the effects of additive materials, which were SBS, crumb rubber, and polypropylene, on the reclaimed asphalt binder and mixture.
- Using conventional and Superpave laboratory tests for the evaluation of the reclaimed asphalt binder and mixtures with and without using the additives materials.
- Evaluating the reclaimed asphalt pavements for the moisture sensitivity using Indirect Tensile Strength (ITS) test.

## 3. Literature Review

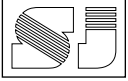
Many studies have been done about characteristics and performance of RAP binders and mixtures with and without using additive materials. J. Han et al. (2011) evaluated characteristics of RAP in Kansas, USA. Many conventional tests were used to evaluate asphalt binder and aggregate of the RAP material. The performance grade tests were used to evaluate the aged and recovered asphalt binder, too. The aggregate properties of the RAP were compared with the original aggregates that are used for the new mixture design. Reyes-Ortiz et al. (2012) assessed the mechanical response of dense-graded HMA mixtures after partial and total replacements of aggregates by RAP and using grades of 60/70 and 80/100 of asphalt. Four different percentages of 15%, 20%, 35%, and 100% of RAP replaced the granular materials. The highest indirect tensile strength and resilient modulus values in both dry- and wet-condition were obtained for the HMA mixtures produced with 100% replacement of granular material by RAP. Khosla et al. (2012) investigated the rheology of reclaimed binder blends using Superpave binder tests. Three virgin binder performance grades, a PG 52-28, PG 58-28 and PG 64-22 were mixed with two different RAP concentrations, 20% and 40%. The stiffness of the blend increased 150% to 200% for

the blends containing PG 52-28 and PG 58-28 virgin asphalts when the RAP binder increased from 20% to 40%. E. Johnson et al. (2013) showed that pavement performance of Minnesota county highways that were contained an average of 20% to 26% RAP improved 40% of transverse cracks per mile along with a 34% improvement in crack spacing when low PG-34 asphalt binder was used instead of low PG -28. Hussain A. and Yanjun Q. (2013) concluded that the stiffness, viscosity, and critical temperature of the blended binder increased when the RAP binder content was increased. Based on the bending beam rheometer (BBR) test results, the creep stiffness increased with the increase in the RAP content under low temperature conditions. Zaumanis et al. (2016), investigated the concept of 100% RAP as conventional asphalt mixes, and summarized available production techniques for using 100% RAP material. Rheological, micromechanical and chemical characterization tests were performed with eleven rejuvenators to confirm true rejuvenation of aged binders. Low temperature cracking resistance was improved significantly while providing a moisture and rut resistant mixture. Noferini et al. (2017) investigated the performance of asphalt mixture made with different RAP content (10%, 20%, and 30%). As well as, the effects of RAP on the physical and rheological properties of the bituminous blend were investigated. The aged binder resulted in a more viscous and consequently harder composite bitumen. The presence of 20% or higher of RAP binder caused a significant increase in viscosity, whereas a RAP binder content of 10 % did not affect the blend viscosity. Based on the Dynamic Shear Rheometer (DSR) test analyses, the RAP binder hardened and increased elastic behavior of bitumen. When the RAP content was below 10%, the aged bitumen had little influence on the rheology final blend; while it had significant effects with more than 20% of RAP content. In addition, the increase in the cross-over temperature with RAP content indicated a widening of the temperature range where the mechanical response of the bitumen was predominantly elastic. Kim S. et al. (2009) used asphalt pavement analyzer (APA) and the indirect tensile tests (IDT) to investigate rutting and cracking performance of SBS polymer-modified asphalt mixture with reclaimed asphalt pavement.



Different percentages of RAP were used, which were 0%, 15%, 25%, and 35%. The RAP mixtures with modified binders worked well regardless of amounts of RAP materials in HMA. Stimilli et al. (2014) investigated the mechanical performance and innovative rheological tests of blends prepared with different percentages of an artificial reclaimed bitumen and three virgin modified bitumen, characterized by different percentages (1.8%, 2.8%, and 3.8%) of SBS polymer content. The artificial reclaimed bitumen did not penalize the final bituminous blend characteristics thereby indicating that the maximum amount of reclaimed asphalt incorporable in a mixture did not appear to be limited by the rheological characteristics of the final bituminous phase. Liu et al. (2015) investigated the influence of different grades of soft virgin bitumen on the chemical and rheological properties of three reclaimed polymer-modified binders (PMB)s from different old surface-layer asphalt mixtures. The three old PMBs reclaimed from surface layers were porous, dense, and stone mastic asphalt. The soft virgin bitumen influenced the chemistry and rheology of reclaimed binder significantly to restore the rheological properties of the reclaimed PMB binder; however, the chemical and rheological changes were not consistent. Singh D. and Sawant D. (2016) evaluated rutting, fatigue, and rheological performances of an SBS co-polymer modified binder (PMB40) blended with different percentages (0%, 15%, 25%, and 40%) of RAP binder. Adding the RAP made PMB40 binder stiff and less temperature susceptible, however, it did not change mixing and compaction temperatures significantly. Rutting resistance of the binder was poor after adding RAP binder, because significant reduction in recovery and increment in non-recoverable creep compliance of PMB40 binder with addition of RAP was obtained. Rate of damage was increased and number of cycles to fatigue failure of PMB40 binder was decreased with addition of RAP. Also, sulfoxide and carbonyl content increased with addition of RAP. Yan Y. et al. (2017) prepared fourteen reclaimed asphalt pavement mixtures with different combinations of polymer modified RAP content including 0%, 20%, 30%, and 40%. The Polymer Modified Asphalt (PMA) blends behaved effectively when they met the recovery requirements for

multiple stress creep recovery (MSCR); as well as they had satisfactory values for the energy density of the binder fracture. When the RAP content was increased, higher tensile strength, and lower failure strain and lower fracture energy of the mixtures were obtained. It meant that with increasing the RAP content stronger mixtures and more brittle mixtures were obtained. All of the RAP mixtures had acceptable cracking performance because they exhibited dissipated creep strain energy to failure (DCSEf) values above  $0.75 \text{ kJ/m}^3$  and energy ratio (ER) values well above 1.0. Wang J. et al. (2017) evaluated the effect of rejuvenating agent on different modified RAP contents (0%, 30%, 50% and 70%) mixtures. Tests of freeze-thaw split, semi-circular bending (SCB) and dynamic modulus (DM) were conducted for the reclaimed RAP. The rejuvenating agent could recycle the properties of aged modified asphalt effectively. The initial phase structure of the aged modified asphalt was not changed by adding rejuvenating agents. Using the rejuvenating agent in the modified asphalt for the RAP was harmful to moisture susceptibility and low-temperature cracking resistance, especially with high agent content. When loading frequency reached a higher value, the DM of recycled mixtures and HMA mixture tended to be consistent. J. Wang et.al. (2018) evaluated the properties of hot mix asphalt with different percentages 0%, 30%, 50%, and 70% RAP-SBS replacement in terms of rutting, low-temperature anti-cracking, and moisture susceptibility. HMAs mixture with higher percentages of RAP-SBS exhibited better rutting resistance, and lower anti-cracking properties and moisture susceptibility. When the RAP-SBS percentage was less than 30%, the anti-cracking property of the recycled mixture was basically close to that of HMA mixture between  $-20$  to  $-10^\circ\text{C}$ , and the moisture susceptibility of the two types of mixture was similar when the percentage was less than 50%, but the durability of both recycled mixtures was poor. When subjected to F-T cycles, the strength of mixtures with RAP-SBS was more sensitive than that of HMA mixtures, especially for mixtures with high RAP-SBS percentages.



#### 4. Methodology

The samples of RAP materials were taken from Sulaimani municipality stockpile, where is used to store the recycled asphalt material obtained from cold milling process. Care was taken to prevent RAP samples from the stockpiles being contaminated with unwanted waste materials. Based on the Sulaimani municipality, the deteriorated streets are milled approximately every 15 to 20 years. The designed optimum asphalt content was 4.6% of 50/60 grade asphalt was used for the milled RAP.

Two methods were taken to know the asphalt binder content in the RAP mixture that were ignition and binder extraction using centrifuge testing machine. Ten samples of two kilograms were taken for each one of the tests; then the average value of both tests was considered as the asphalt binder content of the RAP material. In order to obtain the aged binder, a light solvent material (benzene) was used to separate the asphalt binder and aggregate. The standard deviation of the asphalt content that obtained in the tests mentioned was used as the basis for choosing the RAP and new asphalt mixture percentages.

In order to evaluate the RAP aggregate, many tests were done that were sieve analysis, Los-Angeles abrasion, impact resistance, specific gravity, angularity, sand equivalent, and flaky and elongated tests. The same tests were done to the new and blended aggregates, too.

The aged binder was evaluated using many conventional tests including penetration, softening point, ductility, viscosity, specific gravity, elastic recovery, and flash and fire point tests.

After mixing the aged binder with virgin binder and then additive materials, the same conventional tests were done, too. The virgin binder had 60/70 grade, while the additive materials were SBS, CR, and PP. The additive materials were mixed with the reclaimed binder with three different percentages: 3, 5, and 7%.

For the Superpave mixture design, three different aggregate gradations were designed and evaluated for the volumetric analysis. One of the aggregate gradations was selected to be used as the designed one for the Superpave mixture. Maximum theoretical specific gravity ( $G_{mm}$ ) tests

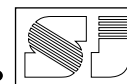
were done for two samples of the selected gradation, and then the average value was taken. Based on the  $G_{mm}$ , the effective specific gravity ( $G_{se}$ ) of the RAP and new aggregate was obtained. In order to find the optimum asphalt content for the reclaimed asphalt mixture with and without using additive materials, Superpave gyratory compactor device was used to prepare 50 samples of mixtures. To evaluate moisture sensitivity of the mixtures and finding the indirect tensile strength ratio (ITSR), sixty samples were compacted using 7% of air voids. Thirty of the samples were conditioned and thirty were unconditioned. The average value of each three samples were taken to find the ITSR.

For each of the additive materials, the percentage that obtained the optimum ITSR were selected for further analysis that was Superpave performance grade; and then, compared with the performance grade of the reclaimed asphalt binder without using additive materials. The selected samples were aged for short-term and long-term aging using rolling thin film oven (RTFOT) and pressure aging vessel (PAV) tests, respectively. To find the performance grade of the selected binder blends, the aged binder samples were then tested for the dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests.

#### 5. Results

##### 5.1. RAP Asphalt Content

As shown in Table 1, the mean values of ten samples of asphalt content for the RAP material using ignition and centrifuge methods were 4.38% and 3.1%, respectively. The obtained asphalt content in the centrifuge method was underestimated because some asphalt remained in the voids of the aggregates; however, the asphalt content obtained from ignition method was overestimated because some of the mineral aggregates were burnt off. As a result, the asphalt content obtained from the centrifuge method was lower than that obtained from the ignition method. The average value of the means of the two mentioned methods, which was 3.74%, was taken. The asphalt content of the RAP was decreased compared to original asphalt content, which was 4.6%. Based on the study of (NJDOT, 2009), the percentage of the RAP that should be used was 50% when the ignition method was used



because the standard deviation was 0.14 that was less than 0.3; while, the percentage of the RAP that should be used was 30% when centrifuge method was used because the standard deviations of the centrifuge method was 0.37 that between 0.3 and 0.4. Therefore, 40% of the RAP was used as an average value.

### 5.2. Characterization of RAP Aggregate

Figure 1 shows the comparison of the aggregate gradations extracted from ignition and centrifuge methods. However, the aggregate gradation lines indicate that there is no significant difference between the gradations of the aggregates, the average values of the gradations can be considered as the gradation of the RAP material.

Table 2 shows the types of specific gravity of the RAP aggregate extracted from ignition and centrifuge method. All types of the coarse and fine aggregates specific gravities obtained from ignition method were higher than the aggregate specific gravities obtained from the centrifuge method; however, the differences are slight. Because all of the asphalts in the coarse and fine aggregate voids were burnt in the ignition method, the absorption value in the ignition method was higher than the absorption value in the centrifuge method.

Because the aggregates in the ignition method was burnt and weakened, the aggregate weight loss in the ignition method was higher than the aggregate loss in the centrifuge method. As shown in the Table 3, the weight loss of the aggregates using both mentioned methods are acceptable for road construction because the weight losses are less than 30%.

The flaky and elongated aggregate particle test showed that 2.73% of the aggregate particles' weight were flaky and elongated, which is appropriate for using in the Superpave mixture design because it is less than 10%. The angularity of the coarse aggregate was 88.23%, which is acceptable to be used for Superpave mixture because for the particles having 10 mm or greater diameter and for 3 to 10 ESAL, the percent of angularity should be greater than 60.

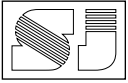
### 5.3. Conventional Asphalt Binder Tests for the RAP and Blends

Table 4 shows the results of the conventional asphalt binder tests for the RAP, virgin, and blends with and without additive materials. The grade of the RAP binder was 20/30 because aging hardened the asphalt binder of the RAP material. The grade of the virgin asphalt that blended with the RAP binder was 60/70, which changed the RAP and virgin blend grade to 40/50. As the percentage of the additive materials increased, the penetration of the asphalt binder decreased. Blending of the virgin asphalt changed the ductility of the RAP binder from 110 cm to 127 cm. The ductility of the blends with additive materials decreased with increasing the percentage of the additive materials. Regarding the elastic recovery, the additive materials increased the reclaimed blends elastic recovery differently. Different SBS content roughly had the same effect on the elastic recovery of the blends, the elastic recovery of the reclaimed blend was increased from 0.07 to 0.8 after mixing with additives. As the percentage of the additive materials increased, the softening points of the blend increased. The specific gravity of the reclaimed blend was not changed significantly when the SBS, PP, CR materials were added. The flash and fire point temperatures increased when the percent of the PP additive material was increased to the blend; however, the flash and fire point temperatures decreased when the percent of the SBS and CR additive materials increased.

### 5.4. Superpave Mix Design

Figure 2 shows the three blends of aggregate gradations consisting 40% RAP and 60% new aggregates that were prepared to select the best one that meet the gradation requirements of Superpave mixture design.

Two samples were taken for each blend to find Gmm and Gse and the average value were taken. Table 5 shows volumetric analysis results and Superpave mixture design criteria for aggregate nominal size of 19 mm. The blend 1 was selected because it was passed from the criteria; however, blend 2 and 3 were not selected because their VMA were smaller than 13%.



The coarse-aggregate angularity for blend 1 was 92.42%, which was greater than the required coarse-aggregate angularity 90% for the particle size greater than 10 mm. The percentage of flat and elongated particles of coarse aggregate was 2.7, which is smaller than 10 %. The Los-Angeles and impact tests for aggregate blend 1 were 18.26% and 20.89%, respectively. Table 6 shows the results of the volumetric analyses of the reclaimed asphalt binder with and without using additives at the optimum asphalt content.

The results of the ITSR for the conditioned and unconditioned sample mixtures are shown in Table 7. Most of the mixtures ITSR were greater than 80%, while only two mixtures were sensitive to moisture conditions that were the mixtures containing 3% SBS and 7% PP. The highlighted cells in the table show the best obtained ITSR for each additive material, which were 7% SBS, 3% CR, and 5% PP that had 99.71%, 97.1%, and 90.7%, respectively. The blends with optimum moisture sensitivity were taken for future analyses conducting Superpave tests for their binder.

### 5.5. Superpave Asphalt Binder Tests

Table 8 shows the results of the PG tests for the selected reclaimed asphalt binder blends. As shown in the table, the average seven-day maximum design temperature of the reclaimed asphalt pavement binder without using additive material was 64 °C, while the temperatures raised after blending with additives. SBS additive material with 7% affected the blend more than the PP and CR additives. The SBS could raise the maximum temperature to more than 88 °C, while 5% of PP and 3% of CR raised the maximum temperature to 82 and 76 °C, respectively. Regarding the low temperature grades, 3% CR changed the temperature from -22 to -28 °C; while 5% PP raised the temperature to -16 °C.

### 6. Conclusion

The characteristics of the RAP and blended mixtures were evaluated and summarized as follows:

- The asphalt content average value of the RAP mixture was 3.75% using centrifuge and ignition

methods; however, the original mixture was designed for 4.6% of asphalt content.

- Standard deviation of the RAP asphalt content determined the allowable percentage of RAP to be mixed in a new HMA that was 40% of RAP and 60% of new asphalt mixture.

- The more additive materials of SBS, CR, and PP were added to the blended asphalt binder, harder asphalt grades were obtained.

- However, mixing additive materials did not change specific gravity of the blended binders significantly, they affected the elastic recovery of the blends; for example, approximately 80% of the elastic recovery was obtained when 7% of SBS was used. The other two additives had less effects on the elastic recovery of the asphalt binder.

- Using additive materials was beneficial for the reclaimed mixtures regarding moisture sensitivity.

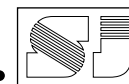
- The best obtained ITSR for each additive material were 7% SBS, 3% CR, and 5% PP that had 99.71%, 97.1%, and 90.7%, respectively.

- The PG of the blended reclaimed asphalt binder with no additive materials changed from 64 -22 °C to PG of over 88-22 °C for 7% SBS, PG of 76-28 °C for 3% CR, and PG of 82-16 °C for 5% PP.

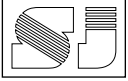
- Based on the results of the PG of asphalt binders' blends, it is recommended to use 7% of SBS in the reclaimed asphalt mixtures for hot climates because it obtains better rutting resistance; however, for cold climates 3% of CR is recommended to be used because it obtains better thermal cracking.

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## تقييم خصائص مواد رصف الإسفلت المعاد تدويره (RAP) مع وبدون استخدام المواد المضافة

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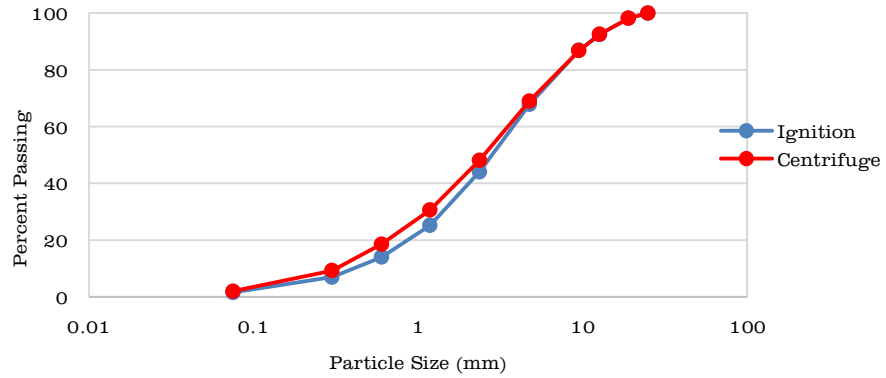
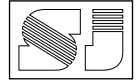
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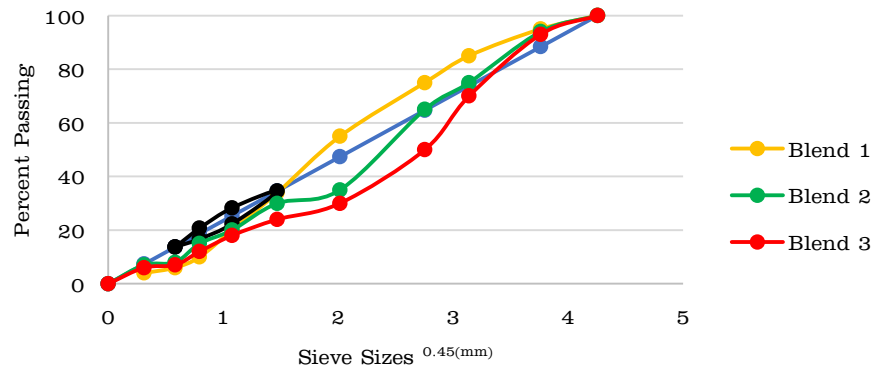
### المستخلص

في الوقت الحاضر ، يتم استخدام الإسفلت المعاد تدويره كخلطه اسفلتيه حارة (HMA) لأن له فوائد اقتصادية وبيئية. تم إجراء هذه الدراسة كمحاولة للحفاظ على موارد الركام الخام وتوفير الأموال. لتقييم خصائص ركام الإسفلت المعاد RAP ، تم إجراء العديد من الاختبارات التي تشمل التدرج ، الكثافة ، الشكل ، الاستطالة والتفلطح ، التاكل ، الصدمة ، ( Coarse Aggregate ) CAA ، Flat and Elongation (F&E) ، Angularity Los Angeles ، تم استخدام ثلاثة أنواع من ( Abrasion (LA ، و impact test . تم استخدام ثلاثة أنواع من المواد المضافة ، وهي CR ، SBS ، و PP ، مخلوطة مع خلطات الإسفلت المعادة بثلاث نسب مئوية مختلفة هي 3% ، 5% ، و 7% . تم إجراء اختبارات الأسفلت التقليدية للأسفلت القديم والمعدل بالإضافة. مع زيادة النسبة المئوية للمواد المضافة ، انخفض penetration and ductility للخلاطات الإسفلتيه. ازدادت elastic recovery للخلاطات الاسفلتيه من حوالي 7% إلى 80% عند استخدام نسب مختلفة من مادة SBS . مع زيادة النسبة المئوية للمواد المضافة ، زادت نقاط الليونة للخلاطات. لم تتغير الكثافة النوعية للخلاطات المعادة بشكل ملحوظ بعد إضافة المواد المضافة. زادت درجات نقطة الوبيض ونقطة الاحتراق عند زيادة نسبة المواد المضافة PP إلى الخليط ؛ ومع ذلك ، انخفضت درجات نقطة الوبيض ونقطة الاحتراق عند زيادة نسبة المواد المضافة SBS و CR . بناءً على الانحراف القياسي لمحتويات الأسفلت RAP ، تم اختيار مزيج الخليط ليكون 40% اسفلت معاد RAP و 60% خلطة جديدة. تم خلط الاسفلت RAP القديم مع الإسفلت الجديد من نوع 70/60 درجة. تم إجراء خلطات حسب تصميم Superpave لإيجاد أفضل محتوى للأسفلت ومعرفة تأثير المواد المضافة على حساسية الخلاطات للماء. إضافة المواد المضافة يفيد الخلاطات المعادة فيما يتعلق بحساسية الماء . نسبة المواد المضافة الأكثر فائدة على حساسية الخلاطات المعادة للماء كانت 7 % SBS ، 3 % CR ، و 5 % PP الحصول على 99.71% TSR ، 97.1% ، و 90.7% على التوالي. تم اختبار نسبة المواد المضافة الأكثر فائدة للأسفلت المعاد مع الإضافات للمزيد من الاختبارات باستخدام اختبارات الأداء Superpave . غيرت المواد المضافة PG للأسفلت المعاد بدون مواد مضافة من 64 - 22 درجة مئوية إلى PG أكثر من 88 - 22 درجة مئوية باستخدام 7% من SBS ، PG الى 76 - 28 درجة مئوية باستخدام 3% من CR ، و PG الى 82 - 16 درجة مئوية باستخدام 5% من PP . نوصي باستخدام 7% من SBS في خلطات الإسفلت المعاد للمناخات الحارة ، و 3% من CR للظروف المناخية الباردة.

**الكلمات المفتاحية:** الأسفلت المعاد تدويره، ستيرين بوتادين - ستايرين ، البوليبروبيلين ، المطاط الفتات ، درجة الأداء ، تأثير الرطوبة.



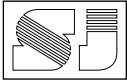
**Figure 1: Comparison of the gradations of the RAP aggregates extracted by the centrifuge and ignition methods.** (Source: Researcher)



**Figure 2: Trial gradations for the three blends.** (Source: Researcher)

**Table 1. Average value of asphalt contents of RAP samples.** (Source: Researcher)

Sample No.	% Asphalt Content Ignition Method	% Asphalt Content Centrifugal Method
Mean	4.38	3.10
Avg.	3.74	
SD	0.14	0.37



**Table 2: Specific gravity types of RAP aggregate.** (Source: Researcher)

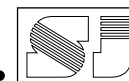
Description	Coarse Aggregate		Fine Aggregate	
	Ignition	Centrifuge	Ignition	Centrifuge
Apparent Sp.G	2.708	2.644	2.453	2.456
Bulk Sp.G	2.574	2.552	2.408	2.420
Effective Sp.G	2.641	2.598	2.427	2.435
Water Absorption	1.919	1.355	0.766	0.610

**Table 3: LA and Impact of RAP aggregate.** (Source: Researcher)

Description	Centrifuge	Ignition
LA	18.9 %	23.7 %
Impact	21.9 %	28.1 %

**Table 4: Asphalt binder results.** (Source: Researcher)

Binder Type	Additive %	penetration	Ductility	Softening Point	Specific Gravity	Flash Point	Fire Point	Elastic Recovery
RAP	-	22.40	110.0	56.50	1.07	255	293	0.07
virgin	-	63.07	135.0	49.55	1.06	240	274	0.06
blend	-	43.20	127.3	52.35	1.07	248	287	0.07
SBS	SBS 3%	33.97	72.5	62.43	1.06	273	285	0.73
	SBS 5%	29.43	68.1	77.78	1.06	247	269	0.78
	SBS 7%	25.40	53.9	88.00	1.05	242	263	0.80
PP	PP 3%	36.40	10.1	57.60	1.08	210	220	0.20
	PP 5%	26.60	3.5	65.30	1.08	288	316	0.12
	PP 7%	26.80	3.0	73.05	1.08	307	319	0.13
CR	CR 3%	41.70	10.6	54.70	1.07	244	268	0.20
	CR 5%	38.53	8.1	55.68	1.07	224	257	0.35
	CR 7%	37.10	8.5	59.38	10.71	223	259	0.46

**Table 5: Volumetric properties summary for the three blends.** (Source: Researcher)

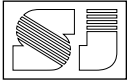
Description	Blend 1	Blend 2	Blend 3	Criteria
Avg. Gmm	2.399	2.393	2.407	-
Avg. Gse	2.540	2.533	2.549	-
OAC %	5	4.9	4.4	-
VMA %	14	12.7	12.9	> 13
VFA %	66	69	69.7	65 - 75
Gmm at Nini %	87	86	85	< 89
Gmm at Nmax %	98.4	95.7	95.2	-
D/B	0.87	0.84	0.76	0.6 - 1.2

**Table 6: Optimum asphalt content and volumetric properties for the mixtures.** (Source: Researcher)

Mixture Types	OAC %	VMA %	VFA %	Gmm at Nini %	D/B
Designed	5	14	67	87.1	0.87
SBS 3%	6	16.3	76.5	87.7	0.7
SBS 5%	5.65	13.45	74	86.7	0.75
SBS 7%	6.2	16.64	75	87.5	0.67
CR 3%	5.75	15.8	74	86.4	0.71
CR 5%	6.25	16	73	86.4	0.7
CR 7%	6.5	16.7	75.93	87.2	0.65
PP 3%	6.2	16.1	75	86.1	0.69
PP 5%	6.45	16.75	75	87	0.65
PP 7%	6.4	16.7	75.1	87.3	0.65

**Table 7: Average value for the ITSR of conditioned and unconditioned mixtures.** (Source: Researcher)

Type	Conditioned		Unconditioned		ITSR
	Load, KN	S1, KPa	Load, KN	S2, KPa	
Blended	13860	1410.45	16867	1716.46	82.17
SBS 3%	13036	1316.50	16485	1664.82	79.08
SBS 5%	13210	1339.17	14533	1473.29	90.90
SBS 7%	12945	1297.23	12983	1301.04	99.71
CR 3%	12003	1183.65	12361	1218.96	97.10
CR 5%	12292	1216.86	13188	1305.56	93.21
CR 7%	10621	1057.36	12113	1205.89	87.68
PP 3%	12499	1262.27	14714	1485.96	84.95
PP 5%	15421	1552.69	17001	1711.77	90.71
PP 7%	12594	1269.45	16675	1680.81	75.53



**Table 8: Performance grade of asphalt binder.** (Source: Researcher)

<b>Blend with no additives</b>			
<b>Properties</b>	<b>Specification</b>	<b>PG (T) C°</b>	<b>Measured value</b>
Original DSR, G*/sin δ	≥ 1.0 KPa	64	1.69
RTFO DSR, G*/sin δ	≥ 2.2 KPa	70	3.39
S @ 60/sec Mpa	Max. 300 MPa		149.476
m Value @ 60/sec	Min. 0.3	-22	0.312
Grade (PG)			64 - 22
<b>Blends with 7% SBS</b>			
<b>Properties</b>	<b>Specification</b>	<b>PG (T) C°</b>	<b>Measured value</b>
Original DSR, G*/sin δ	≥ 1.0 KPa	over 88	1.8
RTFO DSR, G*/sin δ	≥ 2.2 KPa	over 88	2.29
S @ 60/sec Mpa	Max. 300 MPa		133.815
m Value @ 60/sec	Min. 0.3	-22	0.323
Grade (PG)			over 88 - 22
<b>Blends with 3% CR</b>			
<b>Properties</b>	<b>Specification</b>	<b>PG (T) C°</b>	<b>Measured value</b>
Original DSR, G*/sin δ	≥ 1.0 KPa	76	1.02
RTFO DSR, G*/sin δ	≥ 2.2 KPa	82	2.41
S @ 60/sec Mpa	Max. 300 MPa		202.036
m Value @ 60/sec	Min. 0.3	-28	0.303
Grade (PG)			76 - 28
<b>Blends with 5% PP</b>			
<b>Properties</b>	<b>Specification</b>	<b>PG (T) C°</b>	<b>Measured value</b>
Original DSR, G*/sin δ	≥ 1.0 KPa	82	1.34
RTFO DSR, G*/sin δ	≥ 2.2 KPa	88	3.72
S @ 60/sec Mpa	Max. 300 MPa		128.000
m Value @ 60/sec	Min. 0.3	-16	0.301
Grade (PG)			82 - 16