A case study on the evaluation of rubberised asphalt containing reclaimed asphalt pavement and setting up of possible guidelines

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Abstract

This paper outlines the possibility of combining Reclaimed Asphalt Pavement (RAP) and crumb rubber in asphalt mixes meant for the construction of wearing courses without compromising on performance. The results reported that rubber and RAP were complementary materials and would adapt to each other's properties adequately. The optimum rubber content was determined, upon comparing Marshall Stability, Flow and Voids of the different CRM asphalt mixes, to be 10% by weight of the binder, with up to 15% being acceptable. The optimum RAP content was found to be 10% by weight of the coarse aggregates when combined with 10% rubber. The addition of RAP reduced the void content providing better resistance to moisture infiltration. It was concluded that the performance of the asphalt mixes were upgraded with the addition of rubber and RAP, showing that they can effectively be combined in wearing courses. The design of such a mix has shown to be adequate for complete road maintenance as well for repairing of parts of the roads and also for pavement resurfacing, as practiced locally. Hence, recommendations of possible guidelines were also made.

Keywords: Recycled Asphalt Pavement (RAP), Crumb rubber modified (CRM), Marshall Stability, Marshall Flow

1. Introduction

The construction of flexible pavement involves the production of Hot Mix Asphalt (HMA) and consists of different well defined layers and courses each of which has its own function. The wearing course receives the initial load and effectively transfers it to the sub base. It should have low permeability to water, low plastic deformation, be flexible enough to allow elastic recovery and reduce cracks while having enough strength to sustain traffic loading.

With the increasing number of vehicles on the roads across Mauritius, the road surfaces have undergone much degradation. According to Statistics Mauritius (2014), an increase of 2.5% was registered from December 2013 to June 2014 with 10 931 new vehicles. Hence, it is undeniable that the traffic loads being subjected to the road pavement are also undergoing similar increases. It is critical that current local Standards concerning asphalt wearing course construction undergo major developments with new materials which would better resist these increasing traffic loads.

Pavement resurfacing has been a common road maintenance technique around the island. However, as witnessed locally, this method bears certain deficiencies such as the increase in road levels as compared to buildings causing water accumulation, the non-consideration of the ageing pavement layers underneath and the obstruction of the drainage systems due to improper casting of the overlay. The design of bitumen overlays should address the specifications and thickness of materials needed while taking into account the ageing problems of pavement. Moreover, Statistic Mauritius (2014) recorded a total of 2356 km of road of which 98% are paved and figures from the Road Development Authority (RDA) estimate the cost of maintenance to be 4000/ m^2 MUR (Mauritian Rupees).

RAP has been used in many countries around the world according to Xiao *et al.* (2007), with over 73 million metric tonnes being reused in the USA in wearing courses, base courses and embankments. The recycling of old pavement materials can prove to be economic in terms of materials, money and energy savings. Moreover, experiments by Putman *et al.* (n.d.) and Xiao *et al.* (2007) have shown that incorporating RAP in HMA does not reduce the performance of the mixes. Various studies have been carried out in the recent years concerning the use of polymer modified asphalt mixes. Putman *et al.* (n.d.) described two types of polymers, namely elastomers (rubber) and plastomers (plastic) and a recent study carried out by Gunesh (2013) showed that rubber was one of the best additives to asphalt.

The main beneficial property of rubber, as described by Presti (2013), is the formation of a viscous gel-like substance upon interaction with bitumen at high temperatures. Mashaan *et al.* (2011) mentioned that the final properties of the asphalt mix would greatly depend on the interaction of the rubber with the bituminous binder. The gel formed would increase the viscosity of the blend. Xiao *et al.* (2007) described the ability of the rubber particles to absorb light oils from the bitumen. This leads to the increase in volume of the rubber particles, thereby increasing the viscosity of the binder. The main advantages of rubberised asphalt mixes are described by the Clemson University as exhibiting: better resistance to cracking, lower maintenance cost, better rutting resistance, greater pavement life, better skid resistance, reduction in reflective cracking in asphalt overlays and reduction in noise.

The advantages of including both RAP and rubber in asphalt mixes can be summarised as follows: improved stiffness of the mix (Brown *et al.*,1990), enhanced resistance to thermal cracking (Pavement Interactive, 2010), higher rubber content would increase the rut resistance of the mix (Putman *et al.*, n.d.), greater flexibility and elastic recovery due to rubber content (Mashaan *et al.*, n.d.), improved Marshall Stability due to rubber and RAP (Gunesh, 2012 and Beeharry, 2015), better moisture resistance (Putman *et al., n.d.* and Xiao *et al.*, 2007), Addition of RAP improve the indirect tensile stress of the mix and provide stronger bonds (Putman *et al., n.d.* and Xiao *et al.*, n.d.) and lower deformation during service (Gunesh, 2013 and Beeharry, 2015).

Previous studies showed that both crumb rubber and RAP performed well when implemented individually to wearing courses and asphalt pavements. However, no attempts were made to combine both of these construction materials in a single wearing course mix design. Hence, it was justified to combine both crumb rubber and RAP in asphalt mixes with the expectancy of getting even better performances. For Mauritius, Beeharry (2015) showed how the implementation of RAP improved the properties of the mix. Additionally, the investigation of Gunesh (2013) with CRM asphalt mixes gave promising results, however, the rubber content was very low, not exceeding 6%. Further investigations can be made to promote the use and better understand the use of greater percentages of rubber. The behaviour of higher rubber contents on asphalt mixes for local use has not been studied, while such studies have showed great prospects in other countries such as USA and Malaysia (L'express, 2015).

With the construction industry moving towards the green concept, there is a need for the pavement construction industry in Mauritius to innovate and adopt sustainability without neglecting quality. The recycling of rubber and use of RAP in pavement construction are major steps towards a greener pavement construction.

This paper was divided in three main stages. First, Crumb Rubber Modified (CRM) binders were produced by blending different percentages of crumb rubber (10%, 15% and 30% by weight of the total binder content) with bitumen. The aim was confirm the possibility of combining crumb rubber and RAP in the design of asphalt mixes for wearing courses without lowering their performance. The main objectives of this study were to evaluate the properties and performance of the control mix which did not contain any additives, to assess the properties and performance of Hot Mix Asphalt (HMA) having high rubber content and determine an optimum rubber content. The next goal was to evaluate the properties and performance of HMA which contained that optimum rubber content and also low, medium and high RAP content as a substitute to coarse 10/14 crushed aggregates. These were determined by carrying out Marshall Stability and Flow tests on samples which have been prepared accordingly. Following these tests, an assessment of the cost implications of the optimum mixes and a cost benefit analysis were carried out. As a result, some general guidelines concerning the use of RAP and rubber in wearing courses would be established.

2. Materials and Methodology

2.1 Aggregates

Crushed and clean aggregates of sizes 0/3, 3/6, 6/10 and 10/14 were obtained from a local asphalt batching plant. As per BS EN 12697, a representative sample of these aggregates was collected by using a riffle box.

2.2 Reclaimed Asphalt Pavement (RAP)

RAP was obtained during a milling activity at Vallée Des Prêtres, by a local construction company and during a road maintenance process. These materials were labelled as waste products and would have been discarded. They were protected from direct sunlight and rain, so as to prevent them from sticking too much to each other and avoid any kind of moisture damage respectively. Part of the RAP sample is shown in Figure 1.

Figure 1: RAP sample

The RAP sample obtained was of different sizes and it was thus necessary to separate them into different fractions. The sample was divided into 6/10 and 10/14 fractions by the use of available standard sieves. Rap retained on the 14 mm as well as those passing the 6mm sieve were rejected. A sieve analysis was then carried out on these two samples to determine the particle distribution.

2.3 Bitumen

Bitumen, grade 35/50 was used for the asphalt mixes.

2.4 Rubber

The rubber was obtained in shredded form from a local rubber tyre company. The rubber provided was previously being used as rubber tyres and according to the company personnel, these tyres were completely worn out and would have been discarded.

2.5 Specimen preparation

2.5.1 CRM modified binder

The control binder did not contain any rubber content. 10%, 15% and 20% of crumb rubber by weight of the total binder content (Table 1) was blended with virgin bitumen using a mechanical mixer which was set at 700 rpm for 30 minutes (until all rubber had dissolved in the bitumen). A heating plate controlled the temperature of the blend at 177°C as specified by Xiao *et al.*(2007).

Table 1: CRM binders

Sample	**Percentage of rubber**	**Mass of bitumen/g**	**Mass of rubber/g**
1	0%	700	0
2	10%	700	78
3	15%	700	124
4	20%	700	175

2.5.2 Asphalt mixes

The correct proportion of aggregates was derived from the sieving analysis curve and were found to be 40% of 0/3, 18% 3/6, 22% of 6/10 and 20% of 10/14 aggregates. The binder content, obtained from the laboratory, was 4.7% of the total mix. The correct proportion of the materials were measured and blended. The Marshall Compactor (which is still the current testing method in developing countries) was used to compact each of the mixes in accordance with BS EN 12697-30. 75 blows, as prescribed by ORN 19 (2002), were struck on the top layer and the bottom layer of the specimen. For each of the mixes prepared, three Marshall Specimens were compacted and were subjected to the Marshall Stability and Flow tests as per BS EN 12697-30. Table 2 displays the different mixes; 5000 g of each of the mixes was prepared for the different tests required.

Table 2: Asphalt mixes

Mix no.	Rubber content (%)	RAP content (%)
1(control mix)	0	0
2	10	0
3	15	0
4	20	0
5	10	10
6	10	25
7	10	40

2.5.2.1 Rubberised asphalt mixes without RAP

The different CRM binders were blended with aggregates and the different mixes as per Table 3.

Table 3: Rubberised asphalt mixes without RAP

Mix number	Mass of materials / g						
	Binder		Crushed aggregates				Total mass
	Rubber	Bitumen	0/3	3/6	6/10	10/14	
1	0	235	1906	857.7	1048.3	953	5000
2	23.5	211.5	1906	857.7	1048.3	953	5000
3	35.3	199.7	1906	857.7	1048.3	953	5000
4	47	188	1906	857.7	1048.3	953	5000

2.5.2.2 Rubberised Asphalt mixes with RAP

The RAP was used as a substitute to the 6/10 and 10/14 aggregates and were divided into equal proportion as shown in Table 4. The mixes designed with RAP and rubber are described in Table 5.

Table 4: Proportion of RAP used

Mix number	Percentage of RAP in mix	Percentage of 6/10 RAP	Percentage of 10/14 RAP
5	10%	5%	5%
6	25%	12.5%	12.5%
7	40%	20%	20%

Table 5: Rubberised asphalt mixes with RAP

Mix number	Mass of materials / g								
	Binders		Crushed aggregates				RAP		Total mass
	Rubber	Bitumen	0/3	3/6	6/10	10/14	6/10	10/14	
5	23.5	211.5	1906	857.7	995.9	905.3	52.4	47.7	5000
6	23.5	211.5	1906	857.7	922.5	833.9	125.8	119.1	5000
7	23.5	211.5	1906	857.7	838.6	762.4	209.7	190.6	5000

3. Results and Discussions

3.1 Aggregates

Table 6 summarises the main results concerning the different preliminary tests on the crushed and clean aggregates.

Table 6: Properties of aggregates

Aggregate size fraction / mm	Flakiness Index	Los Angeles Abrasion	Moisture content / %
0/3			2.4
3/6	19.6		0.93
6/10	10.01		1.19
10/14	20.0	23.0	1.6
Road Development Authority (RDA) specification	<25	<25	

The properties of the aggregates met the standards set by the RDA. The aggregates would be able to sustain the traffic loading during service. Hence, the preliminary tests carried out on the aggregates demonstrated that the aggregates had the proper shape and size as well as satisfactory abrasion resistance due to wear and tear from vehicular tyres. This showed that the performance of the mix would not be affected by the aggregates. The grading of each fraction of aggregates was carried out, leading to the individual grading curves shown in Figure 2. The combined aggregate grading curve was then derived from these curves so that it was within the limits of the RDA. Figure 3 represents the sieve analysis of the 6/10 and 10/14 RAP fractions as compared with the same fractions of crushed aggregates. The curves follow the same trend, implying that the RAP fractions had almost similar particle size distribution as the crushed aggregate fractions and could effectively be used as substitute for coarse aggregates.

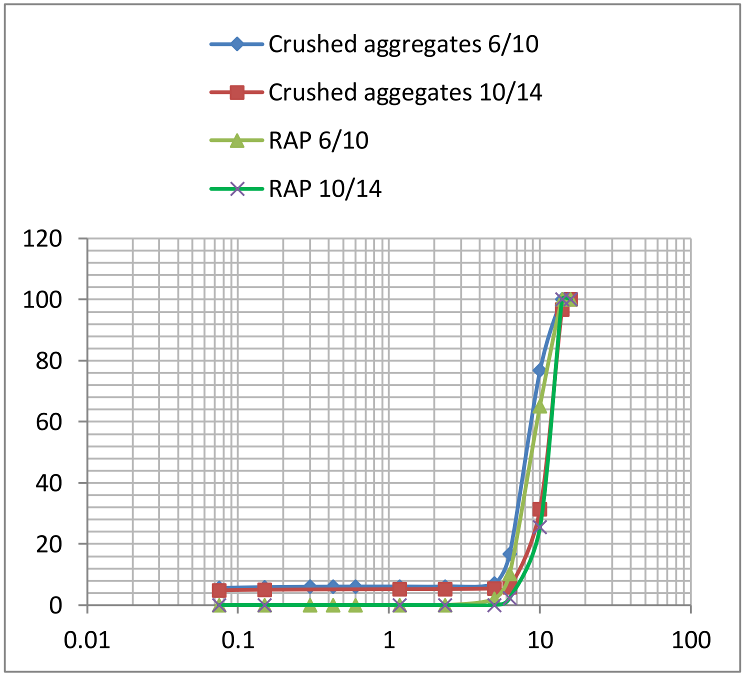

Figure 2 Gradation curves for crushed aggregates

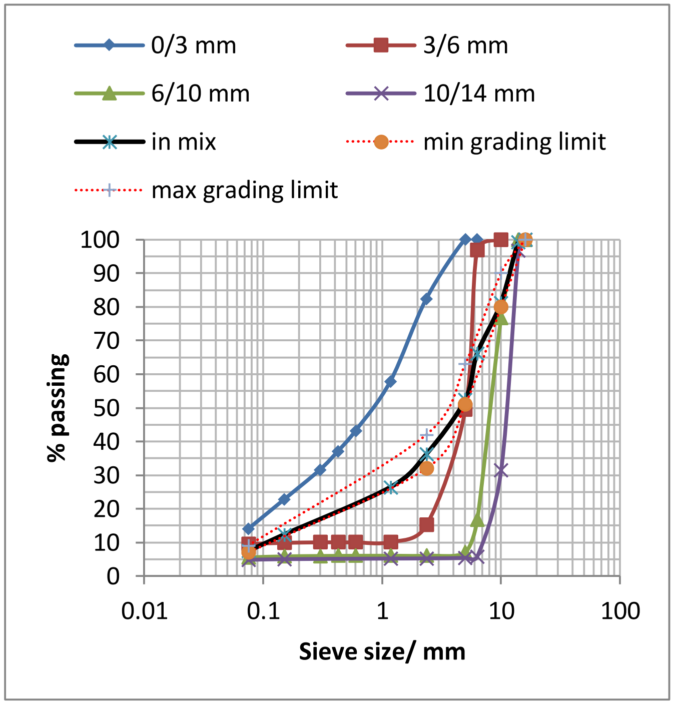

Figure 3 Comparison of the grading curves of the 6/10 and 10/14 RAP to the 6/10 and 10/14 aggregates

3.2 CRM binders

The penetration values (Table 7) underwent a constant decrease with increasing crumb rubber contents in the mix, implying that the CRM binders were harder than the virgin binder and the softening points of the CRM mixes were higher than the virgin mixes, indicating stronger bonds between the rubber and bitumen. As Mashaan *et al.* (2011) described, it was expected that the penetration of the CRM binder would decrease considerably with increasing rubber content. Indeed, the gel like substance formed by the rubber upon blending with the bitumen increased the viscosity of the mix, making it stiffer. According to Presti (2013) upon softening of the bitumen, a better blending would be expected, allowing the long chain polymers of the rubber to mix well and combine effectively with the bitumen. As a result, higher temperatures would be required to overcome these bonds and soften the binder.

Table 7: Penetration and Softening points

Rubber content	Penetration / dmm	Softening point/ °C
0%	48	54
10%	38	65.5
15%	35	68.3
20%	28	71.2
RDA Specifications	> 35	

The 10% and 15% CRM binders were within the range imposed by the RDA; above 35 dmm, while the 20% CRM was beyond this limit. The 30 minute blending recommended by Xiao *et al.* (2007) was not enough for all the rubber of the 20% CRM binder to dissolve completely. Hence, blending was carried out for a longer period of time to ensure the mix was homogeneous. The longer mixing time at high temperature disturbed the long chain polymers present in the rubber (Ibrahim *et al.*, 2013). The loss of properties of the rubber negatively impacted on the binder by lowering its penetration well below the limit expected.

3.3 CRM asphalt mixes without RAP

A general improvement of the stability up to the 15% CRM mix was observed compared to the control mix, while the stability gradually decreased with rubber content higher than 15%, as shown in Table 8. The better Marshall Stability of the 10% and 15% CRM mixes demonstrated better bonding characteristics. However, the 20% CRM mix, having very low Stability, showed that the bonds were too weak and was not adequate.

Swelling of the rubber occurred upon its interaction with the bitumen during the wet process, forming the gel-like substance. The increase in viscosity brought up at high temperature of blending, allowed the long chain polymers of the rubber to mix well with the binder and the resulting CRM binder benefitted of the elastic properties and the hardness of the rubber materials (Presti, 2013).

Xiao *et al.* (2007) described the property of rubber to absorb light oils from bitumen, leading to the hardening of the binder. It can be concluded that the 20% rubber content was too high and might have absorbed too much of these light oils from the bitumen, preventing it from adhering effectively and closely to the aggregates. The 20% CRM mix therefore underwent a major decrease in Stability.

The Marshall flow generally decreased till the 15% CRM mix with a drastic increase to 20% CRM mix, which had its Flow exceeding the limits set by the RDA. The 10% and 15% CRM mix had lower flow than the virgin mix, indicating that they would undergo less deformation and hence had stronger bonds. As Presti (2013) explained, the presence of the long chain polymers created strong bonds with the asphalt which made it less prone to deform. The excessive Flow of the 20% CRM confirms that the crumb rubber got depolymerized and weakened the bonds in the mix. The void content remained almost constant until 10% rubber content, after which it increased considerably with higher rubber content as seen in Table 8. With rubber content higher than 15%, the Void contents exceeded the limit of 6.0% as imposed by the RDA. All the Void content of the mixes exceeded 3% and according to ORN 19 (2002), plastic deformation would be prevented. This may explain the low Flow values obtained for the 10% and 15% CRM mix. The specimens showed satisfactory void contents indicating low plastic deformation and low permeability to water, with the 10% CRM mix displaying better results. At 20% CRM, the mix would contain too much air voids, allowing the penetration of water.

Table 8: Summary of Marshall stability and flow test

Rubber content	Marshall Stability / kN	Marshall Flow / mm	Void content %
0%	24.2	3.25	4.33
10%	28.5	3.1	4.23
15%	25.1	3.17	5.62
20%	13.2	4.56	11.97
Specifications	> 11	2 < Flow < 4	3 < voids< 6

3.4 CRM asphalt mixes with RAP

The main results on the investigation on CRM mixes containing RAP are displayed in Table 9.

Table 9: Summary of Marshall Stability and Flow test

RAP content	Marshall Stability/ kN	Marshall flow / dmm	Void content %
0% (control mix)	28.5	3.1	4.63
10%	30.5	3.85	3.65
25%	28.7	3.67	3.16
40%	19.5	2.53	3.10
RDA Specifications	> 11	2< Flow < 4	

All values lie above the 11kN imposed by the RDA. For low and medium RAP content up to 25%, the stability was higher than the control mix, indicating strong bonds. Xiao *et al.* (2007) found that the addition of RAP would increase the tensile strength of the mix which already contained rubber and hence, proving that the bonds between rubber, asphalt and RAP were strong for low RAP content.

At RAP content higher than 25%, the stability dropped considerably. As Kuenen (2013) argued, too high RAP content would reduce the flexibility of the mix. Therefore it can be deduced that at 40% RAP the mix lost its elasticity, thereby impacting on its ability to undergo elastic recovery, causing the mix to fail at lower loads.

Therefore, this section showed that combining RAP and rubber eventually improved the mixes' ability to withstand higher traffic loading. This concept was also shared by Putman *et al.* (n.d.) and Xiao *et al.* (2007).

From Table 9, all Flow values were within the range imposed by the RDA. A major increase occurred with low amount of RAP till 25% but then decreased considerably. The 10% CRM mix with 10% RAP resulted in a high flow value. This might be due to the aged bitumen content. The increased bitumen content formed a thicker coat on the aggregates, enabling a greater lubrication. Therefore, the specimen was able to deform more until failure. However, a too high flow is not desirable since it might have a tendency to reduce stability (Civil Engineering Department, University of Memphis, 2015.). Nevertheless, it can be observed that the stability did not decrease, which might be attributed to the strong bonds of the long chain polymers caused by the addition of the rubber content (Presti, 2013).

Adding RAP content higher than 25% might not be beneficial to the mix. At 40% RAP content, the flow was too low. Hence, the pavement would not be able to deform enough under loading and hence leading to crack developments (Civil Engineering Department, University of Memphis, 2015.). With 40% RAP and 10% rubber, the mix was too stiff due to the presence of increased aged binder content (FHWA, 2011). The loss in flexibility by a too stiff mix might cause the mix to Flow less (Kuenen, 2013).

According to the results in Table 9, the air voids showed a general decrease with increase in RAP until it stabilised at a constant value at 25% and further RAP content, indicating a minimum air void. The Voids of mixes containing both

RAP and rubber were lower than the control mix. In addition, according to ORN 19 (2002), the air void contents were all above 3% and plastic deformation would be prevented, however, 25% and further RAP content had VMA close to 3% indicating that they will be more liable to plastic deformation as compared to the 10% RAP mix. Furthermore, ORN 19 (2002) also suggested that since all the VMA were low, the mixes with RAP would have a low permeability to water. Putman *et al.* (n.d.) and Xiao *et al.* (2007) indeed described that RAP would actually help to improve the moisture resistance of the mix.

4. Conclusions and recommendations

The combination of crumb rubber and RAP in the same mix was a successful initiative. RAP and crumb rubber functioned as complementary materials, that is, the rubber reinforced the deficiencies of the RAP and vice versa. Moreover, this combination could enable savings up to 10% compared to conventional mixes.

The CRM modified binder displayed excellent properties in terms of performance at high temperature. The reduction in penetration values proved that the addition of rubber would harden and make the mix stiffer, leading to more resistance to rut and less deformation of the mix. Furthermore, the increasing softening points showed that the bonds between the rubber and bitumen were strong, with a greater energy being required to break them. Moreover, this demonstrated that the mix would be able to resist deformation due to high temperatures of the surrounding and arising with traffic loads. This indicated better resistance to thermal cracking as well. The mixes having 10% and 15% had better performance than the virgin mix in terms of Marshall Stability, Flow and void contents. The most adequate crumb rubber content was found to be 10% by weight of the binder content. The Stability of this CRM mix peaked compared to the other mixes prepared. Up to 15% crumb rubber content was acceptable since it showed suitable Stability values and satisfactory void contents. Having rubber content higher than 15% would not be desirable in the mix.

The 10% rubber content was blended along with different RAP contents. The addition of a low 10% and medium 15% RAP content improved the performance of the mix compared to the mix without RAP. The added RAP improved the bonds between the rubber, bitumen and aggregates and enhanced the mixes' ability to resist a higher traffic load. The addition of a high 40% RAP reduced the Stability of the mix and further studies must be carried out to draw a valid conclusion for high RAP content. The combination of rubber and RAP lowered the flow of the mix as well as the void content. It indicated a better resistance to rutting, an adequate resistance to plastic deformation and an excellent resistance to moisture attack as well as permeation of water.

In conclusion, the results show that crumb rubber and RAP can be effectively combined in the construction of wearing courses without compromising on the performance of the mix.

The following recommendations and guidelines emerge from the study:

1. The overlaying of pavement layers by resurfacing over an existing layer should be discouraged, instead milling and scarifying should be the main alternatives, thereby promoting the reuse of RAP as a construction material.

2. Based on the positive sets of results obtained during this investigation, a contractor should be allowed to include between 10%-15% of crumb rubber in his asphalt mixes. A better performance of the pavement would result in the increasing temperatures of the tropics.
3. The addition of the 10% rubber can be allowed for low, medium, as well as heavy traffic, since the performance of the mix has shown to be better than the traditional one. 15% rubber can be allowed for low and medium traffic due to its lower Stability. However, rubber content exceeding 15% should in any case be allowed in any asphalt mixes due to poor performance and load resistance.
4. Furthermore, the addition of crumb rubber to the mix must be allowed only if the rubber being used had been previously used as old tyres as per this study.
5. Concerning the inclusion of both 10% rubber and RAP content, up to 10% RAP content can be allowed in mixes meant for heavy traffic. For the medium 25% RAP content, it can be allowed for minor road construction whereby medium and low traffics are expected. As for higher RAP content, more studies should be carried out to be able to draw a more accurate conclusion.
6. Based on this study, a contractor can be allowed to include 10% of rubber by weight of the binder content and up to 10% RAP from his own stockpile by weight of the mix in any road construction, provided that it is homogenous.
7. With the increasing temperatures being undergone in the island during these last years, it is recommended that a contractor opts for CRM mixes. These mixes would support heat better than conventional mixes due to their high softening points.

5. Acknowledgements

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