Experimental characterization and environmental impact of different grades of CRM-modified asphalt binders

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Abstract. The use of Crum Rubber Modifier (CRM) with asphalt binders improves their properties by reducing their temperature susceptibility; this improvement is dependent on the way CRM and binder react with each other. The CRM particles tend to absorb some oils from asphalt binder and swell, resulting in a higher viscosity and thus stiffer binder. This paper discusses the effect of adding CRM to asphalt binder by applying three different percentages of CRM on two asphalt binders, viz., 60-70 and 85-100. A total of 120 specimens were prepared to test their basic physical properties such as penetration, softening point, ductility, flash and fire points, and rotational viscosity. It was found that the physical properties of asphalt binder are influenced by the percentage of crumb rubber used. The modified asphalt binders with higher crumb rubber content have lower ductility and penetration number, but higher softening point and viscosity values. Thus, it could be expected that they will have improved rutting resistance and extended service life. Furthermore, different analytical methods were utilized to validate the experimental results. It was reported that only penetration displayed change in behavior between 60-70 and 85-100 asphalt binders. CRM Content was found to be influential on all performance-related physical tests. Finally, it was obviously shown that the combined effect of Asphalt-Types and CRM Content is statistically significant on softening point, ductility and rotational viscosity test results. The incorporation of CRM in asphalt mix has multiple environmental benefits as well. The energy saving coupled with other benefits including less cracking and maintenance makes rubberized asphalt very attractive and beneficial in highway construction. Rubberized asphalt technique reduced the environmental impact of highway construction by 5% to 10% compared to traditional practice.

Introduction

Crumb rubber is a term that refers to recycled rubber from vehicular tires; it has been used widely as a modifier in the asphalt mixes since 1930, due to its great effect in improving their performance. Recently, it is recognised as being one of the most innovative sustainable binders used in the pavement industries. Actually, the incorporation of Crum Rubber Modifier (CRM) in various asphalt mixtures offers different manifold environmental benefits [1, 2] for the pavement as well for the surrounding area. These effects are influenced by many factors such as the method of production of crumb rubber, the approach of asphalt mix, the CRM content, and the availability of other additives within the mix.

The CRM usage in asphalt mixtures contributes to the recycling of millions of scrap tires that are discarded annually without proper treatment [3]. Solid tire wastes are materials that cannot be decomposed naturally. Every year, about one billion tires complete the end of their useful lives, and it is estimated to reach at least 1.2 billion end-of-life tires' worldwide by the year 2030 [4,5]. Further, tires can leak chemicals into the air, ground, and water that can disrupt the ecosystem when they accumulate in landfills or junkyards. A used tire emits methane gas into the atmosphere just by being in the sun. Our carbon footprint grows as a result of this greenhouse gas, which may also contribute to climate change. Moreover, in the event that the tire catches fire, poisonous black smoke may be released into the atmosphere. Burning tire wastes also worsen air, water, and soil pollution [6]. Therefore, it is necessary to find alternative options to handle this enormous quantity of tire debris in order to reduce the ecological effect and the depletion of available disposal sites. Over the past few decades, there has been a lot of interest in the use of recycled tire rubber in asphalt pavements [7]. Crumb Rubber Modifier (CRM) has a great role in improving the asphalt binder properties such as rutting resistance, fatigue/reflective cracking resistance, and durability due to the noticeable increase in the viscosity and softening point of the modified asphalt binders [8-12]. In addition, many other advantages were achieved such as reducing temperature susceptibility, traffic noise, pavement maintenance costs and pollution. [13, 14-18].

Previous investigation found that recycled tire rubber could be able to decrease the permanent deformation of flexible pavements [19, 20], improve the pavement's resistance to rutting, lower the cost of constructing and maintaining the pavement, and increase the pavement's resilience to fatigue damage [21,5,4].) In the present study, it is clear that using CRM can improve asphalt binding properties, binder stiffness, asphalt pavement durability and it represents a cheaper substitute for polymers used to modify bitumen. Moreover, reclaimed asphalt surface material with CRM (obtained from waste tires and waste rubber powder) has potential to contribute to environmentally sustainable construction by way of saving energy consumption, less greenhouse gas (GHG) emission, solid waste reduction as well as lowering the cost of hot mix asphalt (HMA) pavement rehabilitation [22,5]. Besides, the study conducted in [23] have referred to the great enhancement of the environmental noise performance of flexible pavements when crumb rubber is included in HMA mixes [23].

On the other hand, the environmental impact of CRM asphalt mixes is influenced by the method of production [24], whether it is ambient mechanical grinding or cryogenic grindingwhich is more expensive and produces smaller and smoother crumbs. The ambient mechanical grinding is a multi-step process in which the scrap tires are broken up at or above the room temperature, it uses the tires in the form of shred or chips by passing them through a shredder. While, in cryogenic grinding process, the grinding of used tires is done at extremely low temperatures near -80 oC so that the rubber becomes brittle and easily crushed. This method requires less energy and produces much finer particles. When quantifying the environmental negative impacts of CRM asphalt mixes in [25], it was found that the production of CRM using the ambient grinding method results in the least score (3 – 20%) while the asphalt mixture production and base course construction present the higher rate that reaches 93%.

The interaction between CRM and other asphalt binders is another factor that would affect the improved properties of produced CRM, and this is related to the method of CRM incorporation in road paving materials. Previous studies proved that the wet technology is much favourable in terms of environmental drawbacks. The CRM asphalt mixture generated with wet process stands behind the lower environmental burdens as per [26] and [24]; although it presents higher annual energy use (by wet process-high viscosity). While dry mixtures induce notable rise in scores of all negative impact categories. Since the rubber absorbs the lighter parts of bitumen, the amount of bitumen augments with the increase of CRM content.

Other aspects of CRM such as CRM content, size particles have been examined in other studies. As per [27 – 29], the improvement of the modified binder performance depends on many factors such as size of crumb rubber particles, blending conditions, surface characteristics of crumb rubber particles, physical and chemical properties and source of original asphalt binder. In terms of blending, [24] found that CRM incorporation requires less energy than virgin asphalt binder in the two ways of blending 1) the terminal blending of rubberized asphalt (TBRA) and 2) field blending of rubberized asphalt (FBRA)by using 18 % and 20% CRM content. However, the mixing process of rubberized asphalt under high temperature, emissions increase, more specifically the cumulative energy consumption is 7.26% lower for TBRA, while it is 1.25% higher than conventional HMA. Therefore, the TBRA blending seems to be more environmentally effective in terms of energy use and GHG emissions.

Finally, the effect of CRM incorporation on the rheological properties of asphalt mixes has been quite a popular topic within the literature. Roberts et al. (1991) examined the effects of incorporating crumb rubber into asphalt mixes and notes that the crumb rubber increases viscosity at high service temperature to improve rutting and shoving resistance. In addition, it increases the relaxation properties at low temperatures, which helps decrease thermal cracking and increases adhesion between asphalt binder and aggregate particles in the presence of moisture to prevent stripping [30]. Navarro et al. (2004) studied the thermo-rheological behavior and the storage stability of the ground tire rubber-modified binder. He recommended to use small CRM particle sizes (less than 0.35 mm) with high shear rates in manufacturing operations. As storage temperature and particle size increase, storage stability of CRM decreases [31]. On the other hand, Navarro et al. (2005) indicated that the rheology, storage stability, and microstructure of the modified binders depend largely on the rubber content concentration. The thermal susceptibility of the modified binder is reduced clearly when adding more rubber and decreases the viscous and elastic moduli at low temperatures and increases binder flexibility, while at high temperatures both moduli were increased significantly. The maximum amount of CRM should not exceed 9% to have a binder adequate for paving applications [32]. Ghavibazoo et al. (2013) showed that CRM dissolution in asphalt with an intermediate interaction temperature of 190 °C and high mixing speed of 50 Hz produces more homogenous CRM asphalt binder with better high service temperature properties. However, more investigation is still needed to butter comprehend other performance related properties such as storage stability, low temperature performance of the asphalt and aging susceptibility [33]. According to Xiang et al. (2009) results, the CRM asphalt binders have better performance compared with matrix asphalt binders, the performance of CRM asphalt binders are improved with increasing ash content and acetone extract [34]. Shen et al. (2009) found that the surface area of the ambient CRM was two times larger than the cryogenic CRM, with a much higher phase angle and G* of the CRM binders. Also the G* and phase angle were both affected by average size and the surface area of CRM particles. Results showed that the ambient CRM binders were 3 °C higher in temperature grade than cryogenic CRM binders [35]. Simultaneously, Thodesen et al. (2009) showed that base binder viscosity and the grinding procedure have the greatest effect on CRM binder viscosity. However, arising changes are due to physical interaction between binder and CRM particles rather than chemical interactions [36]. According to S. Liu et al. (2009), the variance analysis shows that the main influencing factor is the crumb rubber content, then comes the crumb rubber type and last in order the particle size. As the crumb rubber content increases, softening point and penetration index increase, and the low temperature ductility decreases. Results of Bending Beam Rheometer (BBR) and Dynamic Shear Rheometer (DSR) tests reveal that the optimum CRM content is 20% for tread rubber (TR-CRM) asphalt, 15% for heavy truck (HT-CRM) asphalt and 10 - 15% for small truck (ST-CRM) asphalt [37].

The main objective of this paper is to discuss the effect of adding CRM to the asphalt binder and to check if it always improves basic physical properties of asphalt or if it actually has some negative impacts on asphalt. In addition, the motivation of this study was also underlined due to the contradiction present in existing studies regarding the effect of this commonly and widely used modifier on paving materials behaviour. Besides, previous studies did not explicitly clarify the optimum rubber content that best improves asphalt performance, which was evidently assessed in this study. Temperature susceptibility evaluation of the two asphalt grades after rubber modification was another main area of focus in this study. Furthermore, there is an environmental performance evaluation of the suggested samples.

Methodology, Materials and Preparation of CRM Binders

Two binders were used in this study graded as 60-70 and 85-100. The physical properties of the asphalt samples are given in Table 1.

Table 1: Physical properties of asphalt binder

Properties of asphalt binder	Grade 60-70	Grade 85-100	Specification Standard	References
Penetration (25°C,100g,5s)	69.67	85	ASTM D 5	[38]
Softening point(°C)	48.8	38.2	ASTM D 36	[39]
Ductility (25°C, 5 cm/min)	76.3	76	ASTM D 113	[40]
Flash point	263.67	256.67	ASTM D 92	[41]
Fire point	289	286.33	ASTM D 92	[41]
Specific gravity	1.015	1.01	ASTM D 70	[42]

The CRM particles used in this study were prepared using the ambient mechanical grinding process. The physical properties of CRM particles are as follow: size ranges from 0.177 mm to 0.25 mm and specific gravity of 1.056.

The wet process approach was used to mix CRM particles with asphalt binder. In this method, CRM particles dispersed into the asphalt binder and mixed at an elevated temperature of 170 °C, a speed of 1200 rpm, and a mixing time of 60 minutes. In total, 120 specimens were prepared, 30 of them were control specimens. Then these specimens were tested for penetration, softening point, ductility, rotational viscosity, flash and fire points test. Additionally, temperature susceptibility was evaluated.

Three different percentages of CRM were tried (10%, 12.5%, and 15%) on 60-70 and 85-100 asphalt binder grades (the most commonly used grades worldwide and are typically used in the United States). The selected percentages were a result of intensive search in the available literature [28, 29]. The grades 60-70 and 85-100 are characterized with moderate relative consistency that is suitable for intermediate climatic conditions (neither very cold nor very hot). A hundred and twenty (120) specimens were prepared to test their basic physical properties such as penetration, softening point, ductility, flash point, and rotational viscosity. Fig. 1 shows a flow chart of the testing procedure.

Preliminary Results and Discussion

Physical Tests Results - Penetration

It can be seen that as the percentage of CRM used increases, the penetration number for both types of binders decrease due to the increase in the stiffness of the modified binder (Fig. 2). Thus, the consistency of the original asphalt changes and becomes harder. The reduction percentage in penetration number for modified binders is almost 24% of the original 60-70 and 22% of the original 85-100 with the addition of 15% CRM.

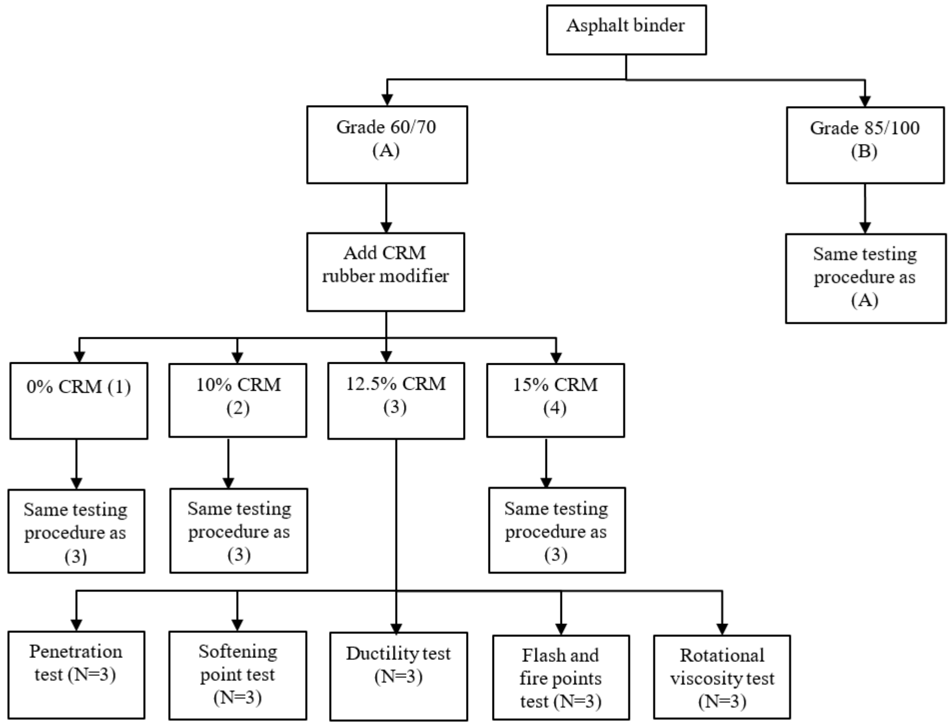

Figure 1: Flow Chart of Testing Procedure

Physical Tests Results - Softening Point
It is obvious that there is an increase in softening point temperature of the CRM modified asphalt as the percentage of CRM added to the base asphalt increases (Fig. 3). The increase in softening point values of modified asphalt with addition of 15% CRM is almost 40% of original asphalt 60-70 and 72% of the original asphalt 85-100, consequently higher softening point is required for achieving better asphalt pavement performance.

Physical Tests Results - Ductility Test
It can be seen that original asphalt ductility appears to decrease as the crumb rubber percentage added increases (Fig. 4). The ductility value of base asphalt (60-70) is 76.3 cm on average, which reduced to 55.5 cm by the addition of 15% CRM; this reduction is almost 27% of base asphalt value. The reduction percentage in ductility for 85-100 original binder is 23 %. This reduction in ductility specifies that there is a significant loss in the flexibility of the original asphalt occurred by the incorporation of such small quantity of crumb rubber.

Physical Tests Results - Flash and Fire Points Test
Flash and fire points are also affected by the addition of CRM as shown in Fig. 5 and Fig. 6. he increment in both flash and fire points with addition of 12.5% CRM to base asphalt 60-70 is nearly 18% and 23%, respectively, and 19% and 22.2% for the addition of CRM to the 85-100 asphalt.

Physical Tests Results - Rotational Viscosity
In order to ensure that the binder is sufficiently workable, a cylindrical spindle is submerged in asphalt binder at a constant temperature of 135^{o}C which simulates the workability at mixing and laydown, then the torque that is required to maintain a constant rotational speed of 20 rpm of the spindle is measured and converted to viscosity [30]. The addition of CRM increases the kinematic viscosity (see Fig. 7). As can be seen the rotational viscosity for original asphalt 60-70 increases averagely from 494.8 mPa.s to 1890 mPa.s with the addition of 15% CRM and increased from 312

mPa.s to 930 mPa.s for original binder 85-100. This result indicates that using CRM is effective in improving the viscosity property of asphalt binder. Rutting is more of a concern early in the asphalt pavement life to mid-life especially at high service temperatures, whereas fatigue cracking is of great concern older in the pavement life at intermediate service temperatures.

Physical Tests Results - Temperature Susceptibility

The temperature susceptibility of asphalt binder means the change in its consistency due to changes in temperature. It is considered one of the control parameters during mixing, compaction, placing and an important tool for evaluating asphalt binder performance. There are several methods to calculate temperature susceptibility, two of which are explained herein:

Penetration Index (PI) method: by using the resulted softening point temperatures and the penetration value at 25°C the PI can be obtained from a nomograph and then the temperature susceptibility can be calculated using the Eq. 1 [31]:

$$\mathrm{PI} = \frac{20(1-25A)}{(1+50A)}. \quad (1)$$

Where,
PI = Penetration Index
A = Temperature susceptibility

Alternatively, for any conventional paving grade bitumen, the softening point temperature is the same as that which gives a penetration of 800 d-mm. This, along with the penetration at 25°C, can be used to compute temperature susceptibility (A) according to Eq. 2:

$$A = \frac{\log\ (\text{pen at}25°\text{C}) - \log\ (800)}{25 - \text{ASTM softening point}} \quad (2)$$

A. Penetration-Viscosity Number (PVN) Method: by using penetration at 25 °C and viscosity at (135 °C or 60 °C), which are usually specification requirement for viscosity graded asphalt cement. Eq. 3 is used to calculate PVN [31]:

$$\mathrm{PVN} = \frac{L-X}{L-M}(-1.5) \quad (3)$$

Where,
X = the logarithm of viscosity in centistoke measured at 135 °C
L= the logarithm of viscosity at 135 °C for a PVN value of 0.0 and,
M= the logarithm of viscosity at 135 °C for a PVN value of -1.5.

It can be seen (refer to Fig. 8) that the addition of CRM modifier to asphalt binders reduces the temperature susceptibility, but the values still in the range since they vary from 0.0015 for highly blown low temperature binders (high PI) to 0.06 for high temperature susceptible binders (low PI).

Temperature susceptibility has an inverse relationship with PVN values. Usually, PVN varies between +0.5 to -2 for most paving asphalt cements. For the CRM-modified asphalt materials in this study one may refer to Fig. 9 for PVN results. Although the PI changes with aging, during mixing and subsequently in service, PVN remains substantially the same.

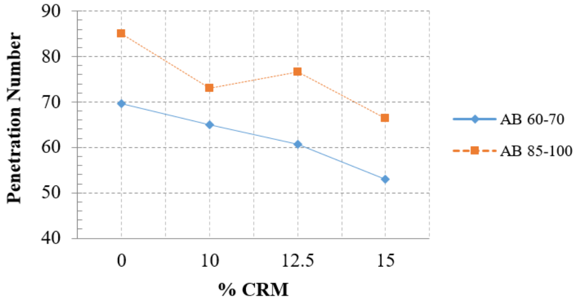

Figure 2: Penetration Number vs. % of CRM

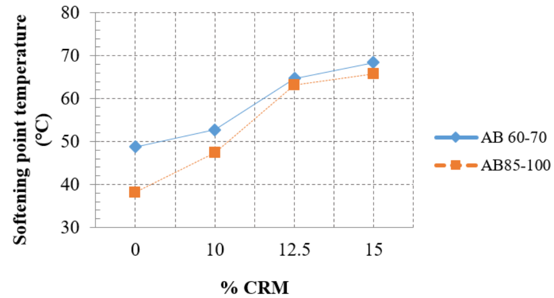

Figure 3: Softening Point Temperature vs. % of CRM

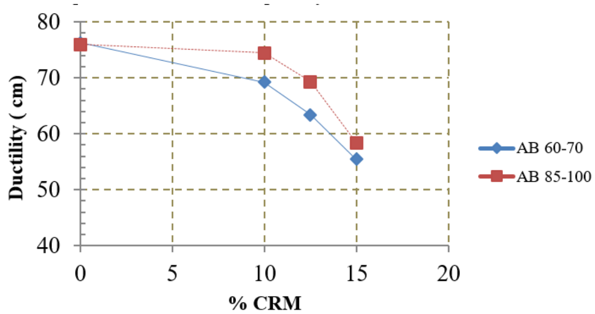

Figure 4: Ductility vs. % of CRM

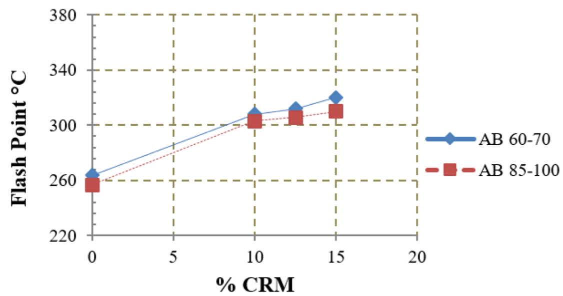

Figure 5: Flash Point vs. % of CRM

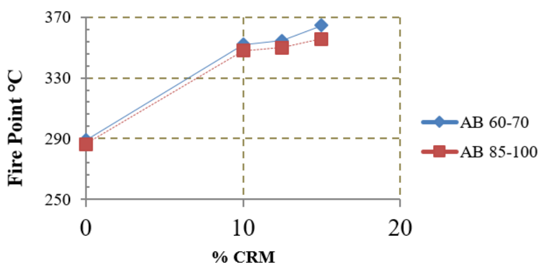

Figure 6: Fire Point vs. % of CRM

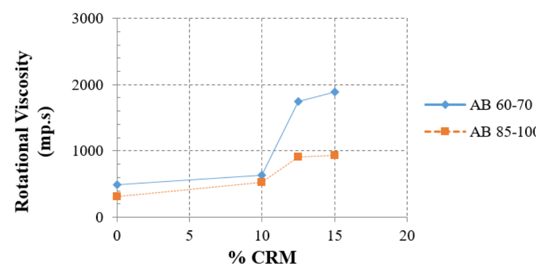

Figure 7: Rotational Viscosity vs. % of CRM

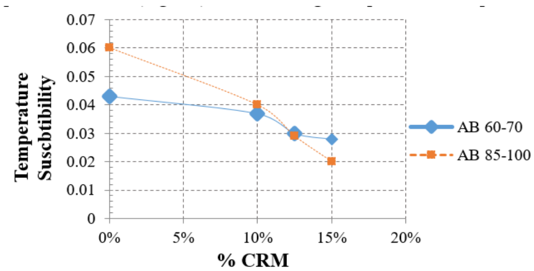

Figure 8: Temperature Susceptibility vs. % of CRM (PI Method)

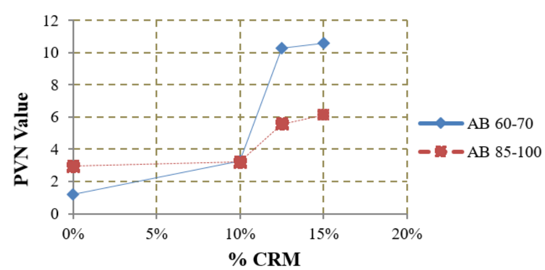

Figure 9: Temperature Susceptibility vs. % of CRM (PVN Method)

Statistical Analysis

The experimental data was statistically analyzed using the Statistical Package for Social Sciences (SPSS Inc. Version 23). Descriptive statistics, independent samples t-test, One-Way Analysis of Variance (ANOVA) or the so called Completely Randomized Design (CRD) and Two-Way ANOVA (AKA the Two Factor Factorial Design; TFFD) were used. Table 2 provides a summary of the descriptive statistics pertinent to all laboratory work conducted as part of this study.

In this study the basis for comparison was the asphalt types (called factor) in which there are two types (called groups), 60-70 and 85-110. It was found that the homogeneity of variance assumption is met (p-value greater than 0.05) for all asphalt physical tests except the softening point and RV tests where the p-value is less than 0.05. From the t-test for Equality of Means, only penetration showed statistically significant difference in behavior for 60-70 asphalt binder as compared to 85-100.

Table 2: Overall Descriptive Statistics

	N	Min.	Max.	Mean	Std.Deviation	Variance	Skewness	Kurtosis
Penetration	24	44.0	91.0	68.7	10.8	117.3	0.17	0.40
Softening Point	24	37.0	69.2	56.2	10.5	110.3	-0.41	-1.19
Ductility	24	53.2	80.2	67.8	7.9	62.6	-0.33	-1.01
Flash Point	24	255.0	322.0	297.4	22.6	512.1	-1.08	-0.53
Fire Point	24	285.0	368.0	337.5	29.9	894.4	-1.10	-0.62
RV	24	310.0	1920.0	930.2	560.5	314171.0	0.82	-0.84

One-Way ANOVA hypothesis tests the difference in population means for more than two groups based on one characteristic or factor. Four groups are used in this single-factor analysis called CRM Content (%). Groups are 0%, 10%, 12.5% and 15%. It was found that the homoscedasticity assumption check is satisfied for all asphalt binder physical tests except softening point and RV tests. Not meeting the test of homogeneity of variances assumption does not matter much as ANOVA test is robust and can overcome this violation.

The one-way ANOVA test with CRM Content in percent having four levels (0%, 10%, 12.5% and 15%) considered as the factor whose effect on penetration, softening point, ductility, flash point, fire point and RV values was evaluated. Results revealed that changing CRM Content has a statistically significant effect on all physical performance-related values on the 0.05 significance level.

Two-Way ANOVA tests perform comparisons between populations based on multiple characteristics or factors. In this study, the two factors considered are Asphalt-Types (60-70 and 85-100) and CRM Content in percent (0%, 10%, 12.5% and 15%).
Table 3 summarizes the two-way ANOVA results for all tests; viz. penetration, softening point, ductility, flash point, fire point and RV tests. It is obviously shown that the combined effect of Asphalt-Types and CRM Content is statistically significant, on the 0.05 significance level, only for softening point, ductility and RV tests. Consequently, the combined effect is NOT statistically significant when considering penetration, flash and fire point tests. Besides, Table 3 presents the individual effects of Asphalt-Types and CRM Content on asphalt physical properties.

Table 3: Tests of Between-Subjects Effects for the Two-Way ANOVA

Dependent Variable: Penetration					
Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F**	**Sig.**
Asphalt-Types	1040.1	1	1040.1	25.1	.000
CRM Content (%)	937.3	3	312.4	7.5	.002
Asphalt-Types * CRM Content (%)	59.1	3	19.7	0.4	.702
Dependent Variable: Softening Point					
Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F**	**Sig.**
Asphalt-Types	153.0	1	153.0	46.8	.000
CRM Content (%)	2259.8	3	753.2	230.8	.000
Asphalt-Types * CRM Content (%)	72.3	3	24.1	7.3	.003
Dependent Variable: Ductility					
Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F**	**Sig.**
Asphalt-Types	23.8	1	23.8	3.9	.065
CRM Content (%)	1235.3	3	411.7	68.1	.000

Asphalt-Types * CRM Content (%)	84.4	3	28.1	4.6	.016
Dependent Variable: Flash Point					
Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F**	**Sig.**
Asphalt-Types	308.1	1	308.1	87.0	.000
CRM Content (%)	11389.8	3	3796.6	1071.9	.000
Asphalt-Types * CRM Content (%)	23.1	3	7.7	2.1	.130
Dependent Variable: Fire Point					
Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F**	**Sig.**
Asphalt-Types	145.0	1	145.0	10.0	.006
CRM Content (%)	20165.7	3	6721.9	466.2	.000
Asphalt-Types * CRM Content (%)	30.4	3	10.1	0.7	.563
Dependent Variable: RV					
Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F**	**Sig.**
Asphalt-Types	1109185.0	1	1109185.0	1366.0	.000
CRM Content (%)	4716445.8	3	1572148.6	1936.1	.000
Asphalt-Types * CRM Content (%)	1387310.3	3	462436.7	569.5	< .001

Environmental Impact Analysis

When compared to energy recovery and landfill disposal, the use of crumb rubber in asphalt has significant environmental and energy savings advantages. Due to the decrease in raw materials and increased pavement service life, it solves the issue of disposing of used tires and produces material savings and environmental advantages. During the rehabilitation stage, using rubberized asphalt hot mixes could use less energy than using conventional asphalt mixtures, saving landfill space and reducing transportation costs.

Wang et al. (2018) claimed that the longer service life and lower raw material requirements of rubberized asphalt applications resulted in energy savings. Energy consumption could also be reduced due to less engineering material uses such as aggregate savings. Due to overall savings, energy usage might be decreased as well. Using rubberized asphalt technique instead of traditional HMA solution resulted in energy savings of 28.651 kWh/m^3 [23]. Application of rubberized asphalt resulted in energy savings of 47% of the total energy used during the repair or rehabilitation stage [43]. In addition, less landfill space is needed and recovered rubberized asphalt does not need to be carried away to disposal site, thus, consume less energy than conventional asphalt mixtures during the rehabilitation stage [23].

Rubberized asphalt is particularly appealing and useful in highway construction because of the energy savings and additional advantages like fewer maintenance and cracking. Rubberized asphalt has better mechanical performance, which allows for lower maintenance and conservation costs over the course of the service cycle, resulting in significant energy and natural resource savings. Rubberized asphalt technique reduced the environmental impact of highway construction by 5% to 10% compared to traditional technology. The benefit came about as a result of the rubberized asphalt road's reduced thickness and the materials, energy, and fuel that were saved during construction [44]. Better structural and functional performance from rubberized asphalt could significantly lessen the environmental impact.

Additionally, the traditional method of producing rubberized asphalt requires a lot of energy because the material's high viscosity necessitates a higher mixing temperature and longer mixing time. However, the Wet Mix Asphalt (WMA) technology has the potential to reduce rubberized asphalt's viscosity and further lower the mixing temperature and duration, resulting in a 20% to 25% fuel savings [23]. The inclusion of rubber powder may reduce the frequency of noise at the tire-to-pavement interaction [45]. One of the advantages of rubberized asphalt pavement for the environment is the noise reduction it provides. When compared to conventional pavement, asphalt rubber can lower tire-pavement noise by 40% to 88% in the frequency range of 500 to 4000 Hz [23].

Conclusions

To examine the physical properties of modified asphalt binders, three percentages of CRM rubber were used to modify asphalt binders 60-70 and 85-100. Based on the work carried out in this study, the following conclusions can be made:

1. The addition of CRM rubber modifier to asphalt binder at increased proportions does not always improve the behaviour of bitumen, it may reflect negatively on its properties. The reduction percentage in penetration number and ductility for modified binders is significant and as it is known that the bitumen with insufficient penetration or ductility gets cracked when subjected to repeated traffic loading. This result can be explained by the fact that the CRM rubber particles tend to absorb the oils from asphalt binder and swell.
2. Adding CRM to the base asphalt has shown an improvement in viscosity, softening point values and safety characteristics. Consequently, improved rutting resistance and extended service life are expected.
3. According to SuperPave specifications, the asphalt binder rotational viscosity must not exceed 3 Pa.s. The addition of CRM rubber modifier increases the binder viscosity, but it can be noticed that the viscosity still in the acceptable range.
4. Different statistical methods have been utilized and provided evidence of the following:
    a. According to the results of the independent sample t-tests, penetration is the only physical test that showed statistically significant difference in behaviour between 60-70 and 85-100 asphalt binders.
    b. One-way ANOVA results revealed that using CRM Content has a statistically significant influence on all performance-related physical tests.
    c. Two-way ANOVA results exposed that the combined effect of Asphalt-Types and CRM Content is statistically significant only for softening point, ductility and RV tests.
5. Rubberized asphalt technique reduced the environmental impact of highway construction by 5% to 10% compared to traditional practice.

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