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ASPHALT BINDER MODIFICATION IN FLEXIBLE PAVEMENT USING DIFFERENT AMOUNTS OF CRUMB RUBBER

SABER SHAH -SABERI*[1], RAIDY GUL-HAMDARD [2], WALIULLAH QASIMI[2]

Abstract: Every year, thousands of tires made of crumb rubber are consumed as scrap. By burning this material, more landfill space is needed, which poses a health risk and environmental problem. The study concentrated on using crumb rubber in PG76 performance grade and 80–100 penetration grade asphalt binder mix. Using the wet method, the asphalt binders were combined with waste crumb rubber to create a powder form of 40 mesh (0.425 micron). The study focused on replacing 15%, 20%, and 25% of the modified asphalt binder mix's total weight with crumb rubber. The Malaysian JKR/SPJ/2008-S4 standard and the American Society for Testing and Materials (ASTM) served as the foundation for the laboratory work. Numerous tests were carried out, including pressure aging vessel (PAV), rolling thin film oven test (RTFOT), penetration, softening point, and viscosity testing on modified asphalt binder. The outcome demonstrates a beneficial effect, with penetration decreasing as 80–100% and PG76 blend asphalt binder are partially substituted with crumb rubber. In contrast to the 80–100 asphalt binder, the PG76 asphalt binder result exhibits reduced penetration in terms of stiffness throughout both short- and long-term aging. The softening point test results indicate that replacing a portion of the asphalt binder with crumb rubber raises the temperature of the PG76 and 80–100 asphalt binder mix. This is especially true after the PG76 short-term aging test (RTFOT) at 20% replacement, when the temperature reached 85 °C, and after the long-term aging test (PAV), when the temperature dropped to 75 °C.However, resistance to increased temperature susceptibility is indicated by the partial replacement of asphalt binder with crumb rubber. According to the results of the viscosity test, the PG76 asphalt binder is more viscous than the original PG76 and the 80–100 asphalt binder replacement made of crumb rubber mix. For the short-term aging (RTFOT) test, the PG76 asphalt binder suggests that a crumb rubber replacement of 20% is ideal. When compared to the RTFOT test, the viscosity decreased in the long-term aging (PAV) test.

Keywords: Crumb Rubber, Modification, Asphalt Binder Mix, Replacement.

[1]**Address:** Shaikh Zayed University, Faculty of Civil Engineering, Khost/Afghanistan
[2]**Address:** UTM Univesity/ UTM, Engineering Faculty, 12345, Johor, Malaysia

***Corresponding author**: s.sabershah@mail.com

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1. INTRODUCTION

Asphalt binder is characterized by both polar and rheological properties. The main motivation for modifying asphalt binder arises from the limitations of conventional refining methods in producing high-performance binders from crude petroleum oil. Research has shown that modification through advanced refining techniques, chemical reactions, and/or additives can significantly improve the functional properties of asphalt binder and increase its resistance to various forms of pavement deterioration. A recent survey of forty-seven State Highway Agencies in the United States revealed that thirty-five agencies intend to increase their use of modified binders in new road construction. Twelve agencies plan to maintain their current usage levels, while a few indicated a reduction. Premature pavement distresses, particularly fatigue cracking and rutting, were identified by most agencies as the main reasons for adopting modified binders (Bahia et al., 1997)Due to the tremendous chemical complexity of asphalt, conducting a comprehensive chemical investigation is often not feasible (Read and Whiteoak, 2003). Scrap rubber and tires have long been recycled for use in highway and road construction across many Asian, European, and African countries. The incorporation of crumb rubber offers multiple

Benefits: it reduces landfill demand, mitigates environmental impact, and conserves raw materials used in road building. Previous studies (Bahia et al., 1994) have shown that crumb rubber can be incorporated into asphalt binders and paving materials through various mixing and blending techniques, most notably the dry and wet processes. In the dry process, crumb rubber is blended with hot aggregate prior to asphalt addition, whereas in the wet process, crumb rubber is blended directly with asphalt binder before application.Crumb rubber–modified (CRM) asphalt binders generally require higher compaction temperatures compared with conventional mixtures (Amirkhanian and Corley, 2004). Insufficient compaction temperatures can lead to poor volumetric properties, such as excessive air voids, ultimately reducing both short- and long-term pavement performance. Furthermore, the increase in viscosity associated with CRM binders can hinder mixture workability, necessitating elevated compaction temperatures to maintain optimal binder viscosity and ensure satisfactory pavement performance.

1.1 Problem Statement

Urban and highway pavements are typically designed for a service life of 10 to 20 years. However, in practice, pavement deterioration often occurs well before the end of this design life. One of the major contributing factors is the repeated application of heavy traffic loads, which generate tensile strains in the bottom layers of the pavement, ultimately leading to fatigue cracking. Similarly, rutting is a prevalent distress mechanism, particularly in warmer regions such as North Africa and South Asia, where the accumulation of compressive strains at the top of the subgrade layer deforms the pavement surface.To enhance pavement durability and performance, numerous trials have investigated the use of crumb rubber as a modifier in asphalt binders. Incorporating crumb rubber into Hot Mix Asphalt (HMA) not only provides an environmentally responsible solution for recycling industrial waste but also improves the overall efficiency and performance of asphalt mixtures produced in industrial mix plants.

1.2 Objectives of Study

The study's main goal is to partially replace the weight of the blended asphalt binder mix utili zing waste crumb rubber at varied percentages (15, 20, and 25%) through a wet process.The p articular goals are:

1) To assess the physical characteristics of the asphalt binder while using crumb rubber as a partial replacement at different weight percentages (15, 20, and 25%) relative to the total weight of the blended asphalt binder mix.
2) To assess the short- and long-term aging performance of replacing asphalt binder with crumb rubber.
3) To ascertain the ideal percentage of crumb rubber substitution in the asphalt binder mix composition

1.4 Scope of Study

This study focuses on evaluating the physical properties and performance of asphalt binder partially replaced with crumb rubber at varying proportions (15%, 20%, and 25% by total binder weight). Two types of asphalt binders will be examined: performance grade PG-76 and penetration grade 80–100. Multiple sample sets will be prepared, each incorporating different crumb rubber contents and subjected to varied mixing temperatures. All experimental work will be conducted at the Highway and Transportation Laboratory, University Technology Malaysia (UTM), in accordance with the standards specified by the American Society for Testing and Materials (ASTM) and JKR/SPJ/2008-S4. To assess the characteristics of crumb rubber–modified (CRM) asphalt binders, a comprehensive testing program will be implemented. The tests will include viscosity, softening point, penetration, rolling thin film oven (RTFOT), and pressure aging vessel (PAV) evaluations.

1.3 Importance of Research

The creation of a novel, modified asphalt binder including crumb rubber is the study's anticipated result. The CRM asphalt binder is made to reduce pavement costs while improving ride quality. Use crumb rubber in construction in place of certain asphalt binder. Lastly, the development of CRM asphalt binder will contribute to the creation of green and sustainable roads and highways by addressing the issue of industrial waste crumb rubber.

2. LITERATURE REVIEW

2.1 Asphalt Binder

Asphalt, commonly referred to as bitumen, is derived from petroleum oil, which originates from the remains of marine organisms and plant materials deposited on the ocean floor millions of years ago (Whiteoak, 1991). Over time, the immense weight of the overlying sediments compressed the lower layers, while heat from the Earth's crust transformed these organic materials into petroleum. Large subterranean reservoirs are formed when petroleum is trapped beneath impermeable rock layers. Occasionally, faults in the overlying strata allow petroleum to migrate and accumulate near the surface. In modern practice, pile drilling techniques are employed to extract petroleum from subsurface reservoirs (Whiteoak, 1991).Only a small fraction of crude oil is suitable for use as a primary component in asphalt design mixtures. According to British Standard 3690: Part 2 (1989), asphalt is defined as a viscous liquid or solid predominantly composed of hydrocarbons and their derivatives. It may be obtained either from refined crude petroleum oil or as a naturally occurring deposit, sometimes in combination with mineral matter.

2.2 AsphaltBinderModification

Ordinary asphalt is used on most public roads and highways to create well-performing pavements. However, the demand for new roads increases annually due to the growth in automobile traffic. Eventually, these roads face significant problems, the most severe of which are caused by heavy truck loads and extremely high temperatures. Furthermore, because high standards for safety, riding comfort, maintenance frequency, and service life have become critical considerations in road design, it is essential to improve the properties of asphalt binders to enhance performance and reduce pavement distress (Brule, 2007).The ideal binder should maintain low viscosity at typical placement temperatures while exhibiting improved cohesion and minimal temperature susceptibility across the range of service temperatures. Its fatigue resistance, fracture strength, and resistance to permanent deformation should be high, while its sensitivity to loading rate should be minimal. Additionally, it should possess adhesion properties comparable to those of conventional binders. Finally, its aging characteristics should be favorable both during placement and throughout its service life (Brule, 2007).

2.3 Crumb Rubber

The Rubber Manufactures Association reports that a significant number of scrap tires, or crumb rubber, are consumed annually and that these tires are causing grave issues such an increase in landfill area and environmental issues (Snyder, 1998). Using the crumb rubber in the modification of asphalt binders is one of the techniques that have been used in an effort to find more efficient ways to recycle the tires with crumb rubber. According to reports, the up to 40% of crumb rubber can be absorbed by the asphalt industry (Avraam, 2005). Tires are mostly made of rubber, steel, and fiber. Of them, rubber makes up the majority of the tire's composition (around 60% of its weight). Furthermore, the rubber is made up of a variety of substances, including carbon black, various mineral fillers, and natural and synthetic rubbers (Mark et al., 2005). The percentage of natural and synthetic rubber varies between truck and passenger vehicle tires, but overall, ground rubber is rather uniform, and the ground rubber industry is not dependent on any one tire type (Ruth, 1995). The impact of ground tire particle size and grinding technique on asphalt binder qualities was investigated by the National Center of Asphalt Technology (NCAT). Twelve samples of crumb rubber combined with one asphalt binder were used in the study. Twelve mixes containing 10% crumb rubber by weight of asphalt were created, and two further mixes containing 15% rubber were created. According to test results on performance grade, crumb rubber's surface area and particle size had the biggest effects on raising the high-temperature performance grade.

Figure 1. Industrial waste (crumb rubber)

Generally speaking, there are two different processes used to make Crumb Rubber Modified (CRM) binder: wet and dry. Fine CRM and asphalt binder are blended together during the wet process. Coarse CRM is substituted for aggregate in the asphalt mixture during the dry phase. According to Takallou et al. (1991), the wet procedure is more effective at enhancing the characteristics and functionality of an asphalt mixture. Given its propensity to absorb liquids and swell, crumb rubber is a cheap modifier for asphalt binder that enhances paving performance and safety for the highway pavement sector (Amirkhanian, 2003).

Figure 2. Different sizes of crumb rubber

2.4 Asphalt Rubber

The American Society for Testing and Materials (ASTM) defines asphalt rubber (AR) as "a blend or mix of asphalt binder, reclaimed tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt binder." The necessary physical characteristics are outlined in ASTM D 6114, "Standard Specification for Asphalt Rubber Binder," which can be found in Vol. 4.03 of the *Annual Book of ASTM Standards* (2001), as well as in the Caltrans Standard Special Provisions for Asphalt Rubber Binder. To maintain crumb rubber particles in suspension and promote physical interaction between the asphalt binder and rubber constituents, asphalt rubber is manufactured at high agitation temperatures (≥177°C). Different extender oils may also be added to improve workability, facilitate spray applications, and reduce viscosity.The reclaimed rubber, also known as crumb rubber modifier, is made from waste tire rubber. Tire thieves combine natural rubber, synthetic rubber, fillers, carbon black, and oils of the extender kind that dissolve in hot 12 grade asphalt. According to California specifications, asphalt rubber must contain between 18 and 22 percent crumb rubber that has been adjusted by the mix's total mass. Additionally, scrap rubber with a high natural rubber content (25 ± 2 percent by mass) that may come from waste tires or other sources must be included in the CRM.

2.5 Wet Process

There are generally two methods for combining waste crumb rubber and asphalt binder: the wet method and the dry method. Compared to the dry process, the wet method is preferred due to its superior resistance to fatigue and rutting. The wet technique involves mixing asphalt binder with crumb rubber prior to adding heated aggregates (Takallou, 1988). The interaction process depends on several variables, including blending temperature and duration, crumb rubber particle size, quantity and type of mechanical mixing, and the type of asphalt binder. During the wet process, the asphalt binder's aromatic components are incorporated into the polymer network of the natural and synthetic rubber (Heitzman, 1991).

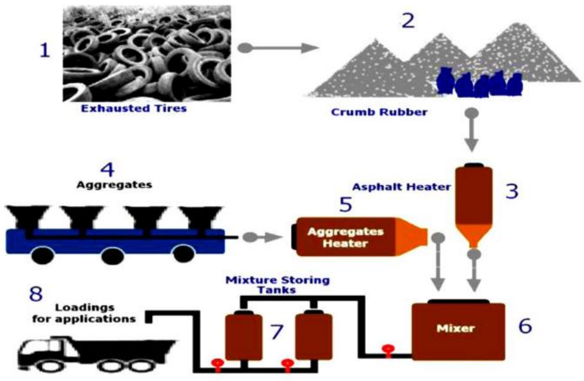

Figure 3. Wet process procedure

2.5.1 Performance of Wet Process

Several researchers have assessed the effectiveness of CRM mixtures produced using the wet technique in both laboratory and field settings. Compared to conventional mixtures, crumb rubber blends produced with the wet method demonstrated superior fatigue resistance in terms of mechanical performance (Harvey et al., 2000; Oliver, 2000). Similar results using the wet technique were observed in dense-graded surface courses, gap-graded surfacing, and binder courses in Louisiana after five to seven years of traffic exposure (Huang et al., 2002). Oliver (2000) also found that the fatigue life of mixtures with 6% or lower binder content was poor and inconsistent. The rut depth of the wet-process mixtures used in Louisiana was equal to or lower than that of the conventional mixtures (Huang et al., 2002).

2.6 **Dry Process**

In the dry method, heated aggregates and crumb rubber are combined before adding asphalt binder. One dry method, known as Plus Ride, involves adding 1–3% crumb rubber to the mixture, with particle sizes ranging from ½ inch to a No. 10 sieve (Federal Highway Administration, 1998). The air void content, typically between two and four percent, is the primary consideration in the design of the Plus Ride system. Other important variables include the temperature and duration of binder interaction with the ground rubber. These parameters must be carefully controlled to ensure that the ground rubber particles maintain the required stiffness and physical form. Studies conducted in various states have reported mixed results, with some indicating improvements in physical properties and others showing a net economic loss compared to conventional pavement mixtures (Huang et al., 2007).

2.7 Surface Distress Mechanisms: An Overview

Numerous researchers offer explanations for the distress mechanisms of various hot mix asphalts (HMA).The state of the pavement structure that shortens its service life or suitability is called distress. The outward manifestations of various distress processes, which typically result in a decrease in serviceability, are known as distress appearances. Repeatedly high traffic volumes and environmental conditions cause distress. Several distresses can occur on pavement, including rutting, fatigue cracking, delimitation shoving, distortion, raveling, and slippage. These are often caused by strong traffic loads on the pavement surface (Mohamed, 2007).

2.7.1 Permanent Deformation

The accumulation of a tiny quantity of unrecoverable strain brought on by repeatedly applying loads to the pavement results in permanent deformations. Unbound base course, troublesome subgrade, or HMA can all lead to rutting. Consolidation and lateral movement of hot mix asphalt (HMA) under traffic are the main causes of the persistent deformation in HMA. The top 100 mm of the pavement surface is often where hot mix asphalt (HMA) shear failure happens. But if the right materials aren't employed, it might go deeper (Moha, 2007).


Figure 4. Permanent Deformation (Rutting)

2.7.2 Fatigue Cracking

When strong traffic loads create a horizontal build-up of tensile strain at the bottom of the hot mix asphalt (HMA) layer, fatigue cracking of flexible pavements results. Tensile strain and the permissible number of high load repetitions are related by the failure criterion. The Hot Mix Asphalt (HMA) bottom is where the cracking starts since there is the most tensile strain under wheel load. At first, the cracks spread as one or more longitudinal, parallel fractures. The fractures get joined in a way that mimics an alligator's skin after recurrent strong traffic loads (Mohamed, 2007).

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Figure 5. Permanent Deformation (Rutting)

2.7.3 Penetration Test

Figure 2.7 illustrates how the concentration of crumb rubber affects the penetration of hot-mix asphalt (HMA). Up to 20% of the total crumb rubber content causes the penetration to decrease. This indicates that the penetration value is significantly influenced by the content of crumb rubber–modified bitumen (CRM). According to Liu et al. (2009), crumb rubber content plays an important role in reducing the penetration value by making the asphalt binder more rigid. This leads to higher resistance to rutting and other forms of permanent deformation. For crumb rubber concentrations ranging from 4% to 20%, the penetration of the modified binder was reduced on average by 16.5% to 61%. Furthermore, the linear reduction in penetration is illustrated in Figure 2.7, where the correlation coefficient is $R^2 = 0.99$. This behavior is expected because the inclusion of crumb rubber increases the viscosity of the asphalt binder. The effective particle size of the rubber increases with higher crumb rubber content, reducing asphalt penetration due to increased interaction between rubber and asphalt during mixing. Consequently, the rubberized asphalt binder is less susceptible to high temperatures and more resistant to rutting.

2.7.4 Softening Point Test

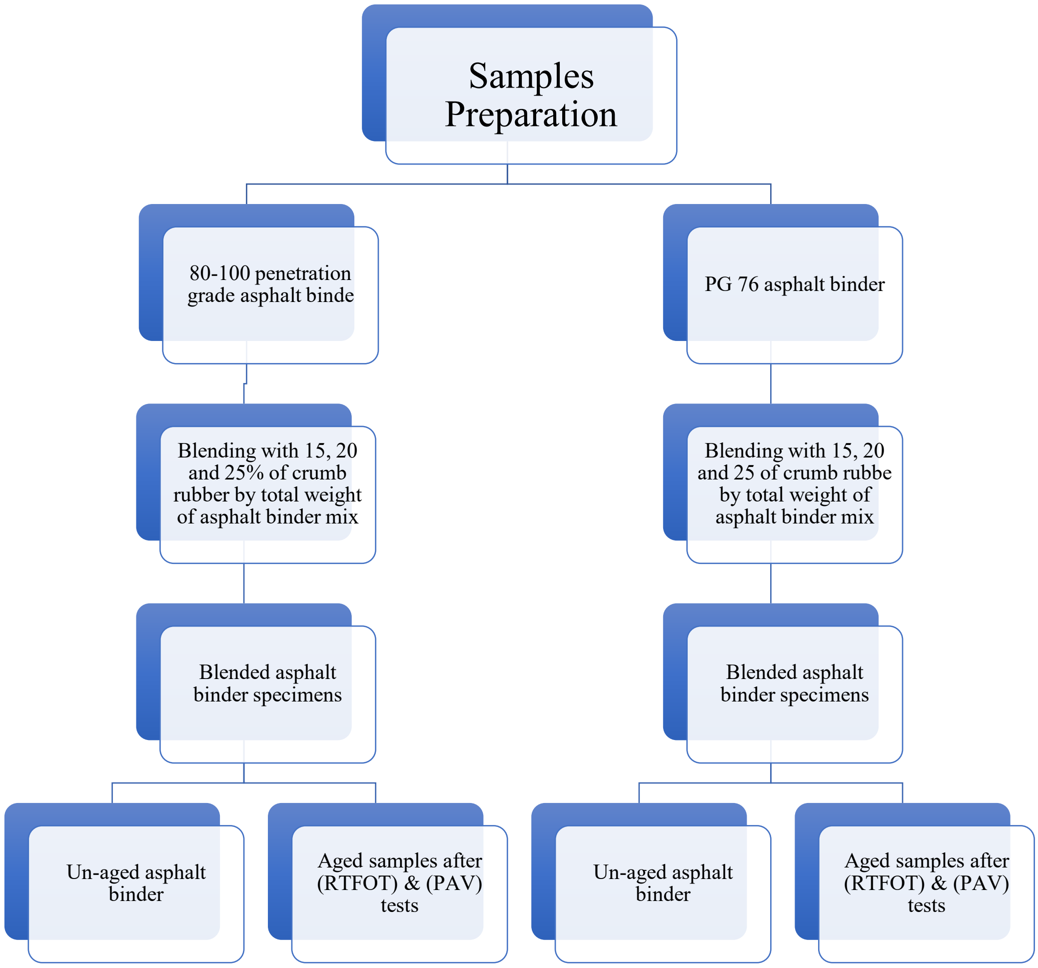
The temperature at which asphalt reaches a specific level of softness is known as the softening point. The softening point increases with higher crumb rubber content when asphalt binder is modified with crumb rubber (Nuha, 2011). The amount of crumb rubber mixed with the asphalt binder affects the characteristics of the blend. Higher rubber content results in significant changes in blend properties, including increases in viscosity, resilience modulus, softening point, and penetration at 25°C. The modified blend also exhibits improved strain values, flexural strength, dynamic stability, and 19–48 h residual stability. Asphalt incorporating rubber particles of 0.2 and 0.4 mm in size produced the best experimental results (Souza and Weissman, 1994).When asphalt and crumb rubber are combined at high temperatures, bitumen components penetrate the rubber, causing it to swell, and interact to form a modified binder during the wet process (Bahia and Davies, 1994). The aromatic oils in the bitumen cause the rubber particles to expand during the initial non-chemical interaction between the asphalt binder and crumb rubber (Heitzman, 1992).

2.7.5 Viscosity Test

Higher crumb rubber content, according to a study, improved the rutting potential qualities and produced more viscosity at 135°C. Additionally, it was noted that higher amounts of fine crumb rubber led to rubberized asphalt binder that had a higher viscosity and a lower resilience modulus (Magar and Nabin, 2014). For every size of crumb rubber and asphalt binder, the ideal crumb rubber content still needs to be ascertained and assessed. The effective physical characteristics and size of the rubber particle are thought to be changed by a physicochemical interaction that takes place between the asphalt and the crumb rubber (Huang et al., 2007). Because of the way that base binders and modified asphalt binder interacted, pavement performance with the use of crumb rubber was superior to that of base binders. The enhancement may result in pavements with a high resistance to rutting (Huang et al., 2007).

3. MATERIAL AND METHOD

This chapter outlines the materials, sample preparation, and testing procedures required to evaluate the performance of crumb rubber–modified (CRM) asphalt binder and achieve the study's objectives. Two types of asphalt binder (AB) are used in this study: performance grade PG76 and penetration grade 80–100. For the 80–100 and PG76 binders, the blending temperatures with crumb rubber are 160°C and 185°C, respectively. In this study, different percentages of crumb rubber (CR) (15%, 20%, and 25%) were used to partially replace the total weight of the asphalt binder mix.The experimental procedures followed the Malaysian JKR standard (JKR/SPJ/2008-S4) and the American Society for Testing and Materials (ASTM), as illustrated in Figure 3.2. The laboratory work includes physical and rheological tests to evaluate the behavior of crumb rubber when used as a partial replacement of the asphalt binder.



3.1 Crumb Rubber Modified (CRM) Asphalt Binder

One provider provided the crumb rubber (CR) used in this investigation. Previous investigations indicated that the lower crumb rubber particle size was experimental work tests physical ASTM D5 Penteration Point; ASTM 4402 Viscosity; ASTM 4402 Rehomological Tests For features of crumb rubber asphalt binder, such as cracking resistance and permanent deformation, RTFOT ASTM 2872 PAV ASTM D454 Result and Data Analysis Conclusion 24 is more effective (Glover and Bullin, 1997). Rubber that had passed through a 40 mesh (0.425 mm) filter was used to create CRM binder, which allowed for inexpensive efficiency and homogenized modification.

Figure 6. Blending Process

Table 1. Test Standard and Equipment

Test Standard	Type of Test	Equipment	Description
ASTM D5	Penetration	Penetrometer	25°C, 100gram, 5 sec
ASTM D36	Softening Point	Ring and Ball	3.5g steel ball, Thermometer for softening temperature
ASTM D 4402	Viscosity	Rotational Viscometer (RV)	135°C and 165°C, spindle 27, 20rpm
ASTM D 2872	Short-term aging	Rolling Thin Film Oven (RTFOT)	163°C for 85min
ASTM D 6521	Long term Aging	Pressure Aging Vessel (PAV)	2.1Mpa for 20 hours

3.2 Penetration Test

The penetration test is regarded as the most traditional physical test for asphalt binder and is used to gauge the consistency of the material. The asphalt binder penetrations measure the centimeters to which a standard needle can pierce the material under constant loading, temperature, and time conditions. The penetration test standard procedure used predetermined conditions, with a fixed temperature of 25°C/75°F, a constant weight of 100g, and a known time of 5 seconds. The test was carried out on both pure and modified asphalt binder with different percentages of crumb rubber (15, 20, and 25%). For instance, the asphalt binder 80-100 penetrations show that the asphalt's range of penetration is 80-100, measured in tenths of a millimeter. A tougher grade of asphalt binder is crucial, as indicated by the lower penetration value.

3.2.1 Procedures of Penetration Test

a) The sample was heated until it melts to pour.

b) The sample was then poured in a specific sample container for penetration test to a depth such that when cooled and kept at room temperature of a test of 25°C.

c) Each container was covered as a protection from dust and allowed it to cool for 1 to 1½ hours for the small container and 1½ to 2 hours for the larger container.

d) The samples were placed in the water bath and maintained the temperature to 25°C for 1 to 1½ hours depending on container choosing.

The penetration needle was cleaned with benzene and dried with a clean cloth.

a) The sample container (100g) was placed directly on the submerged stand in the penetrometer and sample was covered in water bath 25o + 0.5oC.

b) The needle was positioned slowly lowering it until it's just makes contact with the surface of the sample.
c) The pointer of penetrometer was set to zero.

d) The needle holder was released for the specific period of time (5sec) and the distance penetrated was measured in 1/10mm reading.
e) The needle was cleaned after the result was taken.
f) Three determinations were made at points on the surface of the sample not less than 10mm from the side of the container and was obtained the average reading of penetration

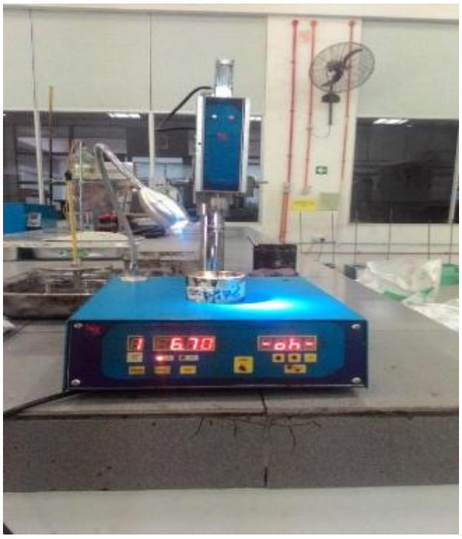


Figure 7. Penetration test setup

3.3 Viscosity Test

Resistance to flow is known as viscosity, and it is a basic property of asphalt binder that governs the material's behavior both at a specific temperature and across a temperature range. The Superpave PG asphalt binder specification test is always carried out at high temperature, which is 329°F (165°C), and at 275°F (135°C). The basic RV test calculates the torque needed to keep a cylindrical spindle submerged in an asphalt binder at a consistent temperature and rotating at a constant speed of 20 revolutions per minute. The RV then automatically converted this torque to a viscosity and presented it. The ASTM D4402 test process was followed in the description that follows.

3.3.1Procedures of Viscosity Test

a) Spindle, sample chamber, and viscometer environmental chamber
(Thermosel) were preheated to (135°C).

b) The unaged and aged asphalt binder were heated until fluid enough to pour. Stir the sample, being careful not to entrap air bubbles.
c) (11g) the weight of asphalt binder was poured into sample chamber; the sample size varies according to the selected spindle (number 27 spindle).

d) Sample chamber was inserted into the rotational viscometer (RV) temperature controller unit and carefully lowered spindle into the sample.

e) The sample was brought to the desired test temperature (typically 275°F) (135°C) within approximately 30 minutes and allows it to equilibrate at test temperature for 10 minutes.

f) The spindle was rotated at 20 RPM, making sure the percent torque was indicated by the RV readout remains between 2 and 98 percent.
g) Once the sample was reached temperature and equilibrated, 3 viscosity readings from RV display were taken, allowing 1 minute between each reading. Viscosity was reported as the average of 3 readings.

Figure 8. Penetration test setup

3.4 Rolling Thin Film Oven Test (RTFOT)

The rolling thin-film oven test (RTFOT) is one of the rheological tests used to examine the behavior of hot mix asphalt (HMA) pavement at early stages, simulating short-term aging of an asphalt binder during the manufacturing or mixing process. The test also measures the mass change in the asphalt binder following the aging process. The RTFOT primarily simulates short-term aging of the asphalt binder during mixing, hauling, and compaction of HMA. Samples tested using RTFOT can subsequently undergo further evaluations, such as the Dynamic Shear Rheometer (DSR) test to measure rutting resistance. This test was conducted in accordance with ASTM D 2872.

3.4.1 Procedures of (RTFOT) Test
a) The sample of asphalt binder sample was heated until fluid or melted.
b) Two RTFOT bottles were labeled and weighed empty and the weights were recorded.
c) The 34.5g weight of asphalt binder was poured into each bottle.

d) The bottles were allowed to cool, after cooling, the two mass changes of bottles were weighed again and recorded the mass loss after the aging.
e) The main switch was turned on and the testing temperature was set at163ºC.

f) Once the temperature was reached 163ºC, the bottles were installed which contain asphalt binder was put into the slot in the oven.
g) The air compressor was turned on and the valve was set at a pressure of 4 bars.

h) The switch labeled "ALARM" was turned on to turn on the motor to spin the bottle in the oven.

i) This testing was completed after 85 minutes.
j) Finally, the test was completed and the pressure was returned to 0 and the air compressor was turned off.
k) The glass bottles were removed one by once carefully and poured the hot asphalt binder into the cup.


Figure 9. Rolling Thin Film Oven Test (RTFOT) machine

4. RESULTS AND FINDINGS

4.1 Introduction

This chapter's primary goal is to study and assess the findings from laboratory experiments in which the impact of substituting different percentages of crumb rubber powder for asphalt binder was examined. Physical testing was utilized in the laboratory to ascertain the physical characteristics of the aged and unaged asphalt binder and the crumb rubber modified mix. Viscosity, softening point, and penetration tests are part of the physical test. The rolling thin film oven and pressure aging vessel
Tests are part of the second step of rheological testing.

4.2 Chemical Components of Crumb Rubber

According to the American Society of Testing and Materials, Yong Fong Rubber Industries provided the crumb rubber in powder form (ASTM). The following is a list of chemicals that make up crumb rubber:

Table 2. Chemical components of the crumb rubber powder used in the study (Source: Young Fong Rubber industry)

Chemical Composition	**Values (%)**
Acetone Extract	10 ± 3
Ash Content	4 ± 3
Carbon Black	32 ± 5

4.3 Penetration Properties Results

A penetration test is typically used to determine the consistency of asphalt binder or the depth to which the material is penetrated by an asphalt binder standard needle under established loading, temperature, and time conditions. As an illustration, the asphalt binder penetration value is 90 if the needle penetrates at 9 mm. Based on penetration value, asphalt binder penetration grade is determined. To assess the impact of the crumb rubber powder percentages (15, 20, and 25%), this study will concentrate on two distinct types of asphalt binder penetration grade (80-100) and performance grade PG 76 containing varying percentages of crumb rubber powder. From the result shown in the Table 4.2 and 4.3 the penetration value of 80- 100 binder respectively of unaged asphalts binder of normal and modified asphalt binder with crumb rubber before the short term aging (RTFOT) and long-term aging (PAV) test.

Table 3. Penetration results of penetration grade 80-100 unaged modified asphalt binder

CR %	Test Number 1	Test Number 2	Test Number 3	Average	Overall Average
0	86.20	92.00	82.00	86.73	
0	88.70	86.20	90.50	88.46	85.14
0	78.00	90.50	72.20	80.23	
15	53.00	74.50	60.00	62.50	
15	49.50	51.00	51.70	50.73	55.56
15	53.20	50.50	57.50	53.73	
20	46.70	44.00	47.20	45.90	
20	48.70	52.20	48.70	49.80	46.72
20	43.70	46.70	43.00	44.46	
25	36.70	43.20	42.20	40.70	
25	40.00	43.00	44.00	42.50	43.03
25	42.20	44.70	42.00	42.90	

Based on Figure 4.1 the penetration value for 80-100 and PG76 are reduced, because the crumb rubber has a strong effect of decreasing the penetration value by increasing the stiffness of crumb rubberPowder of asphalt binder mix. The penetration values of performance grade PG76 of asphalt binder in original form and modified with crumb rubber showed the lower result when compared to penetration grade 80-100 asphalt binder. Therefore, it expected the Hot Mix Asphalt (HMA) using PG76 is more resistance to rutting potential compared with 80-100 asphalt binder

4.3 Penetration Properties Results

A penetration test normally used to measure the consistency of asphalt binder or measure the penetration of asphalt binder to which a standard needle penetrates the material under known conditions of time, loading, and temperature. For example (if the needle penetrates at 9mm, theasphalt binder penetration value is 90). The penetration grade of asphalt binder is based on penetration value. In this study will focus on two different types of asphalt binder penetration grade (80-100) and performance grade PG 76 containing various percentage of crumb rubber powder to evaluate the effect of crumb rubber powder percentage (15, 20 and 25%). 39 of unaged asphalts binder of normal and modified asphalt binder with crumb rubber before the short term aging (RTFOT) and long-term aging (PAV) test. From the result shown in the Table 4.2 and 4.3 the penetration value of 80- 100 binder respectively.Based on Figure 4.4 the penetration value for 80-100 and PG76 are reduced, because the crumb rubber has a strong effect of decreasing the penetration value by increasing the stiffness of crumb rubber powder of asphalt binder mix. The penetration values of performance grade PG76 of asphalt binder in original form and modified with crumb rubber showed the lower result when compared to penetration grade 80-100 asphalt binder. Therefore, it expected the Hot Mix Asphalt (HMA) using PG76 is more resistance to rutting potential compared with 80-100 asphalt binder

4.4 Softening Point Results

The result of softening point or the phase change of temperature of control and modified asphalt binder with crumb rubber before the short-term aging and longterm aging shown in the Tables 4.8 and 4.9 for penetration grade 80 - 100 and performance grade PG76 respectively. Figure 4.4 shows the crumb rubber powder percentage against softening point as the partial replacement of total weight of asphalt binder mix (15, 20, and 25%). The results shows the crumb rubber increasing the softening point of the crumb rubber modified asphalt binder, thus improving the asphalt binder to resist the high-temperature deformation in the road surface.
From Figure 4.5 shown the softening point of performance grade, PG76 indicates strong of temperature change of 61.5oC at 25% replacement compared with penetration grade 80-100 asphalt binder. The increasing of phase change of temperature indicates the asphalt binder more stiffness and hard to resist the effect of higher temperature.

5. DISCUSSION AND CONCLUSIONS

The purpose of the study was to determine how different percentages of crumb rubber powder, which were used to partially replace PG76 and 80-100 in the total weight of the asphalt binder mix, would affect the rheological and physical characteristics of the mixture both before and after aging. The Penetration, softening, rolling thin-film oven, viscosity, and pressure-aging vessel tests are the main emphasis of the examination.

From these tests results, the following conclusions were drawn for the materials used in this study:

i. The increase in percentages with partial replacement of crumb rubber will reduce the percentage value of penetration value for 80- 100 asphalt binder. However, the PG76 asphalt binder shows the lower result of penetration before and after short term and long term aging compared with 80 - 100 asphalt binder in term of stiffness. The optimum percentage of crumb rubber is the 15% as the partial replacement of total weight of asphalt binder after the long term aging.

ii . The softening point results shows that the percentage of replacement of asphalt binder with crumb rubber increased the temperature for penetration grade 80-100 and PG76 asphalt binder mix.

iii. The viscosity results shows that the PG76 asphalt binder replaced with crumb rubber has higher viscosity compared with penetration grade 80-100 asphalt binder replacement with crumb rubber before aging.

The study offers some advice and ideas to enhance the outcome in the future when employing crumb rubber as a partial replacement.

I. When replacing the entire weight of the asphalt binder mix with varying percentages of crumb rubber, research should be done to examine and assess the physical and rheological characteristics of the mixture both before and after the aging process.

II. ii. Greater research should be done to assess the resistance to rutting and fatigue cracking using the Dynamic Shear Rheometer test (DSR). This will provide greater insight into the characteristics of the crumb rubber modified asphalt binder that can be used as a replacement both before and after the aging process.

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All work is done as reveiw paper, I have studied a lot of papers and has writen this paper.

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