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INVESTIGATION OF THE USE OF RECYCLED ASPHALT CONCRETE MATERIAL TO THE SURFACE LAYERS

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Keywords

Deteriorated asphalt pavement, Flow resistance, Indirect tensile test, Reclaimed asphalt pavement, Stability.

Abstract

In this study, Reclaimed Asphalt Pavement (RAP) were used in Hot Mix Asphalt (HMA) samples, stability and flow resistance and Indirect Tensile Strength Test (IDT) of HMA samples were investigated. Initially, optimum bitumen content of wearing course was determined by Marshall Stability test method and then RAP, 5 to 50 % in terms of total asphalt concrete samples weight was added to HMA samples at the predefined optimum bitumen content. Besides, control samples were performed and compared with the RAP added samples. Test results show that Reclaimed Asphalt Pavement (RAP) can be used in wearing course as an additive in accordance with Turkey General Directorate of Highways (GDH) specification limits. This paper demonstrates that the asphalt mixtures containing RAP performed at least like, or better than, that of conventional asphalt materials.

GERİ KAZANILMIŞ ASFALT BETONU MALZEMESİNİN AŞINMA TABAKASINDA KULLANILABİLİRLİĞİNİN ARAŞTIRILMASI

Anahtar Kelimeler

Akma dayanımı, Bozulmuş asfalt kaplama, Geri kazanılmış asphalt, İndirekt çekme deneyi, Stabilite.

Öz

Bu çalışmada Bitümlü Sıcak Karışım (BSK) numunelerinin içerisine çeşitli oranlarda kazanılmış asfalt betonu malzemesi (RAP) ilave edilerek, Stabilite, Akma ve İndirket Çekme (ITS) dayanımları incelenmiştir. Öncelikle aşınma tabakası için optimum bitüm miktarı Marshall metodu ile bulunmuş ve daha sonra optimum bitüm içeriğinde hazırlanan asfalt betonu numunelerine %5 ila %50 oranlarında RAP ilave edilmiştir. Bunun yanında RAP ilave edilmemiş asfalt betonu numuneler de teste tabii tutulmuş ve sonuçlar karşılaştırılmıştır. Test sonuçları RAP ilave edilmiş BSK numunelerinin stabilite ve akma ve İndirket Çekme Deneyi (ITS) yönünden Karayolları Teknik Şartnamesindeki limitler içerisinde Aşınma tabakasında kullanılabileceğini göstermiştir.

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1. Introduction

In the improvement of deteriorated existing asphalt pavements, bringing the new asphalt reinforcements layers application or instead of reconstruction methods, in place of the damaged asphalt layers materials by recycling it, it seems like it is a better alternative for economical reuse, materials, environment and human's health.

Recycling is one of the most important bases of sustainability. The subject of recycling bituminous pavement attracts attention all over the world because it reduces the consumption of the natural resources, lessens the amount of energy used in the process and overall, decreases the negative environmental effects to a certain extent. (Rorrer et al., 2009; Maupin et al., 2009).

Asphalt recycling has become more important and popular due to its resource saving and economical operation (Widyatmoko, 2006; Brown and Cross, 1989). Asphalt pavement recycling may be highly desirable because it can save materials and is environmentally acceptable (Aravind and Animesh, 2007; Shoenberger and Voller, 1990).

RAP rates between 10% and 30% are commonly used in hot recycled bituminous mixes. According to several studies, with these rates, bituminous mixtures perform similarly to conventional mixtures (Kandhal et al., 1995; Xinjun et al., 2008). However, environmental restrictions are causing an increase in RAP content added to recycled mixtures used in bituminous pavement construction and rehabilitation.

The current normative, e.g., the UK Specification for Highway Works – Clause 902, allows RAP material to be used in the production of asphaltic wearing course, binder course and road base with the maximum amount of 10% in wearing course and 50% in all other layers; additional performance requirements are required when the recycled content exceeds 25% by mass. The Clause has allowed manufacturers to adjust their feedstocks and optimise production and performance within their existing manufacturing plant. For Superpave mixes, the amount of RAP allowed ranged from typically 10–15% for wearing courses (except in the highest volume highways) and up to 50% for other layers (McDaniel and Nantung, 2005). In practice, conventional batch plants (with suitable modifications) can handle up to 15– 20% RAP; above this level of RAP addition, preheating of the RAP may be required; whilst drum mix plants can handle up to 70% RAP.

Five broad categories have been defined by Asphalt Recycling and Reclaiming Association (ARRA) to describe the various asphalt recycling methods (FHA, 2001) These categories are:

- Cold Planning (CP)
- Hot Recycling
- Hot In-Place Recycling (HIR)
- Cold Recycling (CR)
- Full Depth Reclamation (FDR)

Within these five broad categories of asphalt recycling, there are several sub-categories which further define asphalt recycling. These include:

- HIR
    - Surface Recycling (Resurfacing)
    - Remixing
    - Repaving
- CR
    - Cold In-Place Recycling (CIR)
    - Cold Central Plant Recycling (CCPR)
- FDR
    - Pulverization
    - Mechanical stabilization
    - Bituminous stabilization
    - Chemical stabilization

In addition, asphalt recycling methods can be used in conjunction with one another on some roadway rehabilitation projects. For instance, an existing roadway could have an upper portion removed via CP and the resultant Reclaimed Asphalt Pavement (RAP) could be stockpiled at the asphalt plant. The cold planed surface, once prepared, could be overlaid with hot mix asphalt (HMA) containing the RAP from the milled off layer. Alternatively, prior to the placement of the recycled mix, the exposed CP surface could have been HIR, CIR or FDR to mitigate or eliminate the effects of reflective cracking (FHA, 2001).

This paper examines the physical properties of RAP and the influence of RAP on the mechanical properties of a wearing course mix. RAP was introduced into the bituminous mixtures at levels of 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50%, replacing the virgin constituents in the mix (coarse and fine aggregate). Control samples (without RAP) were also manufactured. Both the physical properties of the RAP aggregate and the mechanical material properties of the wearing course mix with the inclusion of RAP were investigated using standard laboratory tests.

1.1. Literature review

Many studies are available on performance evaluation with conventional asphalt mixes (mix without RAP). Therefore, there is a necessity for a study on mechanistic evaluation of hot recycled mixes with and without utilization of recycling agents. Among all the recycling techniques, hot mix recycling techniques have large number of advantages and is well suited for Indian conditions (Mittal et.al, 2010). Some studies indicate that utilization of certain percentage of RAP increases the performance properties of mixes (El-Maaty et al, 2015) and some studies indicates that incorporating certain percentages of RAP there are no significant changes in the performance of mixes (Paul, 1996). Some researchers found that Recycled Mixes have good resistance to moisture damage at low RAP percentages whereas there is no significant increase in resistance to moisture damage with increase in RAP percentage in mix (Huang et al, 2005) and some studies state that resistance to moisture damage significantly decreases with presence of RAP (Huang et al, 2010). Some researchers found that presence of RAP increases the stiffness of the mix (Aravind and Das, 2007) and decreases in some studies (Huang et al, 2010).

1.2. Objective of the study

The main objective of this work is to analyze the behaviour of mixtures with large RAP contents (specifically, 5% to 50%) and compare it with that of conventional mixtures. These percentages were selected based on the Turkey General Directorate of Specifications for Highway Rehabilitation, which define and specify the design requirements of recycled mixtures with RAP contents between 5% to 25%. Therefore, the mixture with 5% to 25% RAP is within the specified acceptable range while the mixture with 30% to 50% RAP is outside this range.

In addition, the objective of the present paper is to evaluate RAP's role and its effect on; bulk density, stability, flow, volumetric properties and the indirect tensile strength of HMA through experimental investigation.

In recent years, new technologies related to construction, maintenance and usage of highways have started to be accepted. One of those new technologies is reusing of bituminous pavements by employing various recycling methods.

2. Material Characterization and Experimental Investigation

This section contains the details regarding the various tests conducted on the aggregates and bitumen (virgin and recovered). The details regarding the rejuvenating agent and its optimization are also described. In addition, it was necessary to undertake testing of the materials to check their suitability for use in the bituminous mixes.

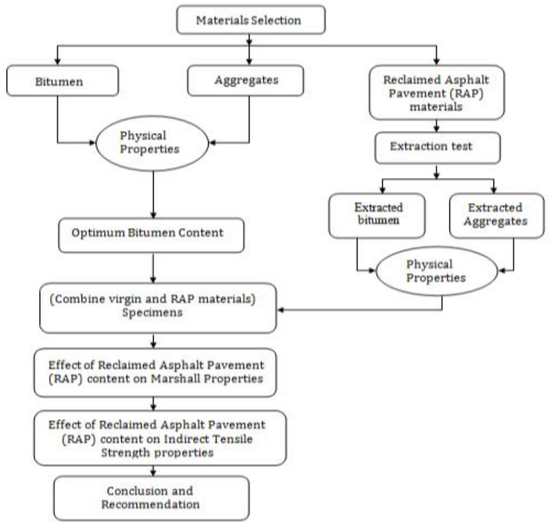

Figure 1. Flowchart of experimental work

2.1. Bitumen

The asphalt cement used in this work is a 50-70 penetration grade. It was obtained from the Isparta Municipality. The bitumen was used for preparing the control mix samples. The properties of the bitumen are reported in Table 1. In addition, extracted bitumen from the RAP materials obtained from Isparta Municipality is given in Table 1.

2.2. Aggregate

The aggregates used in the present study were obtained from Isparta Municipality. The gradation curve for the aggregate is shown in Figure 2. Routine tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits are summarized in Table 2 and 3.

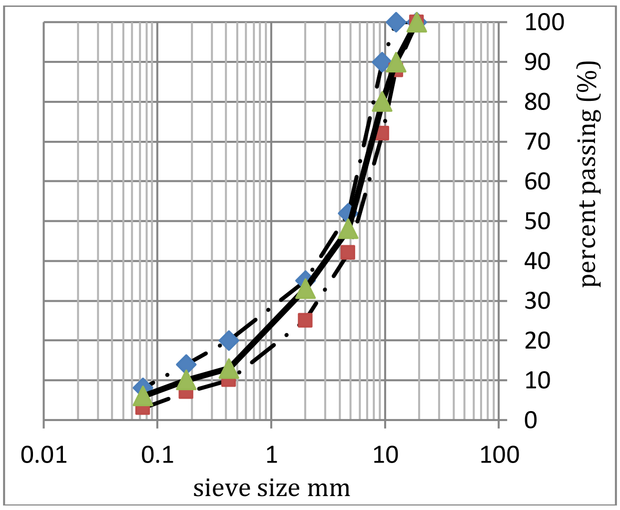

Figure 2. Selected Gradation for Aggregate Used

Table 1. Properties of extracted and virgin Asphalt Cement

Properties	Standards	Test results		TS 1081 EN 12591 B 50/70
		Extracted Bitumen	50/70 Virgin Bitumen	
Penetration at 25°C,100 gm,5 sec. (0.1mm)	TS EN 1426	33	57	50-70
Softening Point. (◦C), R/B, 25°C) °C	TS EN 1427	73.5	50.8	46-54
Specific Gravity	TS 1087	0,976	0,979	0.97-1.06

Table 2. Aggregate Gradation

Sieve Size		Gradation limit for wearing course (%)	Selected Rate (%)	Remainder Aggregate (g)
inch	mm			
¾	19	100	100	0
½	12,5	88 – 100	90	120
3/8	9,5	72 – 90	80	120
N0.4	4,75	42 – 52	48	384
NO.10	2,00	25 – 35	33	180
NO.40	0,425	10 – 20	13	240
NO.80	0,180	7 – 14	10	36
NO.200	0,075	3 – 8	6	48
pan				72
			Total	1200

Table 3. Physical Properties of Mineral Aggregates and Filler (virgin mineral)

Type of material	ASTM designation	Properties	Test results	
			Virgin Material	Extracted Material
Coarse aggregate	(ASTM C 127-88)	Bulk specific gravity, g/cm³	2,64	2,66
		Saturated specific gravity, g/cm³	2,66	2,67
		Apparent specific gravity, g/cm³	2,70	2,71
		Water absorption, %	0,602	0,40
	(ASTM C-131)	Percent wear by Los Angeles abrasion, %	21,57	23,56
Fine aggregate	(ASTM C 128-88)	Bulk specific gravity, g/cm³	2,39	2,45
		Saturated specific gravity, g/cm³	2,49	2,50
		Apparent specific gravity, g/cm³	2,67	2,59
		Water absorption, %	4,4	2,25
Mineral Filler	(ASTM D 854-88)	specific gravity, g/cm³	2,725	2,723

2.3. Reclaimed asphalt pavement (RAP) materials

The RAP samples were collected from Isparta city municipal and binder content of the RAP was determined following the procedure described in ASTM D 2172. A set of five representative samples of RAP were used to determine the binder content which was found to be 4.82% as shown in Table 4. The bitumen was recovered by washing of RAP sample by centrifuge method and subjecting the solution to distillation for the recovery of solvent and further left-over traces were removed by Abson recovery method. The recovered bitumen was tested, and penetration was found to be 33 (0.1 mm units) and softening point as 73.5°C. The relative density of the RAP was also determined using the procedure described in BS 812: Part 2 (1995). Again, five representative samples of RAP were used, and the apparent relative density of the RAP calculated to be 2.39 g/cm³.

Table 4. Bitumen percentage after extraction

Sample No.	1	2	3	4	5	Average
% Bitumen	4,73	4,98	4,92	5,07	4,40	4,82

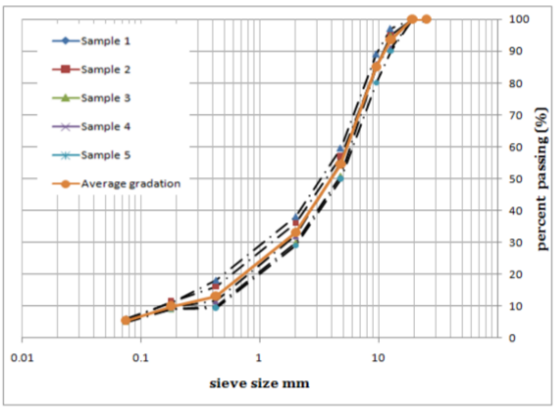

Figure 3. RAP gradation after extraction

2.4. Marshall mix design

The experimental work was started by determining the optimum asphalt content for all the asphalt concrete mixes using the Marshall mix design method. Seven percentages of bitumen were examined to determine the best percentage of bitumen for the aggregates used, which include 3.74, 4.24, 4.74, 5.24, 5.74, 6.24, and 6.74% by weight of the mix with three samples for each percentage.

The coarse aggregate, fine aggregate, and the filler material should be proportioned to fulfil the requirements of the relevant standards. The required quantity of the mix is taken to produce compacted bituminous mix specimens of thickness 63.5 mm approximately. 1200 g of aggregates and filler are required to produce the desired thickness. Each aggregate sample was blended for each specimen separately. Aggregate is first dried to constant weight at 110±5 ºC. The aggregates are then heated to a temperature of 135 ˚C before mixing with asphalt cement. Asphalt was heated up to 145 ºC prior mixing.

The prepared mixture was placed in a preheated mold 4 inches (101.6 mm) in diameter by 2.5 inches (63.5 mm) in height and compacted with 75 blows for each face of the specimen. The specimens were then left to cool at room temperature for 24 hours. Marshall stability and flow tests were performed on each specimen, where the cylindrical specimen was placed in water path at 60 ºC for 30 to 40 minutes then compressed on the lateral surface at a constant rate of 2 inches/min. (50.8 mm/min.) until the maximum load (failure) is reached. The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination were prepared and the average results were reported. The bulk specific gravity, density, air voids in total mix, and voids filled with bitumen percentages are determined for each specimen.

The optimum binder content was found equal to 5.10% by weight of the total mix, which is calculated as the average of binder content values that corresponding the maximum stability, maximum density and, median percent of air voids and percent of voids filled with binder.

3. Performance of Recycled Asphalt Mixtures

3.1. Marshall stability and flow tests

The Marshall Mix design method was employed to determine the optimum asphalt content (O.A.C) for the mix with zero RAP percent. The optimum asphalt content for HMA mixture with 0%RAP was found to be 5.10%.

The mix design for virgin and RAP mixes was carried out as per Marshall method of mix design. All mixtures are prepared with the same binder content (5.10%). To determine the best percentage of (RAP) that could be used in Asphalt Pavement mixture. To investigate the influence of RAP on the fatigue performance of the wearing course mix, varying percentages of RAP were incorporated into the mix design. RAP was introduced to the bituminous mixtures at levels of 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%. Control samples not containing RAP were also used throughout the testing.

New aggregate is heated to a temperature of 145˚C to 165˚C, the compaction mold assembly and rammer are cleaned and kept preheated to a temperature of 100˚C. The bitumen is heated to a temperature of 145˚C to 160˚C. In case of mixture with RAP, the RAP is heated in special oven at 120°C for 60 minutes, before mixing with new aggregate and new asphalt cement. The mixture of new aggregate and new asphalt cement (50-70) and RAP (in case of preparing the mixture with recycled asphalt pavement) is then placed in mixing bowl and mix rapidly until the new aggregates are thoroughly coated. The recycled mix is poured into Marshall mold and then compacted with Marshall hammer with 75 blows on each face. The compacted Marshall samples are tested after curing for 24 h. The weight measurements are done for estimation of volumetric parameters. The Marshall samples are kept in water bath at 60 ˚C for 30 min and then tested for Marshall flow and stability using Marshall testing machine.

Marshall stability and flow tests are performed on each specimen. The cylindrical specimen is placed in water bath at 60 ˚C for 30 to 40 minutes and then compressed on the lateral surface at a constant rate of 2 in/min. (50.8mm/min) until the maximum load (failure) is reached.

The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination are prepared and the average results are reported.

The bulk specific gravity and density ASTM (D 2726), theoretical (maximum) specific gravity of void less mixture is determined in accordance with ASTM (D 2041). The percent of air voids is then calculated.

3.2. Indirect tensile strength test

The Indirect Tensile Strength (IDT) on bituminous mixtures is conducted by loading a cylindrical specimen across its vertical diametral plane at 50 mm/min deformation rate and 25˚C test temperature. The peak load at failure is recorded and used to calculate the IDT Strength of the specimen (REAM-SP 1, 2005).

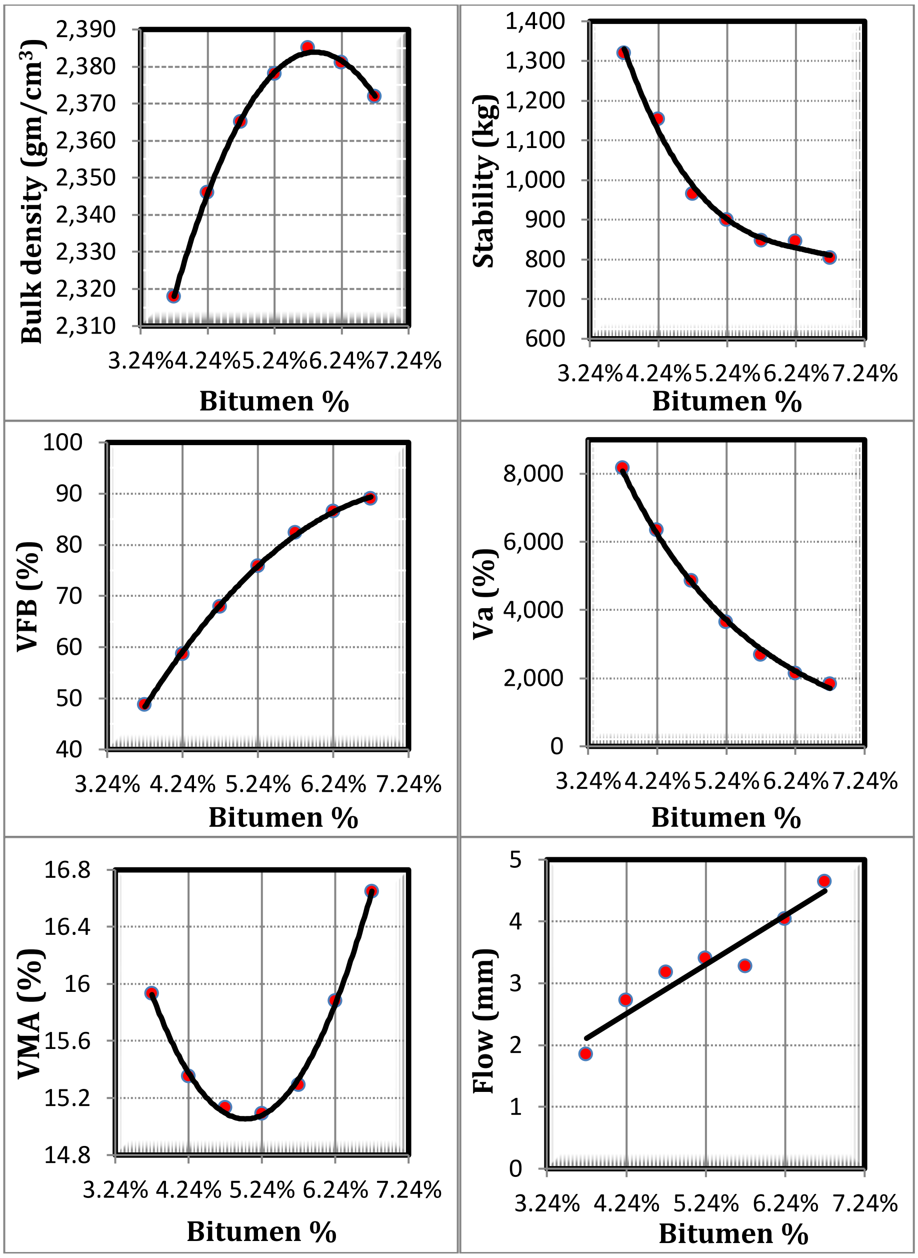

Figure 4. Marshall Test Properties

The value of IDT is used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. The results can also be used to determine the potential for field pavement moisture damage when results are obtained on both unconditioned and conditioned samples (McDaniel and Shah, 2003).

Specimens are prepared by Marshall method and tested for indirect tensile strength according to ASTM (ASTM D6931, 2007, 2012). The prepared specimens are cooled at room temperature for 24 hours.

Preparation of samples was followed closely to Marshall Procedure in accordance with ASTM D6926 (McDaniel and Shah, 2003) and tested in accordance with D6931 – 07 (2007). Samples were compacted with the Marshall Compactor with 75 blows for both surfaces and leave the sample in the mould for 24 hours, allowing sufficient strength to develop before extracting. Samples were cured in the oven at 40˚C for 72 hours and allowed to cool to ambient temperature. Samples were then tested for Indirect Tensile Test (IDT) with two conditions namely unconditioned samples and conditioned samples. For unconditioned samples, samples were tested after cured at 40˚C for 72 hours whilst conditioned samples were obtained by immersed the unconditioned samples in water at 25˚C for 24 hours.

For specimens with 50 to 80 percent saturation, the samples are each wrapped with a plastic film such as Saran Wrap and placed in a plastic bag containing 10 ± 0.5 mL of water and sealed. The plastic bags are placed in a freezer at a temperature of (-18 °C) for 16 hours. After 16 hours in the water bath, the specimens are removed and placed in a water bath at (25°C) for 2 hours. The specimens should have a minimum 25 mm of water above their surface.

The specimen is removed from the bath and then placed on its side between the bearing plates of the testing machine. Steel loading strips are placed between the specimen and the bearing plates. A load is applied to the specimen by forcing the bearing plates together at a constant rate of 2 in. (50 mm) per minute. The maximum load is recorded, and the load continued until the specimen cracks. The tensile strength is calculated using the following equation (1)

$$IDT = \frac{2000P}{\pi\, t\, D} \qquad (1)$$

where:
IDT = tensile strength, kPa
P = maximum load, Newtons
t = specimen thickness, mm
D = specimen diameter, mm

The index of Indirect Tensile Strength Retained (TSR) can be used to measure the moisture susceptibility of the samples.

A ratio of IDT for conditioned samples to unconditioned samples is the criterion to identify a moisture susceptibility of a mix. The TSR was calculated from Equation (2). The minimum requirement of TSR is 80% (ASTM D6931, 2012).

$$TSR = \left(\frac{IDT_{wet}}{IDt_{dry}}\right) 100 \qquad (2)$$

Where;
TSR = tensile strength Ratio
IDT wet = tensile strength of conditioned sample
IDT dry = tensile strength of unconditioned specimen

4. Results and Discussion

4.1. Marshall test results

The results of Marshall Tests show typical relationships between Marshall Properties and control mix (0% RAP), mixes with 5% RAP, 10% RAP, 15% RAP, 20% RAP, 25% RAP, 30% RAP, 35% RAP, 40% RAP, 45% RAP and 50% RAP. Figure 5, shows the Marshall Stability values. It indicates that stability values for various mixes follow the typical trend in the presence of RAP. Where the stability values increase with the increase in RAP content until a maximum value is reached after which stability tends to decrease.

This can be attributed to the increase in the stiffness of asphalt by incorporating more RAP which gives high cohesive strength while maintaining the interlocking between coarse crushed aggregate. The decrease in stability after certain RAP content is due to an increase in the thickness of asphalt film coating the coarse aggregate particles, which lower the internal friction. The decrease in internal friction is also associated with the increased lubrication, which is believed to be the reason for the continuous increase in Marshall Flow values, as shown in Figure 7.

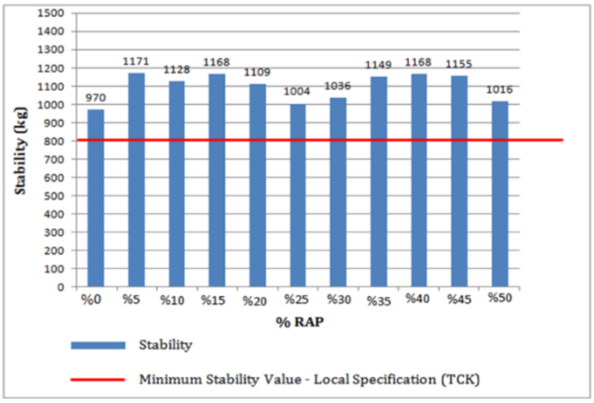

Figure 6. Relationship Between RAP Percent and Stability

4.2. Indirect tensile strength test results

The evaluation of tensile strength for asphaltic concrete mixture used in the construction of pavement becomes increasingly more important. This is partially since pavements during service will be exposed to various traffic loading and climatic conditions. These conditions may cause tensile stresses to be developed within the pavement, and as a result, two types of cracks may be exhibited: one resulting from traffic loading, called fatigue cracking and the other type of crack resulting from climatic conditions and called thermal or shrinkage cracking. The indirect tensile test IDT has been used to evaluate the mixture resistance to low temperature cracking.

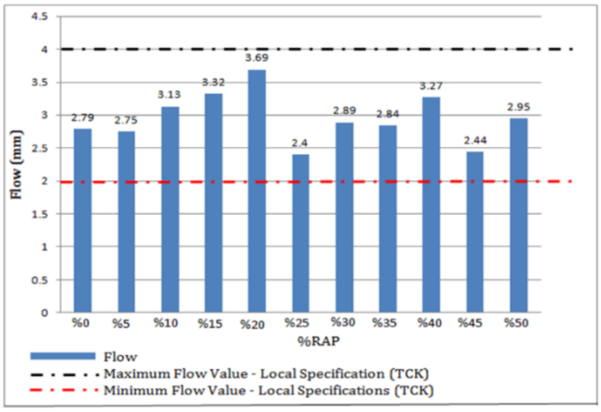

Figure 7. Relationship Between RAP Percent and Flow.

Values obtained for 15 % RAP mixes are higher as compared to the virgin mixes which clearly indicates that mix made with RAP is less susceptible to moisture damage as compared to the virgin mixes. As shown in Figure 8.

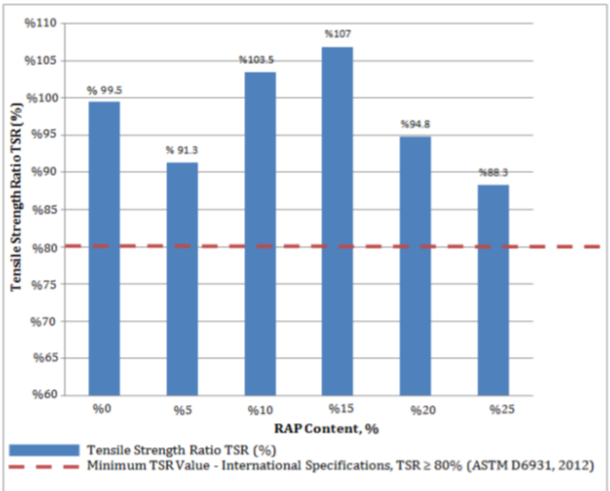

Figure 8. Effect of RAP Content on Tensile Strength Ratio TSR (%)

5. Conclusion

Marshall Method was used to determine the Optimum Binder Content (OBC) and to evaluate the properties of the Reclaimed Asphalt Pavement (RAP) mix. In total, 78 samples were prepared, 21 of which have been used to determine the OBC, and the rest have been used to find out the effects of adding different percentages of RAP to the asphalt mixture. Examining Marshall samples showed that the OBC of bitumen ought to be 5.10 % of the total weight of the asphalt mix. Also, examining Marshall samples containing different percentages of RAP showed that the optimum percentage of RAP that can be used in the wearing course is 15% of the weight of the asphalt mix. The results of the experiments (Marshall stability, Flow & TSR) are consistent with the local and international specifications.

Based on the laboratory testing work carried out on virgin mixes and mixes with different percentages of Reclaimed Asphalt Pavement (RAP), it was found that addition of RAP improves all the properties of the bituminous mixes. In addition, the asphalt mixtures containing RAP performed at least like, or better than, that of conventional asphalt materials. the following conclusions can be drawn.

As expected, it is seen that the Marshall stability increases with the inclusion of RAP content. Marshall Stability values meet the requirements of local and international specifications with (0 -50%) RAP content. when compared to the specification limits of the virgin mix. It is seen that the Marshall stability values almost remained within the permissible ranges and even comparable to the virgin mix.

The inclusion of RAP It was observed that the flow values are remains within specification limits.

The results reveal that the inclusion of RAP into HMA mixtures increases the indirect tensile strength. Conditioned strength tests were conducted to evaluate moisture susceptibility in HMA specimens with RAP. Tensile Strength Ratio TSR increased with the inclusion of higher percentages of RAP mixtures as seen in Figure 8. It was observed that the for 15% RAP is higher than that of conventional and other percentages of content Reclaimed asphalt pavement (RAP). Also, the %15 RAP content corresponded with higher ratios for freeze-thaw conditioning.

When use of the Reclaimed Asphalt Pavement (RAP) materials in asphalt concrete mixture, environmental negative effects will be removed, and it will also make an economic contribution to recycling.

Conflict of Interest

No conflict of interest was declared by the authors.

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