Review of Mixing Mechanism and Performance of Natural Rubber with Bituminous Materials.

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Abstract. Road degradation is a common problem in Malaysia which caused by weather changes, expanding loads as well as the effects of ageing, moisture and temperature results in high maintenance expenses on conventional bitumen pavement. Therefore, it has been recommended on the modification of bitumen as a substitute technique to address this issue and extend the pavement's lifespan. This study addresses the inadequacy of existing solutions by focusing on the direct mixing approach and the use of pre-treatment using chemical solvent and some additives specifically on epoxidized natural rubber, natural rubber latex and cup lump natural rubber (CLNR). Additionally, this study intends to give a brief summary of how bitumen performance is improved by the inclusion of additives or modifiers by emphasizing the key attributes of modified bitumen after the addition of modifiers. Further information is also provided on the quantity and application method of each addition in order to determine the ideal value for different applications. This study will examine the use of several additives based on past research, such as polyphosphoric acid, Zychotherm, as well as the use of toluene and xylene to maintain the homogeneity of the rubberized bitumen. Studies on the usage of cup lump natural rubber (CLNR) are not common, thus future study should investigate more closely at CLNR and its mixing technique. This research contributes to the field by providing insights into the practical application of modified bitumen for sustainable road construction, especially in regions with a significant rubber industry.

1 Introduction

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One of the first known materials utilized in engineering is bitumen. Bitumen has been applied in several ways, such as an adhesive, waterproofing agent, pavement binder, and sealer. As time went on, bitumen's use spread quickly around the world, with pavement construction being its predominant use. Most roads with conventional asphalt function well, but when demands on them rise annually, and inadequate maintenance causes pavement degradation and a reduction in total life. Conventional asphalt may often lead to significant pavement failures, such as fatigue, ravelling, low temperature cracking, and strapping failures, when combined with extreme weather and high traffic. Asphalt binder becomes stiff at low temperatures and has a tendency to break under stress because of its temperature sensitivity. One strategy to improve the functionality of asphalt pavement is to modify the bitumen. In addition to polymer modified asphalt, or PMA, there are alternative methods that include modification using fillers such as fly ash, hydrated lime, carbon black and others. Nonetheless, PMA modification is one of the significant ways to improve road pavement. Prior research has yielded promising outcomes regarding bitumen modified with polymers, underscoring the use of polymers in bitumen, an area of considerable attention in recent times. The primary advantage of polymer technology is in its ability to enhance the bonding properties between bitumen and aggregate, resulting in a significant improvement in the efficiency of traditional bitumen [1]. By creating an aggregate coating material, polymer-modified bitumen enhanced the degree of cohesion, adhesion, and surface roughness of aggregates, leading to better bitumen mixes.

The objective of this review article is to thoroughly assess the process of adding epoxidized natural rubber, natural rubber latex and cup lump natural rubber to conventional bitumen in order to improve the result of rheological, chemical, and physical mixes qualities for improved road performance. As indicated in previous studies, the direct mixing approach and use of some chemical solvent and addition of additives are discussed. We highlight their application on bitumen modification and their noteworthy improvements to bitumen that has been changed. Furthermore, this research concentrates on the addition of xylene and toluene as a solvent for rubber treatment in order to guarantee the homogeneity of the rubber mixture.

2 Natural Rubber as a Bitumen Modifier

The empirical formula for NR was first determined and published to be C5H8. Since rubber is an elastomer, it may regain its original shape after being distorted by tension, compression, or shear. NR is an ecologically friendly elastomer that possesses strong cycle load performance and great elasticity with a high molecular weight of hydrocarbon polymers. These distinctive qualities include elasticity, thermal stability, resilience, and the ability to tolerate high strain [2]. There are three primary different types of natural rubber which are natural rubber latex (NRL), epoxidized natural rubber (ENR) and a recently developed type called cup lump natural rubber (CLNR) [3], which is created when latex is left to coagulate in the presence of bacteria.

Natural rubber made from a milky liquid called natural rubber latex (NRL) that drips from the bark of a tree (Hevea brasiliensis). In addition to its excellent elongation, fatigue resistance, and water resistance, this renewable and ecologically beneficial elastomer may be effectively mixed into asphalt to modify it. Additionally, by functioning as a membrane and enhancing shear strength, it regulates the flow characteristics of asphalt mixes at higher temperatures. In contrast to this, the NRL had a substantial influence on rheological high and low temperature performance and greatly increased the bitumen complex modulus and phase angle [4]. It is important to remember that the C=C double bond allowed for the chemical modification of NR's characteristics for certain uses. According to Mohd Azahar et al. (2019), NR assists in lessening the need on modifiers derived from petroleum as an affordable and ecologically sustainable biopolymer. Thus, widespread adoption of NR may extend the life of low-maintenance roads and encourage industrial economic growth, both of which would greatly enhance the ride quality. Rubberized mixes can also sustain several load cycles before breaking at a reduced strain. Higher strains encourage the creation of fractures since bitumen is hard and cannot be stretched due to its crystallized state.

Additionally, bitumen's physical characteristics have been examined using epoxidized natural rubber (ENR). Natural rubber is chemically altered to create ENR, which is formed by reacting natural rubber with a formic acid substitute. Due to its capacity to withstand strain crystallization, this material has good strength and a higher glass transition temperature. As a modifier, ENR is able to improve the complex viscosity, the storage and the loss modulus of mixes. It was discovered that while bitumen appears to be stiff, its ductile quality initially decreased after adding ENR before beginning to increase, indicating an increased in performance. Furthermore, storage stability shown that 6% ENR is stable when used as a binder at high temperatures.

Raw rubber in the shape of cup lumps has been acknowledged as an additive bitumen modification for the time being since it has the same attributes as natural rubber latex (NRL) and is ideal for combining with asphalt because it contains less water when placed on roadways. When formic acid is added to new latex to aid in coagulation, a rubber cup lump is created. According to [5], the viscosity and storage stability of cup-lump-modified bitumen (CLMB) are strongly impacted by the concentration of CLNR. The increase in mixing and compaction temperatures is directly correlated with the growth in bitumen stiffness. Additionally, using CLNR with additives shows better result in viscoelastic response at higher temperatures, enhanced penetration, softening point, and temperature susceptibility, as well as improved rutting resistance, rheological qualities, tensile properties, and moisture resistance. Since modified bitumen interacts complexly, it should be changed with many additives to improve a variety of features.

3 Mixing Method Challenges and Limitations

3.1 Direct Mixing

In accordance with [1], the natural rubber latex was mixed with the base bitumen at various mixing variables, including varying amounts of NRL modifiers (0, 2, 4, 6, 8, 10 and 12% by bitumen weight). Two mixing temperatures (140°C and 160°C), two mixing times (30 minutes and 60 minutes), and four mixing stirring speeds (500, 1000, 1500, and 2000 rpm) were the variables employed in the mixing procedure. Utilizing PEN 80/100 bitumen with 3% NRL, the investigation was initiated at 160°C, with a 30-minute mixing period and 500 rpm of mixing speed. 500 g of base bitumen were melted at 110˚C and then poured into a 500 ml container in order to make a sample. Subsequently, the bitumen was heated up at 150˚C until it melted. After that, a mechanical stirrer equipped to a high shear mixer was used to gradually add the NRL to the liquid bitumen and shear it. Once the mixing temperature reached 160°C, the cycle was accelerated to 500 rpm for 30 minutes. The temperature was maintained at 160 ± 5°C while the mixing process was going on. After completion, the bitumen treated with NRL polymer was ready for additional physical property testing, such as penetration and softening point, to ascertain its temperature susceptibility using the penetration index (PI).

In the prior studies by [6], amounts of natural rubber latex were used: 5% and 10% of the binder's weight. Several previous study developments served as the basis for choosing the latex content. Based on the findings of previous studies, a maximum of 10% latex by the weight of binder was recommended. The heated asphalt binder was combined with varying amounts of latex at 160˚C, and the mixture was blended for 30 minutes at 1000 rpm using a high shear mixer.

[7] reported that in order to produce NRMA, the original AC60–70 binder was combined with the NR solution at different NRL percentages of 3%, 7%, and 12% of the total binder by weight. The asphalt binder was first heated to a temperature of 140–150 degrees Celsius. Second, at a rate of 2-3 mL/min, the NRL was carefully added to the hot, melted asphalt binder. Ultimately, a high shear rate mechanical mixer operating at 5,000 rpm was used to combine the NRL with the original binder. Deding on the amount of NRL utilized, this condition was maintained for different amounts of time, as indicated in Table 1.

Table 1. Temperature and duration of time needed to combine NRL with asphalt binder.

NRL contents (%)	Mixing temperature (˚C)	Mixing time duration (min)
3	160-170	45
7	170-180	180
12	190-200	260

Referring to [8], the bitumen was heated to 160˚C in a container and mixed through a high-shear mixer running at 4000 rpm. The bitumen was treated with ENR once the temperature reached a constant 160˚C. For one hour, the mixing process was done at a speed of 4000 rpm.

In prior research by [9], bitumen and rubber are combined in a 95:5 ratio. Before mixing, the bitumen is heated to 160˚C. Next, cup lump natural rubber is slowly added to the bitumen until the mixture is nearly uniform. A high shear laboratory mixer running at 1100 rpm is used to prepare the modified bitumen sample. As a comparison, PG76, a commercially modified bitumen, was employed. Table 2 shows a summary of direct mixing mechanism based on previous studies.

Table 2. Summary of the previous mixing mechanism.

No.	Mixing Mechanism	Parameter	Reference
1.	a. 500g base bitumen melted at 100˚C and continue heat up at 150˚C. b. NRL added slowly into the bitumen and sheared using a mechanical stirrer at 500 rpm for 30 minutes at 160˚C. c. The test repeated using different mixing variables.	- Type of Rubber: Latex - Temperatures: 140°C and 160°C - Duration: 30 minutes and 60 minutes - Stirring speeds: 500, 1000, 1500, and 2000 rpm	[1]
2.	a. NRL of 5% and 10% of binder's weight were mixed with asphalt binder at 160˚C b. The mixture blended for 30 minutes at 1000 rpm using high shear mixer	- Type of Rubber: Latex - Temperatures: 160˚C - Duration: 30 minutes - Stirring speeds: 1000 rpm	[6]
3.	a. NR solution was combined with AC60–70 binder at varying NRL percentages of 3%, 7%, and 12% of the total binder weight. b. High shear rate mechanical mixer at 5,000 rpm used to combine the NRL with the original binder at different mixing temperature and duration.	- Type of Rubber: Latex - Temperatures: 160˚C-170˚C, 170˚C-180˚C, 180˚C-200˚C - Duration: 45, 180 and 260 minutes - Stirring speeds: 5000 rpm	[7]

4.	a. Bitumen was heated to 160˚C in a container and mixed through a high-shear mixer running at 4000 rpm. b. The mixing process between bitumen and ENR was done at a speed of 4000 rpm for one hour.	- Type of Rubber: Epoxidized Natural Rubber - Temperatures: 160˚C - Duration: 120 minutes - Stirring speeds: 4000 rpm	[8]
5.	a. Bitumen was heated to 160˚C. b. CLNR of 5% by weight of bitumen were mixed slowly to the bitumen until the mixture is nearly uniform. c. A shear laboratory mixer running at 1100 rpm is used to prepare the modified bitumen sample.	- Type of Rubber: Cup Lump - Temperatures: 160˚C - Stirring speeds: 1100 rpm	[9]

3.2 Pre-processing and chemical treatment

ZycoTherm, the nano-organosilane based asphalt additive used by [10] was shown to be stable at room temperature and pressure. The basic asphalt binder's 0.1% Zycotherm by weight was added during the blending process, increasing the asphalt binder's overall NRL percentages to 3% and 6%. The asphalt binder was heated to 160°C in an oven, and a thermo-cell was employed to keep it at that temperature during the blending process. Utilizing a propeller mixer operating at 1000 rpm for 10 minutes, ZycoTherm and the asphalt binder were thoroughly combined at 160°C. In order to investigate the rheological behavior of the modified and basic asphalt binder at mixing and construction temperature, they were subjected to a high temperature of 163°C for a minimum of 85 minutes, which was intended to simulate the short-term aging process.

According to [11], five different steel containers with lids were filled with different rubber-to-toluene ratios of 1:1, 1:1.5, 1:2, 1:2.5, and 1:3 along with 20 g of cup lump in order to determine the ideal ratio. For monitoring CLNR's physical change on the first day of treatment, the toluene loss was recorded hourly. The next day, the record was maintained until all of the toluene had been absorbed and evaporated. At the conclusion of the trial, the ideal rubber-to-toluene ratio was found to be 1:2. In accordance with Mohd Azahar et al. (2019), toluene was used to prepare 5%,10%, and 15% rubber crumb over a period of 24 hours using a 1:2 rubber-toluene ratio. The treated rubber crumb's surface roughness is torn off in the first step, and asphalt binder is then blended in the next step. The first stage involved attaching the treated rubber crumb sample in the center of the supporting column, which is made up of a shaft that is linked to the motor at one end and the head at the other. The treated rubber crumb was rotated for two minutes at a speed of 2000 rpm in an effort to break down the rubber surface. Since this method requires less time to integrate the two components, it may prevent asphalt from aging as quickly. It also aids in the evaporation of toluene. Melted asphalt that was stable at 160˚C was mixed with shredded treated rubber crumb in the second step of mixing. A high-shear mixer operating at 5000 rpm for two hours was used to mix the substances.

In the application of xylene, [12] treated 50g of dried CLR by placing it in containers with varying CLR-solvent ratios, such as 1:1, 1:2.1:3, and 1:4. Every container was maintained at room temperature for 48 hours on a smooth, flat surface in a laboratory. For bitumen modification, the rubber immersion in xylene for 48 hours at a ratio of 1:3 proved to produce the most effective effects outcomes. During the initial stage, treated CLR was blended with bitumen at weight percentages of 0%, 3%, 6%, 9%, and 12% to create five-

CLR modified bitumen (CLRMBs). The bitumen was first heated in a metal container until the temperature reached 165 °C. Shear mixer was run at 2000 rpm for 90 minutes at 165 °C (±2 °C). In order to improve the amount of xylene that evaporated from the CLR, it was poured gradually in increments into the bitumen at a low speed of 500 rpm. This process can accelerate bitumen aging, improve rubber absorption, and reduce blending time. Rubber-bitumen interactions at high temperatures are frequently caused by the swelling and degradation of the rubber. In pre-treated CLNR, the solvent already controlled the swelling, so only the broken down and disentangled CLNR chains interacted with the heated bitumen. When CLNR interacts with warmed bitumen at a high shearing speed and temperature, the low-molecular-weight fraction of bitumen (maltenes) is dispersed and absorbed by the network of polymers; this process promotes more xylene evaporation.

Referring to [5], 60/70 PEN bitumen is blended with 2.5%, 5.0%, 7.5%, and 10.0% (by weight) of treated CLR in the first stage using a high shear mixer set to 170°C and 4000 rpm/min for two hours. Before undergoing the aforementioned procedure, the CLR was divided into smaller pieces using a paper cutter and placed in a toluene solution for two days. The mixture is known as "treated Cup lump rubber" and is made out of a 2:1 toluene to CLR ratio. The following investigations were used to assist with the selection of the blending duration, temperature, and speed. The ideal proportion of cup lump rubber was chosen using storage stability and conventional binder tests. Table 3 shows a summary of pre-treatment mixing mechanism using chemical solvent based on previous studies.

Table 3. Summary of the previous mixing mechanism.

No.	Mixing Mechanism	Parameter	Reference
1.	a. 0.1% ZycoTherm by weight of the base asphalt binder was added, with NRL percentages of 3% and 6%. b. ZycoTherm and asphalt binder mixed at 160°C using a propeller mixer running at 1000 rpm for 10 minutes.	- Type of Rubber: Latex - Temperatures: 160°C - Duration: 10 min (+20 minutes) - Stirring speeds: 1000 rpm - Additives used:Zychoterm	[10]
2.	a. Toluene was used to prepare 5%, 10%, and 15% rubber crumb over a period of 24 hours using a 1:2 rubber-toluene ratio. b. Treated rubber crumb rotated for 2 minutes at a speed of 2000 rpm. c. Melted asphalt that was stable at 160˚C was mixed with shredded treated rubber crumb. d. A high-shear mixer operating at 5000 rpm for two hours used to mix the substances.	- Type of Rubber: Cup Lump - Temperatures: 160°C - Duration: 120 minutes - Stirring speeds: 5000 rpm - Chemical solvent used: Toluene	[13]
3.	a. 50 g dried CLNR placed in containers with varying CLR-solvent ratios are 1:1, 1:2.1:3, and 1:4 b. Treated CLR was mixed with bitumen at weight percentages of 0%, 3%, 6%, 9%, and 12% (CLRMBs). c. CLRMBs was run at 2000 rpm for 90 minutes at 165 °C (±2 °C).	- Type of Rubber: Cup Lump - Temperatures: 165°C (±2°C) - Duration: 30 minutes - Stirring speeds: 2000 rpm - Chemical solvent: Xylene	[12]
4.	a. CLNR was divided into smaller pieces and placed in a toluene solution for two days. b. 60/70 PEN bitumen is blended with 2.5%, 5.0%, 7.5%, and 10.0% (by weight) of treated CLR (CLMB) using a high shear mixer set to 170°C and 4000 rpm/min for two hours	- Type of Rubber: Cup Lump - Temperatures: 170°C - Duration: 120 minutes - Stirring speeds: 4000 rpm - Chemical solvent:Toluene	[5]

The use of NR as a bitumen modifier was previously disregarded despite its exceptional qualities, mainly due to the high cost of processing NR modified bitumen. High temperatures and high shear rates are necessary for the blending of NR with asphalt binder in order to create a homogeneous mix of the blend. This is extremely energy-consuming and sometimes leads to the polymer breaking down. Similarly, heating results in the asphalt binder aging prematurely and releases a large amount of greenhouse gases into the atmosphere. It is important to remember that the high initial manufacturing costs of the NR modified pavement will be compensated by the cost of routine maintenance for the unmodified HMA pavement. The separation of the bitumen's polymers is another difficulty for bitumen NR modification. Ineffective dispersion frequently leads to a heterogeneous mix, with the rubber serving only as an elastic filler. In theory, the lifespan of NR-modified asphalt pavement ought to be greater than that of crumb rubber-modified asphalt. However, research and field testing are necessary to ascertain the true impact.

Therefore, if NR is to be utilized in asphalt modification, this limitation must be solved. In contrast with conventional road materials, numerous researchers worldwide used natural rubber in a new form to attain the needed qualities. As one method of consuming NR domestically, RSS has been used with asphalt to improve its qualities. Next, some studies have recently used cup lump, a new alternative form of NR that requires very little manufacturing procedure and has received attention as an asphalt modifier in both performance and rheological tests. Blending conditions have always been a crucial factor when modifying asphalt since they have a significant influence on the mixture's physical characteristics. Additionally, the amount of modifier in the asphalt mixture has a significant role in its augmentation; characteristics may be improved by adding up to 10% NR, but doing so only makes the mixture less mixed and more viscous. On the other hand, adding some chemical additives at the same time might lessen the amount of rubber in the mixture as they were also enhancing its performance

4 Performance of Mixture on Asphalt Binder

According to [1], the outcome demonstrates that physical characteristics are significantly impacted by mixing speed. The physical characteristics of NRL modified bitumen have a beneficial influence from the mixing variables findings when the speed and temperature are mixed at 1270 rpm for 60 minutes. The maximum amount of useful material that could be added to the bitumen was 8% of NRL composition. By raising the PI value when the temperature and blending time are increased, it indicates that the NRL polymer contributes to lowering the temperature susceptibility.

Based on study by [6], the findings indicate that all asphalt binder samples had considerably good effects for the variance in softening points caused by the different latex contents. It may be inferred from the penetration test that the penetration value decreases with increasing latex content. This demonstrates the modifier's potential to transform the binder more rigid. The usage of 10% latex produced the lowest penetration value (56 dmm). High penetration number asphalt binders have a soft texture that makes them ideal for use in cold areas, whereas low penetration number asphalt binders have a rigid texture that makes them ideal for use in warm climates like Malaysia. The operating temperature of modified asphalt binders was determined to be 160°C by applying the technique of the rotating viscosity test. The natural rubber latex modified asphalt binder has good thermal storage compatibility, as demonstrated by a high-temperature storage stability test. The sample's top and bottom sections have different temperatures, but they are still within the allowable range—less than 5°C.

The addition of NRL, regardless of ZycoTherm incorporation, strengthened the asphalt binder because of its elastic nature, according to the physical characteristics (penetration and softening point) findings. The increase in elasticity demonstrated improved performance at low temperatures. Moreover, the ZycoTherm-modified binders demonstrated greater improvement than both the NRL-modified binder and the base asphalt binder. Particularly at high temperatures (76°C and 82°C), the rheological characteristics of the NRL-modified asphalt binders improved under both RTFO-aged and unaged conditions. Regardless of ZycoTherm's existence, the addition of NRL surely improved the complicated shear stiffness and elastic behavior of the asphalt binder. According to the findings of the modified binder test, the asphalt binders applied with ZycoTherm performed better in terms of rutting resistance than the modified NRL binder without ZycoTherm and the control sample.

Based on research by [13] and [11], toluene also assisted in lowering the viscosity value of the CMA, improving performance without altering its characteristics. Additionally, as demonstrated by [14], the combination of toluene, rubber, and bitumen formed a stable and homogenous mixture [13]. They came to the conclusion that bitumen's ability to regenerate itself was enhanced by the addition of toluene, and that this augmentation was amplified by increasing the polymer content [14]. Throughout the test, the cup-lump-modified asphalt (CMA) mix was dragged as thin as a tiny thread, which resulted in an insignificant decrease in the ductility of modified bitumen when rubber chemical solvents were present. As a result, CMA that included a chemical solvent exposed to break apart than CMA that did not contain chemical solvent [13]. Therefore, toluene is among the most effective chemical solvents for treating rubber.

[12] reported that, softening and rotational viscosity improved along with a gradual decrease in penetration when xylene was added to cup lump rubber modified bitumen (CLMB). On the other hand, when the CLR content increases, the viscosity actually increases. The results of the storage stability test showed that CLRMB3 and CLMRB6 met the requirements, and that CLRMB9's high-temperature stability was enhanced by 0.5 wt% PPA. Better high rutting and fatigue performance is achieved with the inclusion of the CLR. Overall, the modified bitumen with 9% CLR and the bitumen with 3% and 6% CLR with 0.5 weight percent PPA have demonstrated good performance. The interaction between the rubber and aromatic hydrocarbons employed as a chemical solvent was noted in studies on surface treatment and rubber swelling to change its form as a sticky substance [15]. At high temperatures, rubber usually expands and deteriorates when it comes into contact with bitumen. However, using xylene to CLNR can shorten the time needed for blending, improve rubber dissipation, and finally slow down bitumen aging.

Four percentages of CLR—2.5%, 5.0%, 7.5%, and 10%—were added to the base bitumen in study by Abdulrahman et al. (2019). The results of the storage stability test verify that bitumen and rubber will separate during storage at 10% of CLR. Likewise, it was discovered that the 7.5% CMB had the lowest ductility value, measuring 43 cm. This falls considerably short of the ≥100cm minimum ductility required by JKR and ASTM, or the ≥75cm minimum ductility required by Indian standard. The P.I.s of the 2.5% and 5.0% cup lump modified bitumen are -0.95 and -0.85, respectively. This indicates that the 2.5% CMB is more temperature sensitive than the 5.0% CMB. Comparably, the PVN computation results indicate that the 5.0% CMB has a PVN value of 0.77 and the 2.5% CMB has a PVN value of 0.57. This suggests that compared to 2.5% CLR, 5.0% CLR has better resilience to temperature susceptibility. As a result, the optimum CLR content for the base bitumen is determined to be 5.0%. Table 4 shows summary of method used and its findings based on previous studies.

Table 4. Summary of significant method used and findings based on previous studies.

Ref.	Type of Rubber	Replacement (%)	Blending Temperature (°C)	Blending Time (minute)	Blending speed (rpm)	Findings
[1]	Latex	2,4,6,8, 10,12	140, 160	30, 60	500, 1000, 1500, 2000	Penetration value decreased, softening point value increased. Asphalt's temperature susceptibility is enhanced by the presence of NRL polymer.
[6]	Latex	5,10	160	30	1000	Higher latex in asphalt binder which also had the highest percentage of elastic recovery could withstand vehicle loads and quickly regain its former shape.
[7]	Latex	3,7,12	160-170, 170-180, 180-200	45, 180, 260	5000	The index values and attributes of the original asphalt may be changed by adding NRL.
[8]	Epoxidized natural rubber	3,6,9,12	160	120	4000	The asphalt binder's G* parameter increased, the δ was decreased, and the resistance to rutting enhanced through the G*/sin δ parameter.
[9]	Cup lump	5	160	-	1100	The findings imply that adding rubber might improve asphalt's flexibility and resistance to rutting.
[10]	Latex	3,6	160	10	1000	The addition of NRL definitely improved the complex shear stiffness and elastic behavior of the asphalt binder.
[13]	Cup lump	5,10,15	160	120	5000	The criteria for storage stability were met (<2.5°C), indicating a stable and uniform bitumen mixture.
[12]	Cup lump	3,6,9,12	165	30	2000	Increased viscosity that enhances the mixture's coherence

						between the aggregates and the binder.
[5]	Cup lump	2.5,5, 7.5,10	170	120	4000	Enhanced storage stability with strong compatibility for thermal storage (<5°C).

Based on this summary findings, it can be concluded that, blending temperature, time and speed have a significant effect on the physical and chemical properties on modified asphalt. It shows that higher penetration index value helps to increase the resistance to temperature susceptibility. It was evident that when the percentage of replacement content increased, the penetration value dropped, indicating a propensity toward strength. With regard to the softening point result, it is evident that the softening point rises as the NRL content does. A decrease in penetration and a rise in softening point may be observed as a result of bitumen modification for varying polymer contents, indicating the modified bitumen's improved stiffness and hardness. To prevent modified asphalt binders from becoming too stiff, the amount of natural rubber latex should be restricted according to the bitumen weight.

Further studies examining the alteration of asphalt using field, concentrated, and skim latex have yielded good results in terms of improved softening, high penetration index (PI), high torsional recovery, and high tenacity and toughness. Following that, a study was done to describe the impact of temperature and time on the physical characteristics of modified NR bitumen. The results showed that 9% NRL is the most effective for improvement and that the temperature and blending duration should not exceed 150 °C and 10 minutes, respectively [16]. On the other hand, a too rigid asphalt binder may be more prone to cracking. Better high rutting and fatigue performance is achieved with the inclusion of the polymer.

5 Case Study of Field Performance Natural Rubber Modified Bitumen

Numerous research is being conducted to use polymer additives to improve the quality of bituminous asphalt mixtures. Using rubber—natural, synthetic, or crumb rubber—in applications for asphalt pavement is one of the alternatives. A case study utilizing waste rubber powder as an asphalt additive found that it significantly reduces rut depth on asphalt mixtures under various stresses and temperatures, and that asphalt mixtures containing 10% waste rubber powder perform better at higher temperatures. The crepe rubber, which is generated from cup lump rubber, is probably going to be a fresh assessment of the usage of natural rubber as an asphalt modifier. The new asphalt mix has enhanced asphalt pavement quality to the point where it may be utilized for road construction projects without requiring significant changes to the construction process. The results of a six-month site monitoring period are not very compelling in terms of acknowledging the overall success of the site. In summary, in order to get better results, performance monitoring still has to be extended. It is claimed that using natural resources, such rubber, can lower the price of modified asphalt without compromising the road's condition.

Table 5. Summary case study of field performance on asphalt pavement using various type of rubber.

Location	Type of Rubber used	Duration after construction	Condition of Pavement	References
1-kilometer Rembau - Tampin	Natural rubber latex and	-	The trials lack of systematic long-term performance data; thus, no firm conclusions can be drawn	[17]

	rubber powder			
3-kilometer road of Sg Buloh	Crumb rubber	After 8 years operation	The structure only needs minor repairs, but the restricted parts have to be resurfaced	[17]
0.6-kilometer road at Bukit Kuantan	Crumb rubber	After 9 years operation	No major maintenance has been done since then; the road's performance is deemed satisfactory	[17]
Route 4, Jalan Kupang – Gerik, Baling, Kedah	Cup lump rubber	After 6 months of construction	The performance of the CMA portion was nearly identical to that of the conventional section.	[17]
Jalan Kuala Lumpur – Kuantan (FT02), Daerah Temerloh, Pahang	Cup lump rubber	After 1 months of construction	CMB with 50% bitumen 60/70 and 50% fresh cup lump performs quite similarly with PG76. The performance of the CMA combination (5% CMB) equaled that of the conventional mixture and satisfied PWD requirements	[18]

6 Conclusion

Bitumen treated with natural rubber (NR) has demonstrated significant improvements in flexible pavement durability, fatigue resistance, and stability against temperature changes, and moisture. Despite these advantages, challenges such as increased energy use and unintended pollution during Hot Mix Asphalt (HMA) production have been identified. As a consequence of this issue, the development of clean asphalt exemplified by the use of warm mix asphalt additives like Zychoterm, is crucial for maintaining mechanical performance while minimizing environmental impact. This study highlights on earlier research on the application and effects of the direct mixing method and the use of chemical solvents (Zychotherm, xylene, and toluene) in bitumen modification with natural rubber. Rubber treatment involved the effective manufacture of a homogenous rubber mixture that could be mixed with bitumen using xylene and toluene at rubber-to-solvent ratios of 1:3 and 1:2, respectively. Compared to toluene, xylene is not as widely utilized. Hence, more research required which delve into specific parameters to determine its suitability and optimize the rubber treatment process. This ongoing exploration is essential for advancing the understanding of rubberized bitumen and its potential applications in sustainable road construction. In conclusion, this paper underscores the mixing method and its performance, importance of clean asphalt practices, introduces potential additives for further improvement, and highlights the need for continued research to optimize rubberized bitumen's performance, contributing to the longevity of roads, reduced maintenance costs, and enhanced driving comfort.

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