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## Physical properties of warm cup lump modified bitumen

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**Abstract.** Despite the several benefits of modifying bitumen with polymer; it is increasingly becoming difficult to ignore concerns about its high energy consumption and fume emissions during asphalt production. Previous studies found on natural rubber (NR) modified binders applied it as a hot mix asphalt (HMA), however in recent years there has been increasing interest in warm mix asphalt. This research explores the possibility of applying NR in warm mix asphalt (WMA) by comparing the physical properties of cup lump rubber modified bitumen with and without warm mix additive. Four percentages (2.5%, 5.0%, 7.5% and 10%) of Cup lump rubber (CLR) was used to modify 60/70 penetration grade bitumen, while three percentages (0.3%, 0.4%, and 0.5%) of Evotherm chemical was added to produce warm cup lump modified bitumen (WCMB). Storage stability, penetration, softening point, viscosity, ductility, and elastic recovery tests were conducted to determine the effect of CLR and Evotherm. The results show that storage stability and viscosity of the cup lump modified bitumen heavily depends on the CLR content. While a positive correlation exists between the increase in binder stiffness with increasing mixing and compaction temperatures. The addition of 0.5% Evotherm reduces the viscosity by 14%. Contrary to expectations, CLR was found to reduce the ductility of the bitumen while the presence of Evotherm in the blend increases the softening point. The use of warm NR modified bitumen in road construction is expected to lower the asphalt production temperature, carbon emission and cost without compromising the performance of the mix.

### 1. Introduction

The inability of unmodified bitumen to accommodate the rapid increase in heavy traffic loading and severe environmental conditions compels the use of polymer modified bitumen (PMB) in road construction. Natural rubber (NR) is a renewable and environmentally friendly elastomer having good elasticity and exceptional properties under cyclical loads. It is more economical compared to synthetic polymers especially in rubber producing countries. Majority of the success achieved by NR in bitumen modification is due to its unique elasticity and thermal stability at a given or range of temperatures. NR can dissipate high tyre pressure, increase bitumen resistance to flow, rutting and significantly increase fatigue life and dynamic stability of asphalt mix [1–4]. Furthermore, NR modified bitumen have higher tensile strength ratio (TSR) values than the conventional bitumen, indicating better resistance to moisture damage [5]. These are some of the reasons why roads paved with NR-modified bitumen have more strength and durability than the unmodified one.



While there is a great deal of promise that comes along with modification of bitumen with NR; there are concerns about its high energy consumption and greenhouse gas emission. This is because previous laboratory studies and field trials conducted on the use of NR modified bitumen applied it as HMA. The addition of NR increases the viscosity of the base bitumen which in turn requires higher mixing and compaction temperatures. Thus, generating a lot of fumes and polluting the environment, as well as oxidative ageing. It also consumes a lot fuel during heating thereby increasing the overall cost of asphalt production. Therefore, clean production of bituminous mix should involve lowering the manufacturing temperature without compromising the level of mechanical performance. To achieve this; the road construction industry needs to step-up its effort in reducing the additional amount of CO<sub>2</sub> emission to the environment through WMA [6–11].

WMA is a technology that reduce mixing and compaction temperature of HMA up to 50 °C. This is achieved by incorporating additive that lower the bitumen viscosity or expand its volume which in turn helps the aggregates to get completely coated with bitumen at temperatures lower than HMA [12,13]. Some of the benefit of WMA include reduction in fuel consumption, carbon emission, bitumen oxidative ageing, and cracking. Others include longer paving season and hauling distance, early opening to traffic and improved working condition of the workers [14,15].

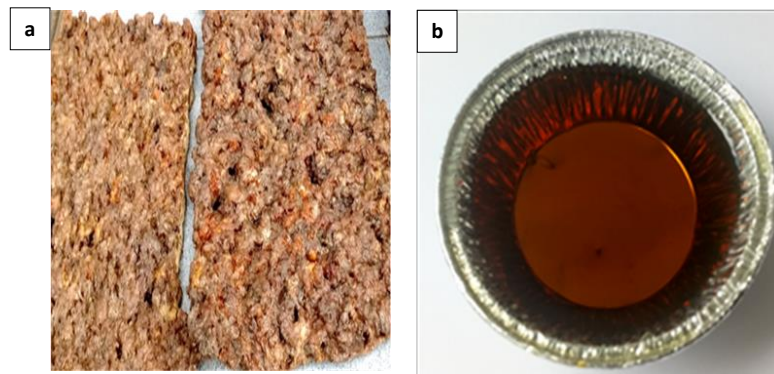
Although lots of research have been conducted on NR modified bitumen, its performance in WMA has not been fully explored. The aim of this research is to investigate the physical properties of warm cup lump rubber modified bitumen. CLR is a freshly coagulated NR where the coagulation takes place in the cup at the tree with no manufacturing process involved [16]. The application of cup lump rubber in bitumen modification is getting more popular after the construction of three test sections (cup lump modified asphalt) in Tampin, Negeri Sembilan; Baling, Kedah; and Temerloh, Pahang. After two years of monitoring, results obtained from field and laboratory indicate improvement in resilience, durability, resistance to cracking and rutting over the conventional HMA [17].

## 2. Experimental Work

### 2.1. Materials

Base bitumen of 60/70 penetration grade commonly used in Malaysia was selected for this research. The bitumen was supplied by Kemaman Bitumen Company (KBC) located on the east coast of peninsular Malaysia. It can be described as a black viscous material consisting of high molecular weight hydrocarbons. The obtained bitumen from this company was used throughout this research to alleviate any variation that may arise from having multiple bitumen source.

Cup Lump Rubber: NR in form of “Cup Lump” was used as a bitumen polymer modifier. The CLR was obtained from Chip Hong rubber factory in Johor, Malaysia. The rubber sheet has a dimension of 2000 x 580 x 200mm weighing about 10 Kg. Although cup lump rubber contains certain amount of water in it; this one has been air-dried at the factory to reduce its water content. Upon reaching the laboratory moisture content determination test was conducted to ascertain the remaining moisture present in the rubber and was found to be 5.2%. The specific gravity of the rubber was also found to be 0.94 when measured in the laboratory using Gas Displacement Pycnometer machine (AccuPyc II 1340 V2.01). Figure 1 below depicts the CLR sheet as obtained from the rubber factory.



**Figure 1:** Materials used a. 300 x 200mm CLR sheet b. Evotherm warm mix chemical

Evotherm: Evotherm warm mix additive produced by MeadWestvaco in USA was supplied by MahaChem company, Malaysia. It is a chemistry package that includes materials to improve workability, adhesion promoters and emulsification agents [18]. Evotherm can be described as a brown oily liquid that is partially soluble in water, and fishy amine smell. The product can reduce the mixing and compaction temperatures of asphalt mixtures without compromising the quality. Table 1 shows a detailed description of the tested binders and their respective code as used in this research.

**Table 1:** Binder identification and content

Binder I.D	Content	Description
BB	Original 60/70 penetration bitumen	Base Bitumen
2.5% CMB	60/70 Bitumen + 2.5% CLR	CMB: Cup lump Modified Bitumen
5.0% CMB	60/70 Bitumen + 5.0% CLR	
7.5% CMB	60/70 Bitumen + 7.5% CLR	
10.0% CMB	60/70 Bitumen + 10.0% CLR	
0.3% WCMB	60/70 Bitumen + 5.0% CLR + 0.3% Evotherm	WCMB: Warm Cup lump Modified Bitumen
0.4% WCMB	60/70 Bitumen + 5.0% CLR + 0.4% Evotherm	
0.5% WCMB	60/70 Bitumen + 5.0% CLR + 0.5% Evotherm	

### 2.2. Binder preparation

A total of eight (8) binder types were prepared by adding CLR and Evotherm to the base bitumen in two stages. The first stage involves blending of 60/70 PEN bitumen with 2.5, 5.0, 7.5, and 10.0% (by weight) of treated CLR using high shear mixer at 170°C and 4000 rpm/min for two hours to produce cup lump modified bitumen (CMB). Prior to the above process; the CLR was cut into smaller sizes passing 10mm sieve using paper cutter and soaked in toluene solution for 2 days. The ratio of toluene to CLR used is 2:1 and the mix is referred to as “treated Cup lump rubber”. The blending time, temperature and speed was selected based on the following studies [19,20]. Storage stability and conventional binder testing were used to select the optimum percentage of cup lump rubber.

The second stage involves making the selected CMB warm by incorporating Evotherm additive to the binder. Here; 0.3, 0.4, and 0.5% was blended to the selected CMB using high shear mixer at 160°C for 5 minutes as practiced by the following researchers [20,21]. Physical, rheological and microstructural properties of this blend was determined and compared with the selected CMB in stage one to evaluate the effect of Evotherm.

### 2.3. Softening point and penetration test

Several tests were conducted to determine the consistency and rheology of the base bitumen and modified binders according to ASTM standards [22,23]. Softening point test is used to determine the

temperature at which the bitumen changes from semi-solid to semi-liquid state. At this temperature; the bitumen cannot support its own weight and starts to flow. Penetration test was conducted by loading a standard needle of 100g onto a container filled with bitumen sample in a thermostatically regulated water bath at 25°C for 5 seconds. The 25°C testing temperature approximates the yearly average service temperature of HMA pavement [9,24]. The penetration range is used in specifying the binders' penetration grade, as well as its temperature susceptibility by calculating the penetration index (PI).

#### 2.4. Ductility and elastic recovery

Ductility test measures the tensile property of a bitumen or its ability to be stretched without breaking. The test was conducted by pulling a briquet of bitumen specimen at the rate of 5cm/min in a water bath maintained at  $25 \pm 5^\circ\text{C}$ . The distance at which the material elongates before breaking is the ductility value [25]. One limitation of this test is that it only covers the stretching ability of the bitumen but not its recovery. Therefore, this research went further to conduct elastic recovery test to measure the ability of the binder to absorb large stress and recover to its initial state without cracking or deforming. The test was conducted by pulling the two clips of the testing hooks at a uniform speed to an elongation of  $10 \pm 0.25\text{cm}$  before cutting the mid-point. The broken specimen is left undisturbed in the machine for one hour, then the length of the specimen was measured again. Results from this test is useful in evaluating whether the polymeric material that has been added to a bitumen provides substantial elastomeric property or not [26,27].

#### 2.5. Viscosity and storage stability

Viscosity test was carried out to determine binder's resistance to flow and workability at high temperature. Test specimen were prepared according to ASTM 4402 specification and conducted using Brookfield (DV-II + Pro) rotational viscometer with spindle number 27 at 20 rpm speed [28,29]. Furthermore, to ensure the stability of the CLR modified binders at manufacturing and laying temperatures; storage stability test was conducted in accordance with ASTM standard. Aluminium tube with diameter of 25.4mm and height 136.7mm was filled with heated bitumen sample. The tube was sealed and kept vertically in a convection oven at  $163 \pm 5^\circ\text{C}$  for 24 hours. The tube was then cooled at  $-6.7 \pm 5^\circ\text{C}$  for 4 hours to solidify before cutting into three horizontal equal parts. The softening point temperature of the top and bottom sections was determined and the storage stability was calculated by the difference in softening temperature of the top and bottom samples [30,31].

#### 2.6. Temperature Susceptibility

The thermoplastic nature of bitumen makes to become softer when heated and harden when cooled (temperature susceptibility). Penetration Index (*PI*) is one of the best-known equations used to determine binder's susceptibility to temperature using the equation shown below.

$$PI = \frac{1952 - 500 \log Pen - 20S.P}{50 \log Pen - S.P - 120} \quad (1)$$

Where *Pen* is the penetration value at 25°C and *S.P* is the softening point of the bitumen.

(*PI*) values ranges from -3 for highly susceptible bitumen to +7 for highly low temperature susceptible bitumen. It is worthy to note that Pfeiffer et. al assumed that the penetration value of bitumen at the softening point temperature is 800 dmm is not valid for all bitumen especially PMB where the penetration and softening point values largely depends the type and percentage of polymer [27]. Although PI can be used to approximate the temperature behaviour; this research will further use Pen-Vis number (PVN) in confirming the temperature susceptibility of CLR modified bitumen. PVN is calculated based on penetration at 25°C and viscosity at 135°C, such that

$$PVN = \frac{L - X}{L - M} (-1.5) \tag{2}$$

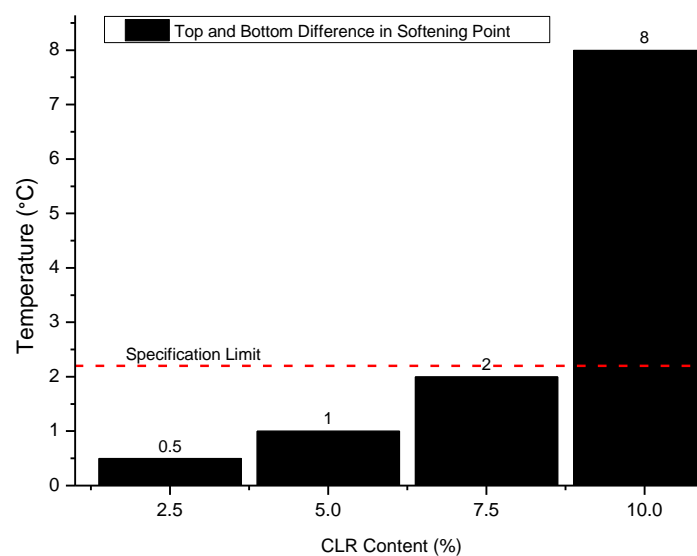
Where  $X$  is the logarithmic of viscosity in centistokes measured at 135°C,  
 $L$  is the logarithmic of viscosity at 135°C for a PVN of 0.0; and  
 $M$  is the logarithmic of viscosity at 135°C for a PVN of -1.5

Most asphalts have a PVN of +0.5 to -2, the lower the PVN value of a bitumen the higher its temperature susceptibility.

### 3. Results and Discussion

#### 3.1. Storage Stability

After conditioning in the oven and freezer as specified by ASTM D7173, the sample was cut in three equal parts and softening point test was conducted on the top and bottom sections of the CLR modified binders. Figure 2 shows that the difference in softening point temperature for 2.5, 5.0 and 7.5% CLR are less than the 2.2 °C ASTM 5976 specification limit [32]. This is an indication that these binders will remain stable when stored at high temperatures [33]. However, the 10% CMB is greater than 2.2°C, therefore this modified bitumen is not suitable for storage. In practice it is possible to use PMBs that are not storage stable, however, they must be handled with great care and stored in tanks with stirrers or extended circulation to prevent separation of the polymer [27]. For this reason; 2.5, 5.0, and 7.5% of CLR are more suitable for used in construction of flexible pavement.



**Figure 2:** Storage stability of CMB

#### 3.2. Penetration and softening point

The penetration and softening point of CMB are presented in Figure 3, all binders revealed decreased penetration with increasing CLR content. This increase in binder hardness can be credited to a hardening effect due to the addition of rubber to the binder. On the hand, the softening points values increased after CLR was added, signifying an equal rise in hardness or stiffness as seen in the penetration graph. A possible explanation for this might be that the increase in CLR results in a polymer swelling consequently leading to an increase in the apparent asphaltene percentage which will form a harder matrix. A harder matrix will lead to more difficulties in softening the mixture, thus causing the softening point to be higher [34]. Based on the outcome of these consistency tests, the binders' modification

appears to agree with the concept of base asphalt stiffening. And the higher the softening point; the better the binder’s resistance to rutting.

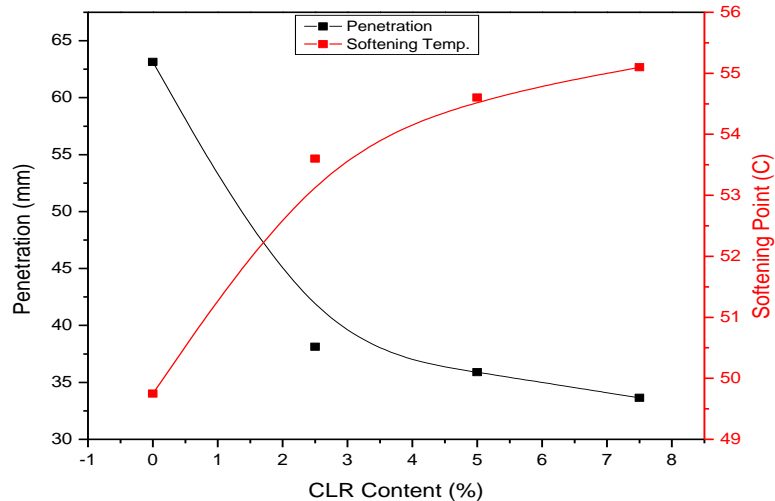


Figure 3: CMB Penetration and softening point result

3.3. Viscosity

It can be seen from Figure 4(a) that the addition of 2.5% CLR to the base bitumen significantly increases its viscosity, and similar linear increase in the binder stiffness was noticed at 5.0 and 7.5 percentages of CLR. Similarly, as the temperature is increasing the rheology of bitumen changes and begins to flow but the NR acts like a polymer chain and resists the CMBs flow thereby increasing its resistance to shear [35]. The viscosity of all the modified binders were found to be less than the maximum allowable limit (3 Pa.s) values of JKR and Superpave specification [36]. A closer look on the effect of increasing viscosity on the mixing and compaction temperatures shows that as percentage of CLR is increased; the mixing and compaction temperatures also increases (Figure 4(b)). This confirms that viscosity or binder stiffness is the main factor responsible for the higher mixing temperature of PMB.

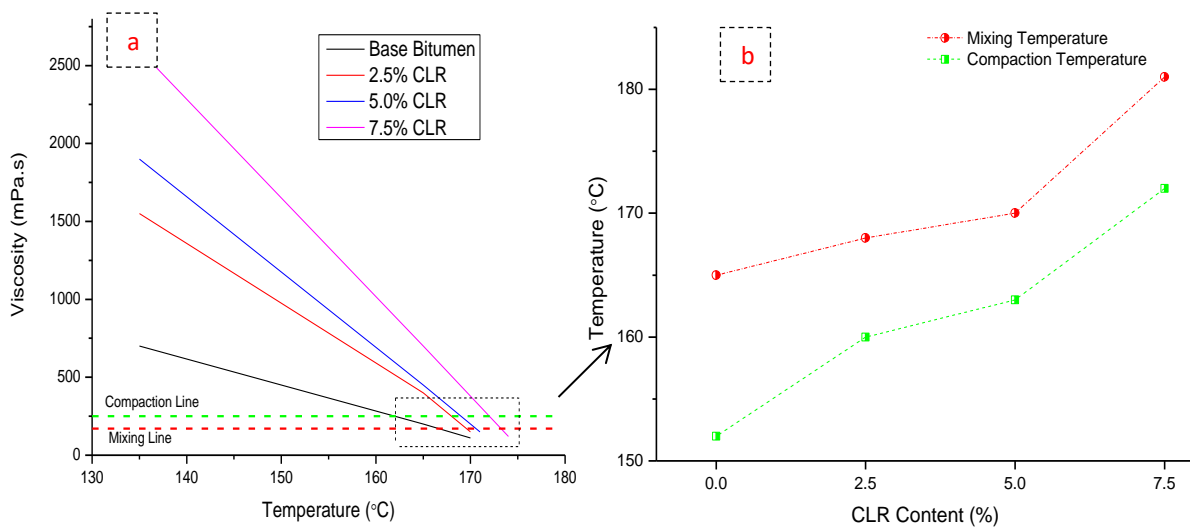
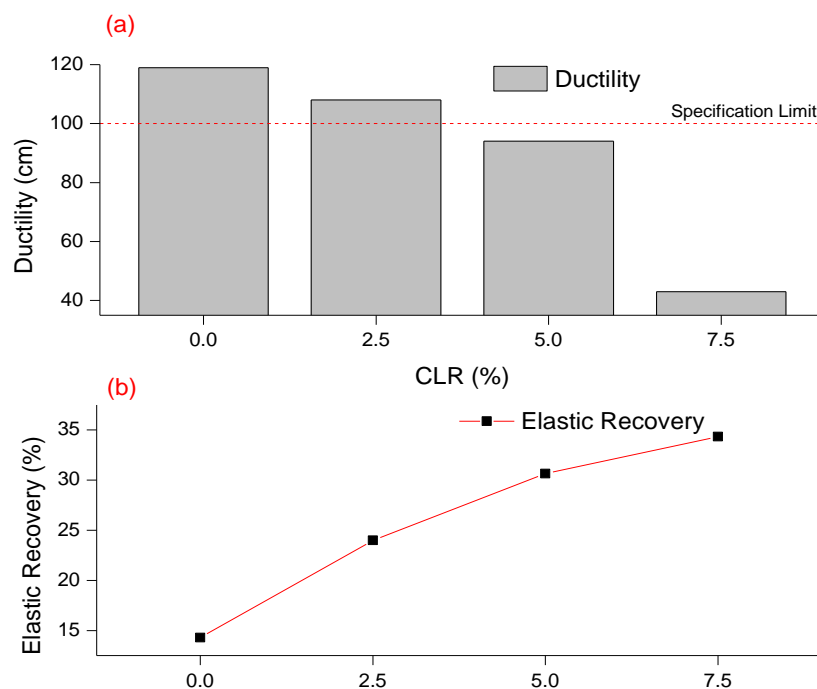


Figure 4: a) Determination of mixing and compaction temperature. b) Effect of CLR in increasing mixing and compaction temperatures

### 3.4. Ductility and Elastic recovery

Figure 5(a) illustrates that the addition of 2.5% rubber slightly decreases the ductility of the bitumen, further increase in the CLR to 7.5% drastically reduced the stretching ability of the binders. This is because NR stiffens bitumen which results in better performance at high temperatures but it makes the bitumen brittle at intermediate temperatures [37]. Contrary to this, the presence of rubber in the blend was found to have a positive effect on the elastic recovery of the bitumen. This is evident from Figure 6(b) where increase in elastic recovery of the modified binders are more than the base bitumen. The elastic recovery of the base bitumen after deformation was increased by more than 100 percent at 5.0 and 7.5% CLR content, signifying an improved fatigue resistance of the binder.



**Figure 5:** (a) Ductility result. (b) Elastic recovery result.

### 3.5. Selection of optimum CLR percentage

In this study, four percentages (2.5, 5.0, 7.5, and 10%) of CLR were added to the base bitumen. Results from storage stability test confirms that at 10% of CLR, separation of the rubber from the bitumen will occur during storage. As such this kind of blend requires specialised equipment that can provide constant heat and agitation during mixing with aggregate, therefore 10% CLR is removed from the selection list. Similarly, the 7.5% CMB was found to have the lowest ductility value of 43cm (Figure 6(a)). This is too far below the minimum ductility requirement of JKR and ASTM of  $\geq 100$ cm or the  $\geq 75$ cm of Indian standard. As such 7.5% CLR is also removed from the optimum CLR selection list. As mentioned earlier; PI and PVN are useful tools used to determine the temperature susceptibility of a binder. The 2.5 % and 5.0% cup lump modified bitumen have a P.I of -0.95 and -0.85 respectively (Table 2). Meaning that the 2.5 % CMB has more susceptibility to temperature than 5.0% CMB. Similarly, results of the PVN calculation shows that the 2.5% CMB has a PVN value of 0.57 while 5.0% CMB has 0.77. This indicates that 5.0% CLR has improved resistance to temperature susceptibility than the 2.5% CLR. Therefore, 5.0% is selected as the optimum CLR content for the base bitumen. The selected percentage will be modified with 0.3, 0.4 and 0.5% of Evotherm to produce WCMB.

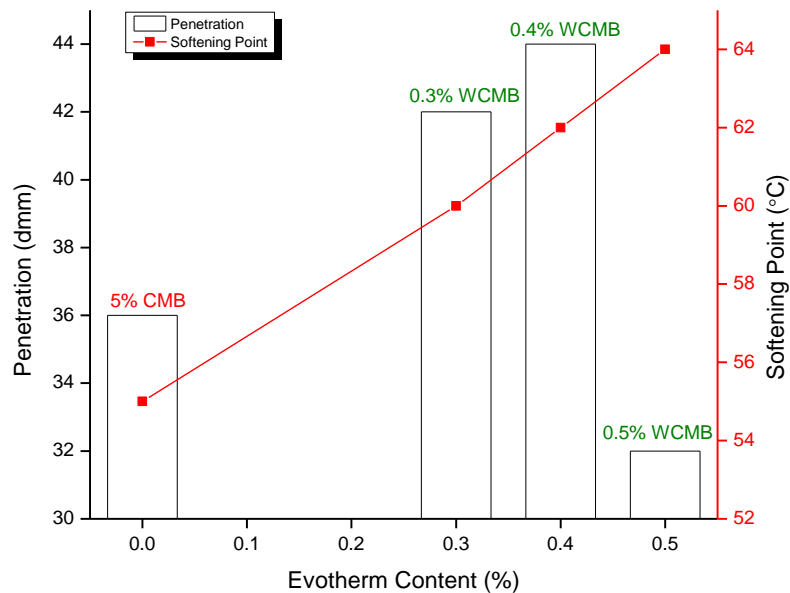


**Table 2:** Penetration index and pen-vis number of the binders.

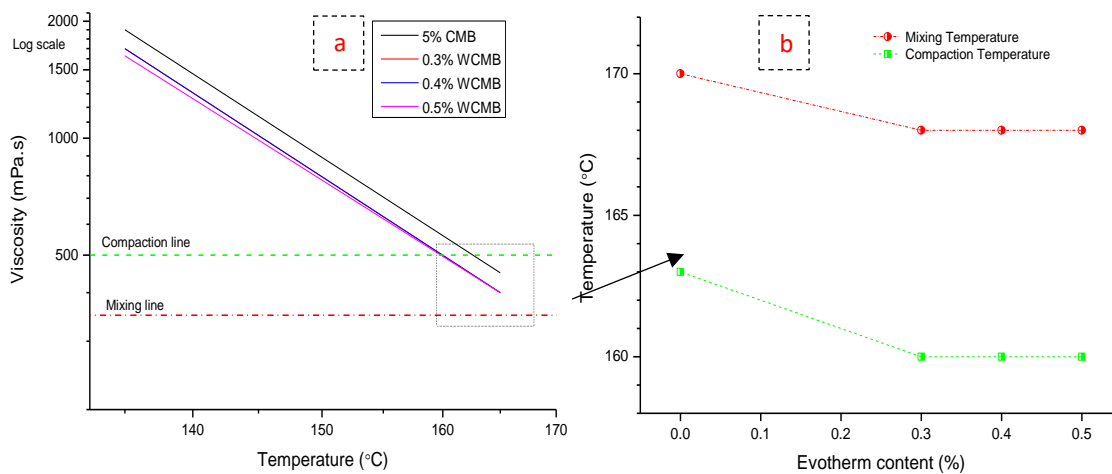
Binder	BB	2.5% CMB	5.0% CMB	7.5% CMB	0.3% WCMB	0.4% WCMB	0.5% WCMB
P.I	-	-0.95	-0.85	0.88	0.67	1.04	0.79
	0.71						
PVN	0.07	0.57	0.77	1.09	0.80	0.86	0.45

**3.6. Effect of Evotherm to CMB**

After determining the optimum CLR content of 5.0%; Evotherm warm mix additive was added to produce WCMB, below are the results from various tests conducted. The results show that the addition of 0.3 – 0.4% Evotherm softens the cup lump modified bitumen by increasing its penetration, however at 0.5% the penetration the was drastically reduced (Figure 6). This is attributed to the oily nature of Evotherm which reduces the molecular weight of the CMB at 0.3 and 0.4%. On the other hand; presence of Evotherm was found to cause an increase in the softening point temperature of the CMB.



**Figure 6:** WCMB penetration and softening point result



**Figure 7:** Viscosity result of WCMB.

Similarly, Figure 7(a) shows that the addition of Evotherm causes the CMB viscosity to decrease by 10% at 135°C. Further increase in the Evotherm content to 0.4% did not lead to further decrease in the viscosity. But at 0.5% Evotherm content the viscosity decreased by 14%. While at 165°C the viscosity of the CMB was decreased by a constant value of 11% irrespective of the Evotherm content. The decrease in viscosity translates to lower mixing and compaction temperature as shown in Figure 7(b). This indicates the possibility of using lower mixing and compaction for NR asphalt production. Furthermore, Figure 8(b) illustrate that the mixing and compaction temperature shows the same value despite increasing the Evotherm content from 0.3% to 0.5%, this is because the warm mix additive mainly acts as a surfactant by reducing the surface tension between the aggregate and bitumen. Hence its real effect (reduction in mixing and compaction temperature) is mainly seen during the asphalt production process [38–40]. The 0.5% Evotherm content is the most economical and beneficial in lowering the mixing and compaction temperature.

#### 4. Conclusion

This study evaluated the physical properties of WMA incorporating cup lump rubber. The addition of NR in the form of cup lump was found to exhibit good dispersion and provides significant increase in softening point and viscosity of the binder while penetration was effectively reduced. The rotational viscosity, mixing and compaction temperatures of the binders rises with increasing CLR content. But the addition of Evotherm slightly reduced the viscosity of the binder by 14%, thus allowing for lower mixing and compaction of the asphalt rubber. Similarly, the presence of Evotherm significantly increased the softening point temperature of the CLR modified bitumen. Storage stability test conducted on the CLR modified binders imposes a limit of 7.5% as the maximum rubber content whereas the ductility test advocates a maximum CLR content of 5.0%. The temperature sensitivity of the binders as represented by the P.I and PVN suggests that CLR reduces temperature sensitivity. Lastly, elastic recovery test shows that CLR modified binders have high elastic response than the unmodified binder and shall therefore resist deformation through stretching and recovering to their initial shape. In a nut shell, the physical properties of WCMB is comparable to that of CMB but of better performance than the base bitumen. The study recommends 5% CLR as the optimum rubber content for the base bitumen, while 0.5% Evotherm as the recommended dosage of the warm mix additive.

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