Comparative study of modified bitumen binder properties collected from mixing plant and quarry.

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Comparative study of modified bitumen binder properties collected from mixing plant and quarry.

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Abstract. Quality control and assurance are essential in pavement construction. In general, the properties of bitumen change as it ages in bulk storage, transport, and storage on site. The minimization of bituminous hardening during storing, transportation and mixing depends on careful control of binder temperature. Hence therefore, bitumen should always be stored and handled at the lowest temperature possible, consistent with efficient use. The objective of the work is to monitor the quality of bitumen samples collected from mixing plant and quarry. Results showed that, samples modified bitumen which collected from quarry showed some adverse effects on rheological properties and physical properties after subjecting to high temperature storage within a period of time. The dynamic stiffness, elastic properties and other common binder properties were deteriorated too. The chemical changes that occurred during storage were analysed using Fourier transform infra-red spectroscopy (FTIR). Thus studies developed an understanding of bitumen ageing in storage.

1. Introduction
Bitumen may be rigid and friable at low temperature, liquid and fluid at high temperature and semi-rigid or rigid at medium temperature. Bitumen dynamic modulus due to temperature fluctuations from –30 °C to 50 °C change even 37 000 times [1]. When asphalt mixture is produced of too cool and, therefore, too viscous (consistent) bitumen, it hardly turns into a thin film, which should coat all mineral particles with solid layers of appropriate thickness and make a strong compacted structure of the mixture. When too hot or overheated mineral aggregates are used, bitumen may burn: it degrades chemically, volatilizes, its colloidal composition changes and rheological properties deteriorate.

Bitumen ageing is one of the main causes of the degradation of asphalt pavement. In bitumen ageing, two mechanisms are involved: chemical changes in binder (irreversible) and physical hardening (reversible). The most important bitumen ageing mechanisms are as follows: oxidation, volatilisation, steric or physical factors and exudative hardening. Ageing due to oxidation is the key factor if compared with other factors impacting on ageing [2, 3]. Oxidation rate mostly depends on temperature [4] duration and intensity of interaction with oxygen as well as the thickness of bitumen film, which coats aggregate particles [5]. Heating duration and temperature have a significant impact on such rheological properties of bitumen as viscosity or complex modulus [6]. In general, a higher viscosity is contributed by modified bitumen. As therefore, the temperature is raised up during mixing and storage at the quarry site unlike normal procedure. However, the concern with elevated temperatures is that they may further degrade the asphalt binder to a level beyond that caused by normal production temperatures; thus increasing the degree of short term aging to a level that may adversely affect the performance of the asphalt pavement.
Several research studies have shown that the volatilization and oxidation are the biggest contributors to the hardening (aging) process of asphaltic binders. The combined effect of elevated temperature and longer exposure time may cause excessive short term aging and adversely affect the performance of the pavement. This research study aimed on quantifying how much further aging occurs beyond normal mixing temperatures and exposure times of asphalt mixes. The quantification is achieved by measuring viscosities of aged binders as well as measuring the dynamic modulus, softening point, penetration and other properties of bitumen at production and quarry plant. The properties of the binder from the tanker were also tested for a comparison. The results were compared to establish correlations between the properties of the aged samples and their laboratory performance, upon which conclusions was drawn.

2. Experimental

Samples of modified bitumen supplied were collected from various locations, production and quarry plant. In general sample from tanker remained almost the same with the one collected from the production plant. As therefore samples from production plant and quarry will only be discussed in this work. The temperature recorded at the production and quarry plant was 160°C and 200°C respectively. Conventional bitumen tests such as softening point (ASTM D36) and penetration grade (ASTM D5) are performed to characterize the bitumen. The rheological properties of modified bitumen at high and intermediate temperatures are measured by using Dynamic Shear Rheometer (DSR) (ASTM D7175) and the viscosity of the bitumen is evaluated by application of Brookfield rotational viscometer (ASTM D4402).

Nicolet 6700 FTIR spectrometer (Thermo Scientific) was used to record the infrared spectra with 32 scans at a resolution of 4 cm$^{-1}$ in the range of 4000 – 600 cm$^{-1}$.

3. Results and discussion

Table 1 shows the viscosity, penetration and softening results of the rubberised bitumen tested in this study from those two locations. In general, the viscosity of bitumen binders at high temperatures is an important property as it is a good indicator of the binder’s ability of pumping through bitumen plant. Results showed that, sample collected from quarry exhibited lesser viscosity and softening point with higher penetration point as compared to fresh binder from mixing plant, which indicating possible ageing of the asphalts.

| Table 1. Bitumen properties collected from Mixing plant and Quarry. |
|---------------------------------------------------------------|
| Viscosity at 135 °C (cp) | Bitumen from Mixing Plant | Bitumen from Quarry |
|-------------------------|-------------------------|---------------------|
| Penetration at 25°C (mm) | 58                      | 80                  |
| Softening Point °C       | 60                      | 50                  |

The rheological properties of the binders with various temperatures are obtained from the Dynamic Shear Rheometer (DSR). Complex shear modulus (G*) is determined as a result of the DSR experiments by applying stress at different frequencies on bitumen samples. The relationship between the complex shear modulus and the temperature is shown in figure 1. Results showed that the complex modulus decreased with temperatures. However, the complex shear modulus of bitumen collected from mixing plant is greater than the one collected from quarry which indicates stiffer binder and greater resistance to deformation respectively.

Figure 2 illustrated changes in values of phase angles to different test temperatures. Lower phase angles value data of bitumen collected from mixing plant than bitumen from quarry. A smaller phase angle values obtained from mixing plant is an indicator greater binder elastic property and of lesser in binder permanent deformation occurred as a result of applied stress.
It is known that the temperature of the bitumen binders when $G^*/\sin \delta$ is equal to 1 kPa is defined as a criterion for the high temperature (good visco-elastic) performance of bitumen. It is also known that higher $G^*/\sin \delta$ values are found to correlate with higher rutting resistance. Changes in rutting parameters ($G^*/\sin \delta$) to temperature decreases is shown in figure 3. It is clear seen that rutting parameters of bitumen collected from mixing plant is lesser than bitumen collected from quarry. These results show that bitumen from mixing plant has more considerable effects on rutting resistance than the one collected from quarry.

Considering the results obtained by all DSR tests it is seen that bitumen from mixing plant exhibits greater complex shear modulus ($G^*$) values and rutting parameters ($G/\sin\delta$), and has lesser phase angle values compared to binder from quarry plant.

Decreased in complex shear modulus ($G^*$) values and viscosity might be attributed to the arrangement /degradation of NR and bitumen into lower molecular weight fragments after long hot storage of the modified bitumen sample collected from quarry. At this elevated temperature there is an increase in phase angle indicating more viscous response. This is could due presence of degradation of unsaturated polymer as in the case of NR. The oxidation of the binder also could attribute to diminishing of physical and chemical crosslink or polymer network decomposed under the influenced of heat and oxygen and rearranged in smaller fragments. Therefore chain scission of the polymer could cause the binder properties to change. Collin [7] observed penetration decreased at a much great rate at high temperature. This behaviour has also been observed in SBR modified bitumen binders. Indeed during the mixing of the modifier with bitumen, there is some polymer breakdown due to thermal and mechanical action of the mixing process, but this is minimal (4-5%) [8].

![Figure 1. Rheological Behaviour of Modified Bitumen collected from Quarry and Mixing Plant.](image)
FTIR spectra of pure bitumen (60/70 grade), samples modified bitumen from mixing plant and quarry are shown in figure 4. The spectra are similar to each other and the typical absorbance peaks are listed in Table 2. However, the new absorbance peak of 1109 cm\(^{-1}\) attributed to the C-O-C is seen for sample collected from quarry. This could be due to some chemical changes in the binder as discussed earlier. Araujo [9] found that a molecular reorganisation and hydrogen/carbon ratio decreased as the bitumen was subjected to weathering chamber test after 150h. Hence, as ageing proceed, ether bonds can be formed and the content of carbonyl decreased as indicated in this work. Therefore further analysis is necessary in order to confirm the ageing mechanism.
Figure 4. FTIR spectra of a) PG60/70 and modified bitumen collected from (b) mixing plant and (c) quarry.

Table 2. Absorbance peaks of bitumen [8].

| Wavenumbers (cm$^{-1}$) | Functional group                      |
|------------------------|---------------------------------------|
| 2920, 2850             | C-H aliphatic stretching              |
| 1600                   | C=C aromatic stretching               |
| 1456                   | C-H of -(CH$_2$)- bending             |
| 1376                   | C-H of CH$_3$ bending                 |
| 1030                   | S=O sulfoxide stretching              |
| 862, 807               | C=C of alkene stretching              |
| 746, 720               | C-H or C-S bending                    |

4. Conclusion
Results showed adverse effects on modified bitumen properties collected from quarry. The properties such as penetration, viscosity and softening point changed drastically after subjecting to high temperature storage at quarry in contrast to modified bitumen collected from mixing plant. The IR analysis indicated that a new peak formation of ether peak at 1109 cm$^{-1}$ which highly possible due to oxidation of the binder.
5. References
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