AN INVESTIGATION ON THE RHEOLOGICAL PROPERTIES OF RUBBERISED BITUMEN

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Abstract: The bituminous binder is considered as one of the essential material of construction in road pavement, and the performance of road pavement is related to the performance of a bituminous binder. Research on the use of rubber crumbs as an additive to bituminous binder has found it suitable for use in bituminous mix for road construction.

The main objective of this paper is to determine some basic characteristics and properties of rubber modified bitumen as compared to unmodified bitumen. The standard test methods were used to evaluate the properties of the modified bitumen in terms of consistency, temperature susceptibility and flow characteristics as well as certain rheological properties. Specific reference to the effect of rubber crumbs on the ageing characteristics of rubber modified bitumen is also highlighted.

The analysis of the different tests results showed that there is a remarkable improvement in the properties of the rubberised bitumen as compared to the normal bitumen. Adding rubber increases the consistency and the stiffness of the binder as well as increasing its resistance to the effect of heat ageing by reducing its tendency to soft. The laboratory tests showed that the visco elastic properties are affected by the increase of the rubber content and resulted in an increase in the complex shear modulus, G* and a decrease in the phase angle, δ.

Key Words: Bitumen, Modified, Rubberised, Ageing, Rheology

1. INTRODUCTION

In the paving mixture design, the general practice is to arrive at a balanced design among a number of desirable mix properties, one of which is durability. Durability is the degree of resistance to change in physico-chemical properties of pavement surface materials with time under the action of weather and traffic. The life of a road surfacing will depend primarily on the performance of the binder and the aggregate, the mix design and construction techniques (Fernando *et al.,* 1984).

The main functions of the bitumen when used as a binder in road pavement, is to hold the aggregates firmly and to act as sealant against water. However, due to certain factors such as fatigue failure, the performance and durability of bitumen are affected by changes in its characteristics, which may lead to the deterioration of pavements.

To cope with the growing demands of heavy traffic and tropical climate, there is a need to improve the properties of the binder. The addition of any modifier to a binder almost certainly adds to the cost of the modified material and therefore the use of such a binder must provide improved performance and be cost effective. It must be more viscous at high temperatures to prevent irreversible plastic flow, and sufficiently flexible at low temperature to avoid brittle fracture (Bethune *et al.*, 1978, Fernando *et al.*, 1984). The use of scrap rubber in binder has been practised for many years, and very attractive from the point of view of availability, cost, and preservation of the environment (Bethune *et al.*, 1978).

The basic experimental approach of this research is specially focused on the determination of certain characteristics and properties of a rubber modified bitumen as compared to unmodified bitumen in different phases of ageing. This would be of great interest as it may provide a cost effective solution in improving the properties of the surfacing materials at high temperature and under extreme loading conditions.

2. TESTING METHODOLOGY

2.1 Rubberised binder materials

Rubberised bitumen was prepared by mixing 80/100 penetration-grade bitumen with various percentages of fine grain rubber crumbs passing the 40-mesh sieve. The content of rubber additive was varied to see the effect of rubber contents. Three levels of rubber content were used, namely 3%, 9% and 15% by mass of bitumen.

The rubberised bitumen was prepared using the propeller mixer. Mixing is done at a speed of 250 rpm for two hours at 150°C

2.2 Binder testing

All testing were carried out on both unaged binder (original sample) and aged binder of the same material. The aged binders are treated with different ageing tests represented by Thin Film Oven Test (TFOT), Rolling Thin Film Oven (RTFO) and Pressure Ageing Vessel (PAV).

Binders were characterised by using a number of standard physical tests such as penetration test (temperature, load and time are 25°C, 100g and 5sec respectively), softening point test, viscosity test using Brookfield viscometer (temperature range from 80 to 190°C, spindle No.27, and a rotating speed of 20rpm), and including rheological measurements by using a Dynamic Shear Rheometer (tests conducted by using a temperature sweep starting from 30°C to 80°C, and the frequency is 1.159Hz).

3. RESULTS AND ANALYSIS

3.1 Penetration test results

The Figures (1-1, 1-2) show that the penetration values decrease with ageing phases, indicating that the binder becomes stiffer after ageing. The penetration values for the original binders (before ageing) decrease as the rubber content in the mix increase, which is similar to that Valkering *et al.* (1990) reported by using thermoplastic rubber (SBS). This may be explained by the hardening of the binder during blending or mixing due to evaporation of low molecular weight oil fractions, and the swelling of rubber particles. Figure (1-1) shows that the penetration values are almost the same for all the binders (unmodified and modified binders) after TFOT and PAV tests. The rate of decrease in penetration value due to ageing is lower for rubber modified bitumen as compared to ordinary 80/100 penetration-grade bitumen. This means that the unmodified and the modified bitumen when aged have similar characteristics in terms of consistency even though the modified bitumen was much harder than the unmodified bitumen before ageing.

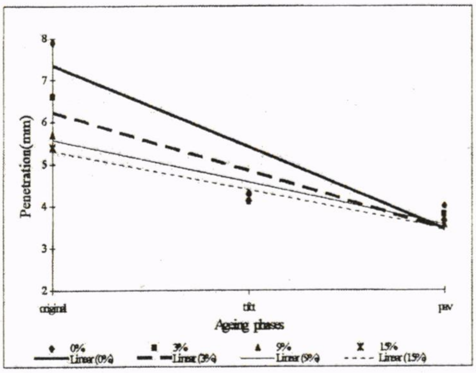

Figure (1-1): Penetration Vs Ageing Phases

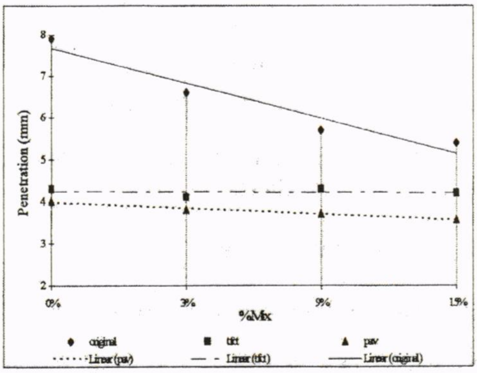

Figure (1-2): Penetration Vs Different % in Mix

3.2 Softening Point test results

It appears clearly from the results that the addition of rubber to bitumen increase the softening point value, and as the rubber content increase the softening point also increase, similar to results obtained by Valkering *et al.* (1990). This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. The effect of softening point of a binder on resistance to permanent deformation of bituminous pavement mixes has been studied by various researchers. An example is hot rolled asphalt where it was found that the rate of rutting in the wheel tracking test at 45°C, was halved by increasing softening point by approximately 5°C (Fernando *et al.*, 1984). In the present study, it is noted also that in all samples (unmodified and modified bitumen) the softening point increase with ageing phases. Figure 2-2 reveals that the apparent increase in the softening point for the different rubber content in the binders is not constant.

The addition of rubber crumbs before ageing increases the softening point of 80/100 bitumen grade from 46°C to 54°C, 55.5°C and 58°C with 3%, 9% and 15% of rubber respectively. Therefore it is expected that by using the rubberised bitumen in the mix the rate of rutting will decrease due to the increase in softening point.

It's clear from the figure (2-1) that the softening point in all the samples increase after the ageing tests. The rate of increase in softening point between the unaged samples and the samples aged with PAV ageing test, showed that the increase is about 12%, 7%, 13% and 18% respectively for the samples with 0%, 3%, 9% and 15% rubber.

For hot climate, binders with higher softening point are, therefore, preferred with a benefit of reducing the rutting problems since the road surface temperature is expected to be less than the softening point.

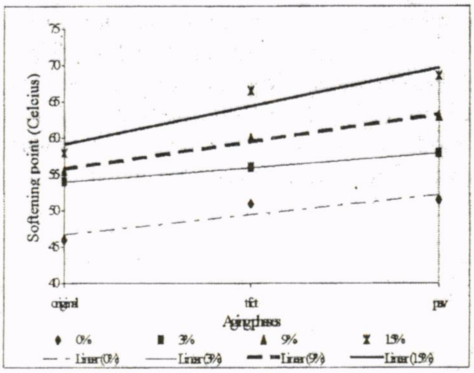

Figure (2-1): Softening Point Vs Ageing Phases

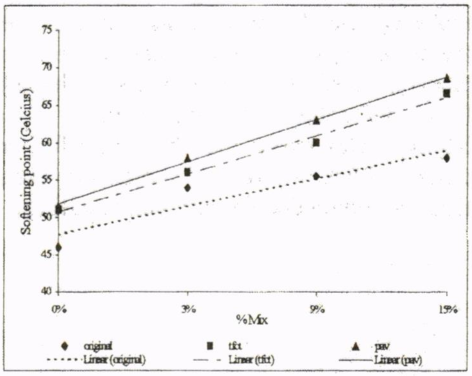

Figure (2-2): Softening Point Vs Different % in the Mix

3.3 Viscosity test results

3.3.1 Effect of temperature on the viscosity

The figures (3-1, 3-2, 3-3, 3-4) show that the viscosity in all the samples (unmodified and modified bitumen) decrease as the temperature increase and this is valid before and after ageing. As an example if we consider compaction temperature of 120°C for the unmodified bitumen than the corresponding viscosity is 1331.5 mPa (Figure (3-2)). To achieve the same viscosity, modified bitumen need to be compacted at temperatures of 125°C, 142°C and 173°C respectively for the samples with 3%, 9% and 15% of rubber. This means that the viscosity for unmodified bitumen is equal to the viscosity of rubberised bitumen at higher temperature, and as the rubber content increase in the sample the higher would be the temperature. Consequently, the workability of the bituminous mix is partly dependent on the viscosity of the binder which in turn is partly dependent on its temperature. As the workability of the mix decreases it becomes more difficult to lay and compact the bituminous mix to achieve the desired density (Karim *et al.*, 1997). Therefore, the issue here is not only consideration of the percentage of rubber to be added but also to satisfy the desired properties of the material.

Since the viscosity is very related to the temperature the investigation on the proper mixing temperature of the aggregates with the binder must be identified. This is achieved by determining the temperature at which the binder would maintain a reasonably acceptable viscosity so as to be able to effectively coat the aggregates before the binder gets too viscous. Otherwise, some problems related to lack adhesion may creep in and the air voids may increase, thereby increasing the possibility of oxidative hardening of the binder, and hence reducing the durability of the bituminous pavement.

3.3.2 *Effect of rubber content on the viscosity*

The addition of rubber crumb increase the viscosity of the binder. Figures (3-1, 3-2, 3-3, 3-4) show that the viscosity increase as the rubber content increase and this is true before and after ageing.

This phenomenon is explained by the absorption of the lighter fraction of bitumen by the rubber particles, causing the swelling of rubber particles. Rubberised bitumen can be considered as the suspension of swollen rubber particles in thick viscous oil. The swollen particles provide greater hindrance to flow since they occupy more space than the unswollen rubber particles. The higher the rubber content within the binder, the higher would be the density of rubber particles within a unit volume of binder. This explains the phenomenon which shows as the rubber content increase the viscosity also increase.

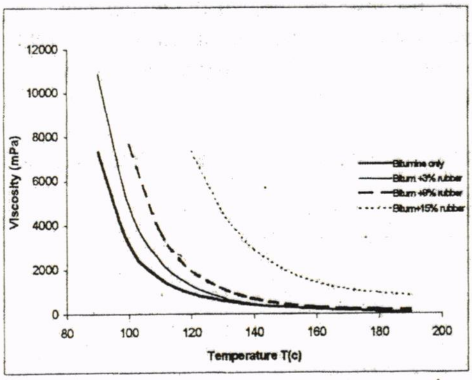

Figure (3-1): Viscosity for the Original samples

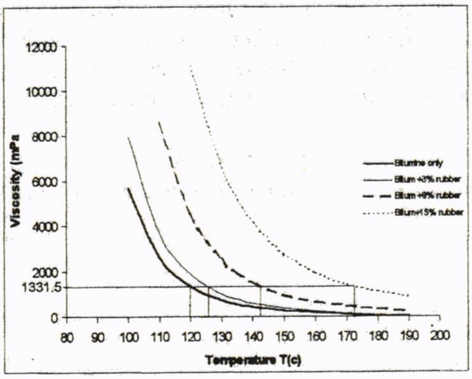

Figure (3-2): Viscosity for the samples after RTFO

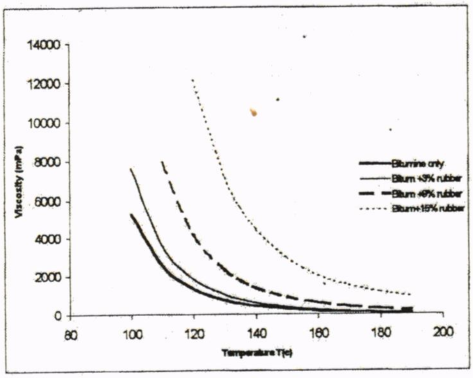

Figure (3-3): Viscosity for the samples after TFOT

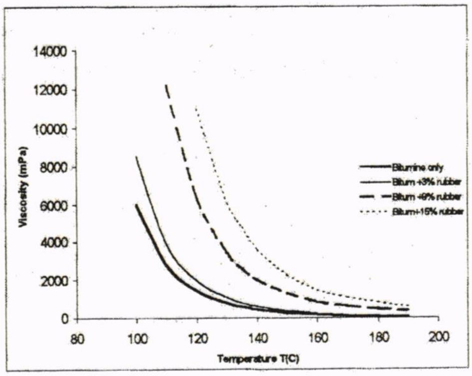

Figure (3-4): Viscosity for the samples after PAV

3.4 Viscosity and Softening Point relationship

The increase in viscosity in all the binders due to the addition of rubber content appears to follow a similar pattern to that of the increase in softening point of the same binders due to the addition of rubber. The higher the rubber content the higher will be the viscosity and so is the softening point, this is shown in Figure (4-1). Similar results for the unaged samples were found by Karim *et al.* (1997).

It was reported that there is a linear relationship between the viscosity and the softening point Karim *et al.* (1997). The plot of the regression line in figure (4-2) showed that the relationship between the viscosity and the softening point is polynomial with a highest value of R square ($R^2 = 0.80$) compare to the linear relationship with a lower value of R square ($R^2 = 0.71$).

The increase in the viscosity due to ageing or rubber content is followed by the increase in the softening point. The increase of the viscosity means that the binder became much more resistant to flow and harder. The increase in the softening point means that the binder has less tendency to soften and flow, and its stiffness is much higher, hence its hardness. The two phenomena are almost the same and this confirms the relation and the dependency between the viscosity and the softening point for the same binder.

Thus for a particular mixing (or bleeding) condition, the viscosity of the binders may be predicted if the softening point is known and vice versa.

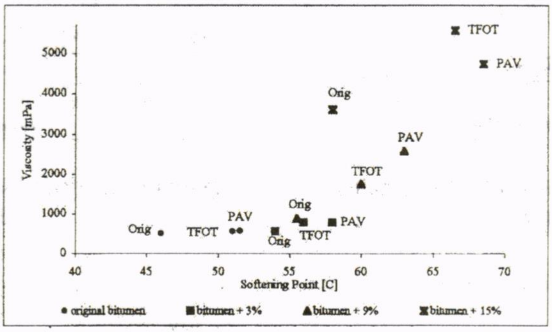

Figure (4-1): Viscosity Vs Softening Point for all the samples before and after ageing

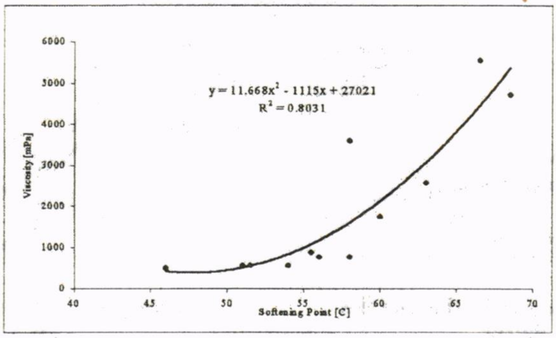

Figure (4-2): Viscosity Vs Softening Point for all the samples before and after ageing with the regression line

3.5 Effect of temperature and rubber content on the complex shear modulus (G*)

The figures (5-1, 5-2, 5-3, 5-4) showed that the complex shear modulus (G*) is lowest for the unmodified bitumen as compared to rubberised bitumen. At high temperatures (T > 55°C), it is noticed that in all samples (unmodified and modified bitumen) the complex shear modulus G* decrease as the temperature increase.

From the results we can see that at any temperature, as rubber content increase the complex shear modulus G* increase. We note that this is true for the samples before and after ageing.

A lower value of complex shear modulus G* means that the asphalt is softer, and it can deform without developing large stresses (Samsuri *et al.*, 1997). In addition binders with high complex shear modulus G* may reduce rutting problems (deformations) in the asphalt.

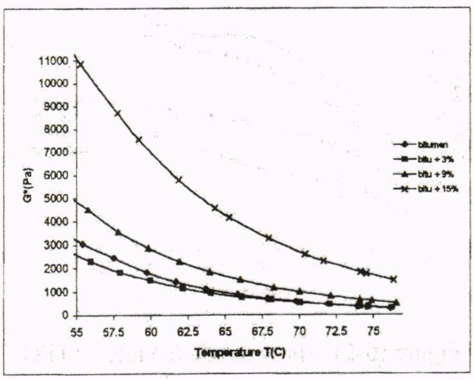

Figure (5-1): Complex Shear Modulus (G*) before the ageing

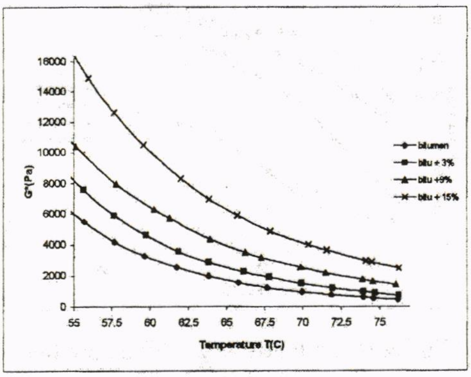

Figure (5-2): Complex Shear Modulus (G*) after RTFO

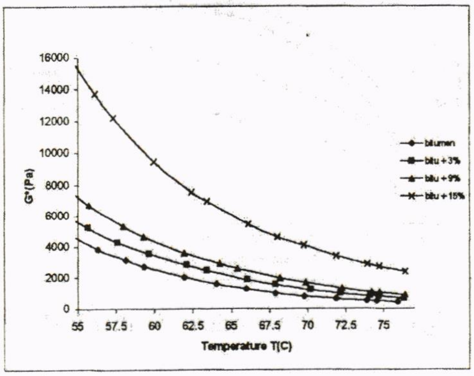

Figure (5-3): Complex Shear Modulus (G*) after TFOT

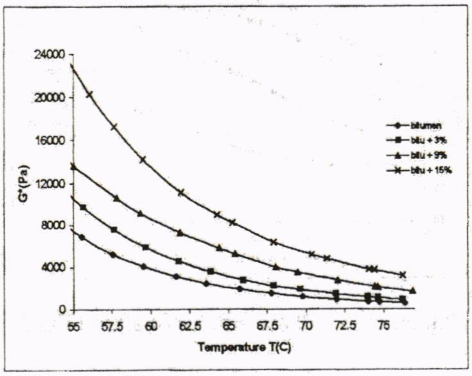

Figure (5-4): Complex Shear Modulus (G*) after PAV

3.6 Effect of temperature and rubber content on the phase angle (δ)

The figures (6-1, 6-2, 6-3, 6-4) show that the phase angle δ for the unmodified bitumen is higher than rubberised bitumen. Generally, as the rubber content increases the phase angle δ decreases. Furthermore the phase angle δ increase as the temperature increase in all the samples (unmodified and modified). Note that this is true for the samples before and after ageing.

Lower value of phase angle δ means that the asphalt is more elastic than viscous, and it will recover to its original condition without dissipating energy. Also at high temperature low phase angle δ is desirable since this reduces permanent deformation (Maccarrone *et al.*, 1994).

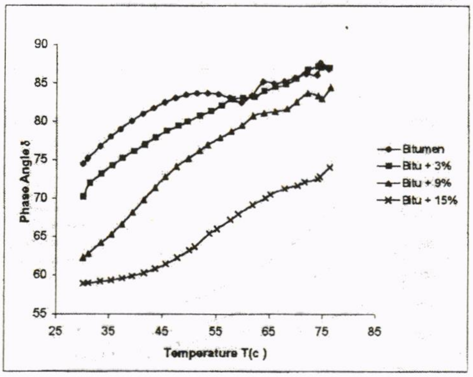

Figure (6-1): Phase Angle (δ) before the ageing

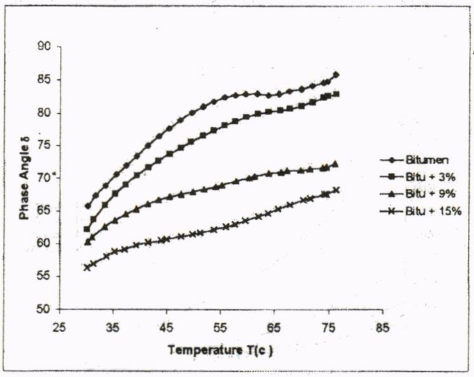

Figure (6-2): Phase Angle (δ) after RTFO

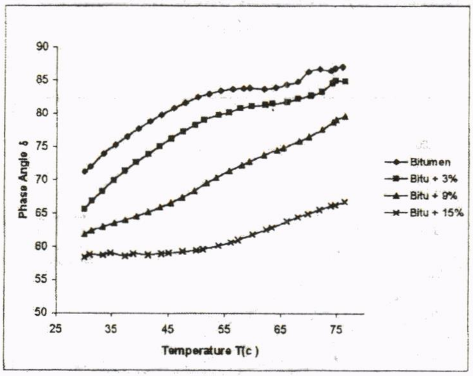

Figure (6-3): Phase Angle (δ) after TFOT

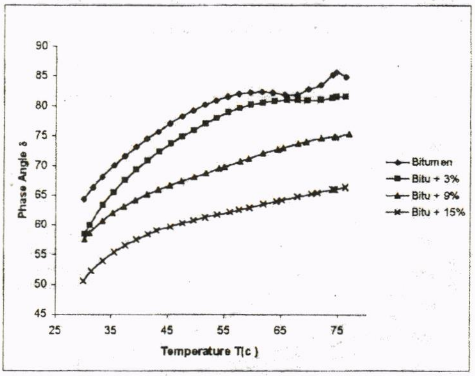

Figure (6-4): Phase Angle (δ) after PAV

4. CONCLUSION

From the analysis of various tests results, we find that the rubber contents in the mix had effects on the properties of the binders, since in all samples the softening point, the viscosity, and the complex shear modulus increase as the rubber content in the binder increase, while the penetration value for the unaged samples and the phase angle in all the samples decrease. Noted that the penetration test results after ageing doesn't show any significant difference between unmodified and modified binders properties since the penetration values is almost the same for all the samples. For the ageing factor both unmodified and rubberised bitumen when aged showed a decrease in the penetration, an increase in the softening point and an increase in the viscosity. The addition of rubber into bitumen has shown to affect the rate of ageing of the binder.

A good correlation was found between the viscosity and softening point data, since the increase in the viscosity due to ageing or rubber content is followed by the increase in the softening point. The relationship is almost polynomial between the two properties, thus for a particular mixing condition, the viscosity of the binders may be predicted if the softening point is known and vice versa.

REFERENCES

Bethune, J. D. (1978). Use of rubber in bituminous surfacing. **Proceedings, 9th ARRB conference, Part 3,** 157-170.

Fernando, M.J. and Guirguis, H.R. (1984) Natural rubber for improved surfacing. **Proceedings 12th ARRB conference, Part 2**, 121-130.

Karim, M. R. and Samsuri, A. (1997). Rheological properties of rubberised bitumen and its implication on processability. **Conference on the use of rubberised bitumen in road construction**.

Maccarrone, S., Holleran, G. and Gnanaseelan, G. P. (1994). Properties of polymer modified binders and relationship to performance. **Proceedings, 17th ARRB conference, Part 3,** 123-139.

Samsuri, A. and Karim, M. R. (1997). Effects of temperature of mixing and heat aging on the physical properties of rubberised bitumen. **Conference on the use of rubberised bitumen in road construction**.

Valkering, C. P. (1990). Thermoplastic rubbers for the modification of bitumens: improved elastic recovery for high deformation resistance of asphalt mixes. **Proceedings, 15th ARRB conference, Part 2,** 1-19.