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Effects of Additive Materials on Indirect Tensile Strength and Moisture Sensitivity of Recycled Asphalt Pavement (RAP)

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Abstract

Using reclaimed asphalt pavement with additives as part of new road construction has economic and environmental advantages. As an attempt to preserve aggregate resources and save money, and knowing the effects of the selected additive materials, this study was done in Sulaimani City. The samples of the RAP were selected from the Sulaimani municipality stockpiles. The ignition and centrifuge testing machines were used to separate the aggregate and binder of the RAP. Based on the standard deviation of the obtained asphalt content, the blend was decided to be 40% RAP and 60% new material. The aggregate tests were conducted to evaluate the characteristics of the PAR aggregate. The performance grade test was done for the reclaimed asphalt binder. Three types of additives, which were Styrene Butadiene-Styrene (SBS), Crumb Rubber (CR), and Polypropylene (PP), mixed with the reclaimed asphalt binder with three different percentages of the binder which were 3%, 5%, and 7%. Indirect Tensile Strength (ITS) test was performed to the conditioned and unconditioned mixtures. To evaluate the effects of additives on the moisture sensitivity of the reclaimed mixtures, ITS Ratios were obtained. Most of the percentages of additives decreased the ITS of the conditioned and unconditioned samples. The only percentage of the additive material increased the ITS was 5% of PP in conditioned case. However, additives did not benefit the ITS, they benefited the ITSR greatly. 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.

Keyword: RAP, Styrene Butadiene–Styrene (SBS), Crumb Rubber (CR), Recycled Atactic Polypropylene (PP), Performance Grade (PG), Indirect Tensile Strength, Moisture Sensitivity.

1. INTRODUCTION

Recycling of asphalt pavement, which is a developed technique to rehabilitate pavement structures having permanent deformation and evident structural distress, dates back to the early 1900s [1]. The first data on the use of reclaimed asphalt pavement were documented in 1915 [2]. The cost of asphalt binder was raised during oil crisis in 1970's; therefore, using of RAP became an interesting subject [3]. Based on the numerous agencies and organizations' experiences, the National Cooperative Highway Research Program (NCHRP) published Synthesis of Highway Practice No. 54, and Recycling Materials for Highways and Report No. 224, Guidelines for Recycling Pavement Materials in 1978 and 1980 [1]. Recycling of asphalt pavement was becoming great attention in highway industry after implementing the Kyoto Protocol in 2005[4]. Increasing oil price made engineers and organizations to implement recycled asphalt pavement in highway constructions. Using RAP does not only have economic benefit, it also has environmental benefits by protecting petroleum and aggregate resources and saving landfill space. Nowadays, the waste materials of road construction have been increasing and they have impacts on environment. Based on the reporting of some municipalities, every year 400,000 tons of recycled materials used in this manner. [5]. Hot recycling, in which virgin materials and RAP are combined, is the most widely techniques that is used for mixing RAP in new HMA [4]. The percentage of blended RAP with new asphalt mixture are determined based on the production process, paving technology and the RAP properties, [6]. In many cases, specifications do not let engineers to use high percentages of RAP. Currently, the amount of RAP used is normally not exceed 25% [1].

Today, polymerized asphalt, which consists of blending additives with asphalt binder, are used to improve the essential properties of asphalt cement binders. Also, polymer modified binders are used to improve the performance of asphalt mixtures such as rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility. In addition, mixing small amounts of polymer dramatically modifies the rheological properties of the asphalt binder [7]. Additives such as SBS, crumb tire, and polypropylenes are among the additives that are used to improve properties of HMA and RAP binders and mixtures.

The most commonly used polymer is SBS, which increases rutting resistance and decreases the fatigue resistance of the recycled polymer modified asphalt pavement mixtures [8]. On the other hand, using SBS polymer modified binder in RAP mixture increases resistance to fracture failure from the semi-circular notched fracture test [9].

Crumb Rubber (CR), which is an elastic binder additive, reduces cost of pavements and solves waste disposal-problem. Dry and wet techniques can be used for blending CR with new HMA. The CR is blended with the aggregates of the mixture in a dry process, while it is blended with asphalt binder in the wet process [10]. Adding ground CR to asphalt binder results in increasing both the linear viscoelastic modulus and the viscosity at high in-service temperatures [11]. Based on the results of Cao W. study, adding recycled CR to asphalt mixtures in a dry process improves the engineering properties of asphalt mixtures, and the rubber content has a considerable effect on resistance of permanent deformation and cracking [12]. Moreover, adding CR increases the mineral aggregate voids in the Superpave mix design, as well as, improves the rutting resistance of asphalt mixtures [13]. The study of Oliver JWH et al. mentioned some positive effects of CR in asphalt pavement such as reducing reflective cracking and low-temperature cracking, increasing fatigue life, and improving tensile strength [14].

Another appropriate additive material that are used with asphalt binder and mixture is Polypropylene (PP). It has many benefits such as appropriate process ability, integral hinge property, low density, low cost, high softening point and good mechanical properties. The application of using polypropylene is somehow limited because it relatively has moderate fracture performance, particularly at sub ambient temperature [15],[16].

Putman, B. J. et al. in 2005 evaluated the performance of 9.5 mm thick pavement using Superpave mix designs containing reclaimed asphalt pavement. Two aggregate types in different resources were used to design twelve asphalt concrete mixtures. The three-tire concept, which was 15% in the first time and more than 25% in the third time, was used. CR was added to the each of the mixtures. Conclusively, the rutting resistance of the mixtures was improved; however, the ITS of the mixtures containing RAP was not affected. In addition, the mixtures with CR binder modifier increased the obtained higher rutting resistance than the mixtures with no CR, while CR did not significantly affect the ITS or moisture susceptibility [17].

F. Xiao and S. N. Amirkhanian in 2009 investigated the moisture susceptibility of Rubberized Asphalt Concrete (RAC) containing RAP material. The tests, which were conducted, were viscosity of the asphalt binder, toughness and ITS. Several mixtures with different CR types, two different sources of RAP materials, and various rubber and RAP percentages were evaluated. Adding RAP materials improved the ITS values and reduced the moisture susceptibility of the mixture; however, adding CR to the mixture had a slightly negative impacts on the mixtures [13].

Kim S. et al. in 2009 used Asphalt Pavement Analyzer (APA) and the Indirect Tensile Tests (IDT) to investigate the performance of rutting and cracking of SBS polymer-modified asphalt mixture mixed with RAP. Different percentages of RAP were used, which were 0%, 15%, 25%, and 35%. Regardless of the amounts of RAP materials in HMA, the RAP mixtures with SBS modified binders worked well [18].

Reyes-Ortiz et al. in 2012 evaluated the mechanical responses of dense-graded HMA mixtures after partial, and then total replacements of aggregates by recycled asphalt material and using asphalt binder grades of 60/70 and 80/100. Four different percentages of 15%, 20%, 35%, and 100% of recycled asphalt material were replaced the granular materials. The values of the highest ITS and resilient modulus in both wet and dry conditions were obtained from the HMA mixtures that produced with 100% replacement of granular material by RAP material [4].

Ahmed, N. G., and Qasim, H. A. in 2017 studied fatigue and moisture susceptibility characteristics of RAP mixtures in Iraq. Four different percentages of recycled asphalt material of 0%, 5% ,10%, and 15% were blended with asphalt binder of grade 40/50. The experimental tests, which include four point repeated load and Indirect Tensile Strength tests, indicated that the inclusion of RAP materials improved fatigue properties of HMA mixtures; fatigue life (Nf) at recycled asphalt pavement material content of (15%) increased by (157.1%), (100%), and (150%) at testing temperature 25, 10, and 40°C respectively. The modified Lottman test indicated that HMA with RAP and additive material had a great resistance to moisture damage through increasing the indirect tensile strength. Based on the four-point repeated load and IDT tests, the amount of new binder that needed to be mixed with the RAP mixture can be reduced because it does not have significant effects on the quality of the produced mix [19].

Yan Y. et al. in 2017 prepared fourteen mixtures of reclaimed asphalt pavement 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, the mixtures had higher tensile strength, lower failure strain, and lower fracture energy. 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 showed dissipated creep strain energy to failure values above 0.75 kJ/m3 and energy ratio values above one [20].

Wang J. et al. in 2017 evaluated the effect of rejuvenating agent on different modified RAP contents (0%, 30%, 50% and 70%) mixtures. Three tests, which included freeze-thaw split, semi-circular bending, and dynamic modulus, were conducted for the reclaimed RAP. The rejuvenating agent was assessed whether improve the properties of aged modified asphalt or not. It was realized that using the rejuvenating agent in the modified asphalt for the RAP had negative effects on moisture susceptibility and low-temperature cracking resistance, especially when high agent content was used. The dynamic modulus of recycled and HMA mixtures tended to be consistent when loading frequency reached a higher value [21].

J. Wang et.al. in 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°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 [22].

D. Singh et.al. in 2018 evaluated fracture properties of asphalt mixture at intermediate temperature, as well as moisture sensitivity of asphaltic mixture containing recycled asphalt pavement and Warm Mix Additive (WMA). Five different RAP contents, which were 0%, 10%, 20%, 30%, and 40%, were used. Two different types of WMA additives with two different percentages were considered that were 2% wax based “Sasobit” and 0.5% chemical based “Evotherm”. Also, a mixture, which was without WMA additive was considered. The fracture properties of different asphalt mixtures were assessed using a test known as semicircular bending test. The fracture property of the mixture with no WMA additive was improved with increasing the recycled asphalt material content. On the other hand, the addition of chemical-based and wax-based WMA additives exhibited an overall reduction in fractured resistance. Moreover, the asphalt mixture with wax-based WMA additive showed better fracture performance compared to the corresponding mixture with chemical-based WMA additive. At the same time, adding of both WMA additives decreased the ITS under both dry and wet conditions. Also, adding WMA additive exhibited a negative effect on moisture sensitivity of the mixtures [23].

2. METHODS AND MATERIALS

In order to take the RAP material samples, six samples in different locations in the stockpiles of Sulaimani municipality were taken, and then mixed. The stockpiles were used to store the recycled asphalt material obtained from cold milling process in different streets in Sulaimani City. In order to avoid taking contaminated RAP with rubbish and other unwanted waste materials, care was taken during sampling process. The pavement ages, taken from streets, were 15 to 20 years old with asphalt content of 4.6% and asphalt grade of 50/60.

To know the asphalt binder content in the RAP mixture, two methods were used to extract it, which were ignition and centrifuge methods. In each method, ten samples of two kilograms were taken, and then the mean value was considered as the asphalt binder content of each of them. The average value of the mean values of ignition and centrifuge methods was taken as the final result of the asphalt binder content of the RAP.

Based on the standard deviation of the asphalt binder content obtained from the ignition and centrifuge method, the percentage of the RAP material mixed with the new hot mix asphalt was determined.

The RAP aggregates obtained from the ignition and centrifuge methods were evaluated and compared to the Superpave specification design. Many tests were done for the RAP aggregate that were sieve analysis, Los-Angeles abrasion, impact resistance, specific gravity, angularity, sand equivalent, and flaky and elongation tests. The same tests were done for the new and blended aggregates, too.

After obtaining the aged binder, performance grade tests were done for the aged and RAP asphalt binder. Short and long-term aging were done for the samples by using Rolling Thing Film Oven Test (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.

To compensate the hard grade of the aged asphalt binder in the recycled asphalt material, softer virgin binder was used that was 60/70 grade. Three percentages of 3%, 5%, and 7% were mixed with the RAP. The additive materials were styrene butadiene–styrene (SBS), crumb rubber (CR), Polypropylene (PP).

Three aggregate gradations were designed for the blended aggregates of new and RAP aggregates, and then were analyzed volumetrically. The best aggregate blend was chosen to be used as Superpave mixture design. Two tests of maximum theoretical specific gravity (G_{mm}) tests were done and the average value was taken. Based on the G_{mm}, the effective specific gravity (G_{se}) of the selected aggregate blend was obtained. Superpave gyratory compactor device was used to prepare 50 samples of the mixtures to find the optimum asphalt content for the reclaimed asphalt mixtures with and without using additive materials. Thirty unconditioned samples with and without additive materials, which were designed for 7% air voids, were prepared to find the indirect tensile strength. To evaluate moisture sensitivity of the mixtures, thirty conditioned samples prepared and tested for the indirect tensile strength. The ratio of the indirect tensile strength obtained from the conditioned samples to unconditioned samples indicated the effects of moisture sensitivity of the mixtures.

3. RESULTS

3.1. RAP Asphalt Content:

The mean values of the ten samples of asphalt content for the RAP material extracted from ignition and centrifuge methods were 4.4% and 3.1%. 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; therefore, the average value of the asphalt binder content of the two methods was considered as the final RAP asphalt content, which was 3.75%. Because of lighting and volatilization during asphalt pavement service, the asphalt content of the RAP was decreased compared to original asphalt content, which was 4.6%. Based on the study of (NJDOT, 2009), [24], 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 deviation of the centrifuge method was 0.37 that it was located between 0.3 and 0.4. Therefore, 40% of the RAP was used as an average value.

3.2. Characterization of RAP Aggregate:

After drawing the gradation lines for aggregates obtained from ignition and centrifuge methods, it was realized that there is a slight difference between them as shown in Figure 1.

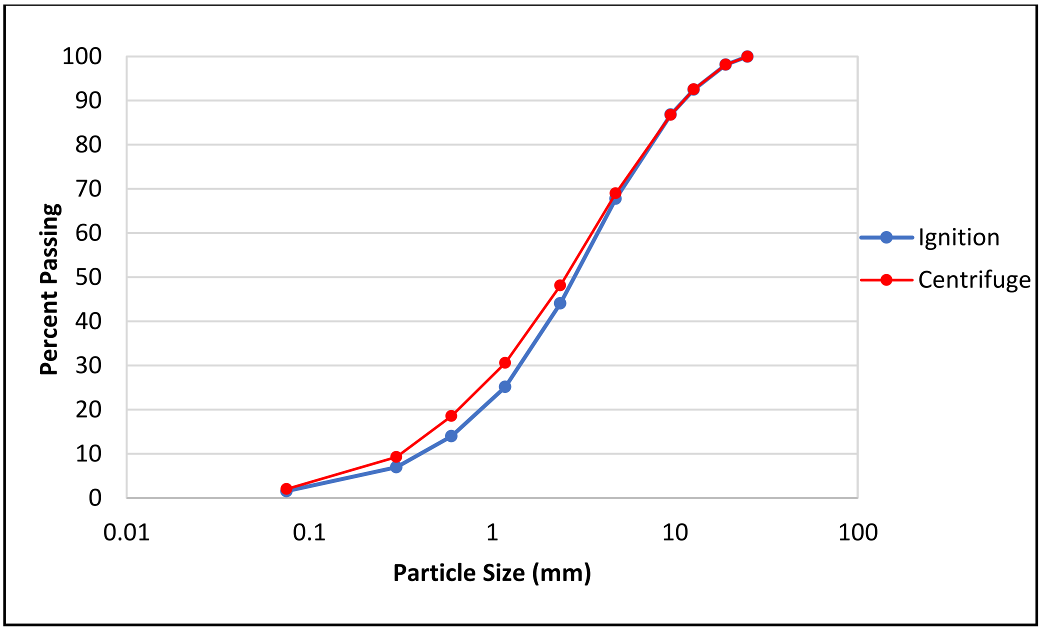

Figure 1: Comparison of the gradations of the RAP aggregates extracted by the centrifuge and ignition methods

Despite the slight difference between the specific gravities of the aggregates obtained from the ignition and centrifuge methods as shown in Table 1, all types of the coarse and fine aggregates specific gravities obtained from ignition method were higher than the values obtained from the centrifuge method; since all of the asphalts in the coarse and fine aggregate pores were burnt in the ignition method, the absorption value in the ignition method was higher than obtained from the centrifuge method.

Table 1: Specific gravity types of RAP aggregate

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

The aggregates in the ignition method was burnt and weakened; therefore, the aggregate weight loss of the ignition method was higher than the aggregate loss in the centrifuge method in the LA and impact tests. As shown in the Table 2, the weight loss of the aggregates using both mentioned methods are acceptable for road construction because the weight losses are less than 30%.

Table 2: LA and Impact of RAP Aggregate

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

The percentage of the flaky and elongated aggregate particle in the RAP was 2.73%, 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 also is acceptable to be used for Superpave mixture because for the particles have 10 mm or greater diameter and for 3 to 10 ESAL, the percent of angularity should be greater than 60.

3.3. *Performance Grade Test for Rap and Blended Asphalt Binders With no Additives*

The blends of 40% RAP with 60% virgin asphalt binder performance grade test results are shown in Table3. 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 low temperature grade is -22. As a result, the performance grade of the blended reclaimed asphalt binder is P 64-22.

Table 3: Performance grade of asphalt binder

40% of aged and 60% of New Asphalt Binder			
Properties	**specification**	**PG (T) C°**	**Measured value**
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	-22	149.476
m Value @ 60/sec	Min. 0.3		0.312
Grade (PG)		64- 22	

3.4 *Superpave Mix Design:*

To obtain the best aggregate gradation for the Superpave mixture design, three aggregate gradations were prepared and graphed. Figure 2 shows the results of the graph of power 0.45 for the three trials of gradations that designed for the blends consisting 40% RAP and 60% new aggregates

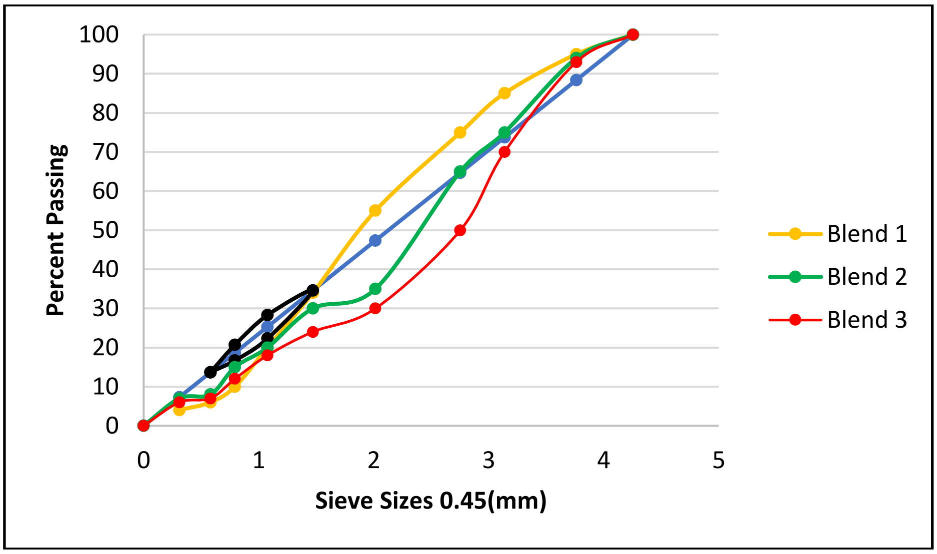

Figure 2: Trial gradations for the three blends

For each of the blends, two samples were taken to find Gmm and Gse, and then the average value were taken as shown in Table 4. After finding the optimum asphalt content for each of the blends, volumetric analyses were done in order to evaluate the trail blends. Then the results of the volumetric analyses were compared with the Superpave mixture design criteria for aggregate nominal size of 19 mm. Because blend 1 had the best results regarding the Superpave mixture design criteria, it was selected as the gradation that was used for preparing the mixtures. Blends 2 and 3 were not selected because their VMA were smaller than 13%. The specific gravity types and water absorption of blend 1 were found as shown in Table 5.

Table 4: Volumetric properties summary for the three blends

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 5: Specific gravity of blend 1 aggregate

Description	Coarse aggregate	Fine aggregate
Apparent Sp.G	2.669	2.551
Bulk Sp.G	2.540	2.472
Effective Sp.G	2.604	2.503
Water Absorption	1.914	1.266

Other tests that are needed as the requirements in the Superpave mixture design requirement were conducted for the blend 1, too. The coarse-aggregate angularity was 92.42%, which was greater than the required coarse-aggregate angularity 90% for the particle size greater than 10mm. 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 optimum asphalt content and volumetric property analyses of the RAP mixtures with and without using additive materials.

Table 6: Optimum asphalt content and volumetric properties for the mixtures

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

The results of the ITS for the unconditioned sample mixtures are shown in Figure 3. As shown in the figure, when the ratios of additive materials of SBS, and CR were increased, the ITSs were decreased. Using PP additive material decreased the ITS, too; however, when 5% of PP was used, a little difference was occurred in ITS.

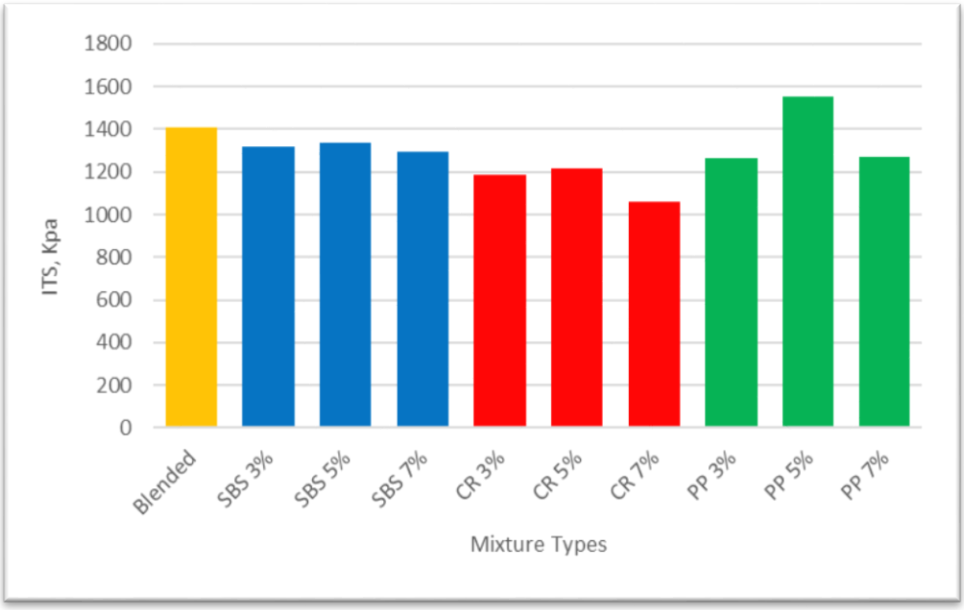

Figure 3: Unconditioned Indirect Tensile Strength vs. Mixture Types

The results of the ITS for the conditioned sample mixtures are shown in Figure 4. As shown in the figure, when the ratios of additive materials were increased, the ITSs were decreased. The only percentage of additive materials that caused increasing ITS in conditioned case was 5% of PP.

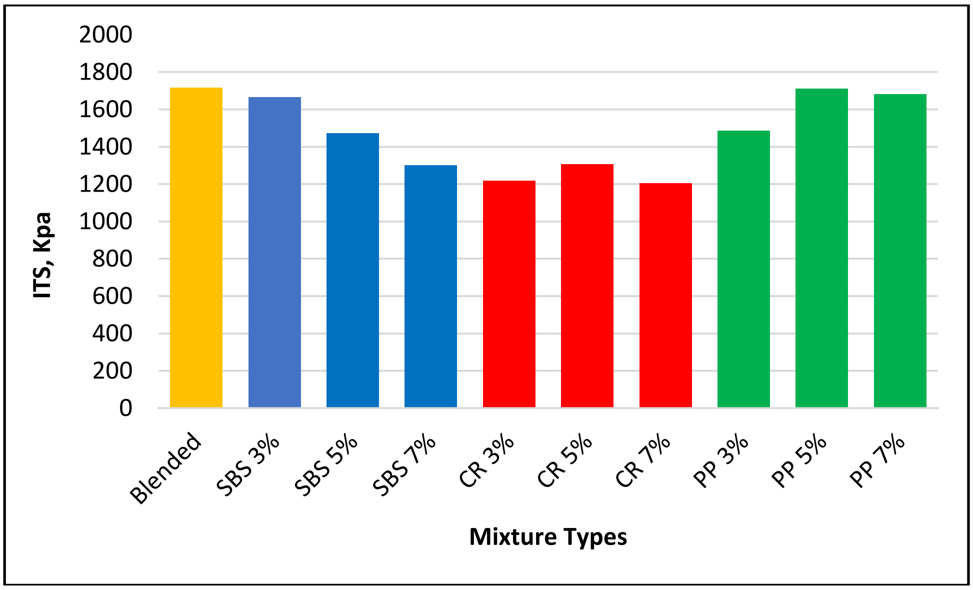

Figure 4: Conditioned Indirect Tensile Strength vs. Mixture Types

Regarding the ITSR, Table 7 shows that 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.

Table 7: Average value for the ITSR of conditioned and unconditioned mixtures

Type	Conditioned		Unconditioned		TSR
	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

4. CONCLUSION

After using SBS, CP, and PP additive materials in RAP, the following conclusions can be reached regarding ITS and ITSR:

- Despite using additive materials decreased the ITS of the reclaimed asphalt pavements for the conditioned and unconditioned situations, using additive materials benefited moisture sensitivity of the reclaimed asphalt pavements.
- The only percentage of the additive material that benefit the ITS was 5% of PP, which increased the ITS for the conditioned case from 1410 to 1552 KPa, and it caused little change in the unconditioned case. Also, 5% of PP increased the ITSR from 82.17% to 90.71%.
- It can be said that using additive materials did not benefit the ITS; however, they benefited the ITSR greatly, because the ITSs were not decreased greatly in the conditioned situations compared with the unconditioned situations.
- 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.

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