AN ASSESSMENT OF POLYMER MODIFIED ASPHALT MIXES

Mohamed Rehan KARIM
Associate Professor
Department of Civil Engineering
University of Malaya
50603 Kuala Lumpur
Malaysia
Fax: +603-7595318, +603-7586154
E-mail: rehank@fk.um.edu.my

Sulaiman ABDULLAH
Civil Engineer
Elcorp Technology Sdn. Bhd.
16B, Medan Pusat Bandar 1
Bandar Baru Bangi
43650 Selangor, Malaysia
Fax: +603-8251667

abstract: There has been increasing interest in the use of polymer modified binders in asphalt mixes for flexible pavements. The use of polymer modified binders in asphalt mixes may improve the properties of the pavement. This paper presents some of the findings from a laboratory study of certain polymer modified binders as well as asphalt mixes using these binders. An evaluation on the characteristics of the modified binders including their rheological properties were conducted and the findings were compared with conventional bitumen. Relationships between various parameters that describe the behaviour of the binders have also been investigated. The performance of the asphalt mixes using the modified binders were studied and contrasted with that of asphalt mixes using conventional bitumen. Emphasis was also placed in determining and evaluating the stiffness and creep characteristics of the various polymer modified asphalt mixes.

1. INTRODUCTION

There is evidently increasing interest in the use of modifiers in asphalt pavement mixes worldwide with the aim of improving the performance of this type of road and airfield pavements. Conventional penetration grade bitumen has been successfully used in flexible pavements for a very long time. However, as the damaging effects on the pavement increase over time particularly due to changes in the traffic environment, the resistance of the conventional bituminous pavement towards various distresses will lessen, thus reducing the time interval between maintenance or rehabilitation works. Changes to the traffic environment include the ever increasing traffic volumes, increased axle loads and wheel loads, increased tyre pressures as well as increased volume and percentage of heavy vehicles in the traffic stream. With the combination of other factors such as environmental factors and characteristics of the subgrade and unbound layers, some of the common pavement distresses manifested include surface cracking, permanent deformation, stripping and fretting.

It has been recognised that in many circumstances the performance of conventional bitumen may not be adequate and the properties of the bitumen need to be improved to meet the new demands imposed by the conditions mentioned earlier. The properties of conventional bitumen can be modified through several ways. One of the common ways is to add suitable polymers to bitumen. The choice of the type of polymer to be incorporated in the bitumen is normally determined by the physical stability and homogeneity of the blend of bitumen and polymer (Robertus et.al, 1996). Polymer modified asphalts are even being specified in several states in the U.S. for heavily stressed pavements which would otherwise become rutted in the summer or undergo fatigue cracking in the winter (Nahas et.al, 1990). Previous studies (Karim and

Abdullah, 1996; Goodrich, 1988) have indicated exceptional physical properties exhibited by certain polymer modified asphalt mixes which makes it more appropriate to be used in cases where the pavement is expected to be heavily stressed such as climbing lanes and truck routes. Although it may appear that the initial cost of having polymer modified asphalt pavement is higher than that of conventional asphalt pavement, the increase in service life of the pavement and the reduction in maintenance frequency will make the investment a worthwhile venture in the long run.

A laboratory study was undertaken to investigate some of the properties of polymer modified binders and mixes and comparing them with conventional bitumen. The aggregate gradation chosen is for a dense mix to be used in heavy duty asphalt pavement. The polymer modified binders chosen were actually having their own brand names and for the purpose of this paper only the polymer used is mentioned. Two of the modified bitumen use styrene butadiene styrene (SBS), one low density polyethylene (LDPE) and the other ethylene methyl acetate (EMA). All the polymer modified binders were supplied by the respective manufacturer.

2. TEST PROCEDURES

The testing program focuses on some of the fundamental properties of the modified bitumen binder itself followed eventually by selected tests on the asphalt mixes to determine the physical properties of the polymer modified asphalt mixes. It is important to determine which test properties of the bituminous binders offered the best correlations with mix performance and this is one of the main emphasis of this study. A brief description on each of the tests performed is given in the following passages.

2.1 Softening Point

The softening point test were conducted on the binders according to ASTM D36 which utilises the ring-and-ball apparatus. Two horizontal disks of binder specimens, cast in shouldered brass rings, were heated at a controlled rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in the binder, to fall a distance of 25 mm.

2.2 Flash Point

The flash point test were conducted in accordance with AASHTO T48 utilising the Cleveland Open Cup apparatus. The test cup was filled to a specified level with the binder sample. The temperature of the sample was increased rapidly at first and then at a slow constant rate as the flash point is approached. At specified intervals a small test flame is passed across the cup. The lowest temperature at which application of the test flame causes the vapours above the surface of the liquid to ignite is taken as the flash point.

2.3 Brookfield Viscosity

The viscosity test were conducted according to ASTM D4402. This standard test method is used to determine the apparent viscosity of the binder using the Brookfield Thermosel apparatus. The equipment used in this case is the Brookfield Rheometer model DV-III. The binder sample was placed in a special container and fixed into a thermosel. The viscosity is determined using a #27 spindle applied at a speed of 20 rpm at 135^0C.

2.4 Dynamic Shear

The visco-elastic characteristics of the binders were determined according to the procedure specified in AASHTO TP5. The apparatus used in this test is the HAAKE RT10 Dynamic Shear Rheometer. The complex modulus (G*) and phase angle (δ) were determined at 76^0C and a frequency of 10 radians/sec. The value of G*/sin δ was therefore determined for each binder.

2.5 Binder Ageing

The ageing effects on the binders were also investigated using the Rolling Thin Film Oven Test apparatus (RTFOT). The test procedures were in accordance with ASTM D 2872. This test simulate the second stage of the binder's life, ie. during mix production and construction. This test exposes films of binder to heat and air and approximates the exposure of bitumen to these elements during hot mixing and handling.

2.6 Marshall Test

The mix design for the polymer modified asphalt is in accordance with ASTM D1559 and the Asphalt Institute Manual Series No.2 (MS-2). The main objective of the mix design is to determine the optimum binder content to be used in the polymer modified asphalt mix. Triplicate specimens were prepared for each binder content which range between 5.0% and 7.0% by weight of mix. The aggregate gradation was the IKRAM 20 wearing course (please refer *Figure 1*). A total of 75 blows per face were applied to each specimen. The optimum binder content for the mix was then determined using the Marshall mix design criteria as specified in the standard test method mentioned above.

2.7 Resilient Modulus

The resilient modulus of each asphalt specimen was determined using the Materials Testing Apparatus (MATTA). The test is conducted by applying a vertical compressive load at a frequency of 1.0 Hz. (with a haversine waveform) on cylindrical Marshall specimens in the diametral plane. Two horizontal LVDTs are used to measure the horizontal deflections. The test temperature is 25^0C. Five conditioning pulses were applied before the actual test is performed. Results obtained from this test will indicate the relative stiffness of each asphalt mix.

2.8 Indirect Tensile Test

This test is used to determine the tensile strength of the asphalt specimen. A vertical compressive load is applied diametrally onto cylindrical Marshall specimen at a constant rate of 51 mm/min at a temperature of 25^{0}C. The load is applied until failure and the ultimate load recorded is used to determine the tensile strength of the asphalt specimen.

2.9 Static Unconfined Compressive Creep Test

This test is performed to examine the resistance to permanent deformation under severe loading conditions. Results from this test can be indicative of the rutting potential of the asphalt surface. Marshall specimens are used in this test which is conducted at 40^{0}C. The sample was initially conditioned to this temperature for about three hours prior to testing. The surfaces of the specimen were also trimmed and polished. After placing the specimen in the loading mechanism, it was preconditioned for 10 minutes at 10 kPa. A constant load of 300 kPa was then applied for 60 minutes. Thereafter, the load is released for 10 minutes for recovery.

3. ANALYSIS OF RESULTS

The use of polymer modifiers affect the softening point and viscosity of the modified bitumen binders (*Figure 2*). All the polymer modified binders showed less temperature susceptibility as compared to conventional 80/100 pen. bitumen. This is an important characteristic especially when significant fluctuation in temperatures do occur within the day. An increase in high temperature stiffness without losing low temperature flexibility is certainly an important attribute of a binder to be used in such an environment.

The viscosities of the polymer modified binders (determined by the Brookfield Rheometer at 135^{0}C) were found to be very much higher than that of conventional 80/100 pen. bitumen. The difference in magnitude obviously depend on the type and quantity of polymer used. In addition, it also appears that there is almost a linear relationship between viscosity and softening point irrespective of the type and quantity of polymer employed. If a linear relationship is to be chosen, the rate of increase in viscosity with respect to softening point would be around 125 mPa.s per ^{0}C rise in softening point.

The flash points of the modified binders as determined by the Cleveland Open Cup method are found to be well above that of conventional 80/100 pen. bitumen (*Figure 3*). It is found that irrespective of the type and quantity of polymers used, the flash point of the modified binder increases at a rate of approximately 4^{0}C per ^{0}C increase in the softening point.

The visco-elastic properties of bituminous binders can best be examined through dynamic mechanical analysis. Through dynamic analysis, one is allowed to fingerprint the viscous and elastic nature of bituminous binders over a wide range of temperatures and loading times. In the context of this study, the procedure stipulated in AASHTO TP5 has been adhered to. The complex modulus (G^*) and phase angle (δ) were determined at 76^{0}C and a frequency of 10 radians/sec. using the dynamic shear rheometer. The values for dynamic shear ($G^*/\sin\delta$) which gives an indication on the stiffness of the binder were then calculated for all the binders.

The higher the value of dynamic shear the higher is the stiffness of the binder.

All the polymer modified binders gave higher values of dynamic shear than that of conventional 80/100 pen. bitumen. This is to be expected since the addition of the polymers is partly to increase the stiffness of the bituminous binder. The relative magnitude with respect to conventional 80/100 pen. bitumen is illustrated in *Figure 4*. All of the polymer modified binders have dynamic shear values well above 1.0 kPa, which is the minimum specification set for modified bitumen to be used in the runway pavement of the new international airport in Malaysia. The higher the softening point of the binder the higher will be the dynamic shear value (*Figure 4*).

Another important characteristic which comes to surface is the perfectly linear relationship that exist between the viscosity and dynamic shear, irrespective of the type and quantity of the polymer used in the modified binder (*Figure 5*). It appears that for every 100 mPa.s increase in viscosity it is expected that there will be a 50 Pa increase in dynamic shear. This result is rather interesting as it provides an almost perfect conversion between the two parameters.

A preliminary investigation on the effect of heat on the ageing characteristic of the modified binders reveals that the stiffness of the binders have all increased including that of conventional 80/100 pen. bitumen (*Figure 6*). The rate of increase in dynamic shear value varies from one modified binder to another. The increase in dynamic shear is expected as the elastic property has become more dominant as compared to the viscous property after being subjected to heat and air. It is observed that the conventional 80/100 pen. bitumen experience much higher mass loss as compared to the polymer modified binders.

As far as the asphalt mixes are concerned, all the polymer modified binders out-performed the conventional 80/100 pen. bitumen in terms of Marshall stability, tensile strength and resilient modulus (*Figure 7*). In addition, results of the static creep test performed at 40^{0}C show that the mixes with polymer modified binders experience very low axial strains as compared to the conventional bitumen (*Figure 8*). The results of permanent strain and the rate of creep for the respective binders are illustrated in *Figure 9*. These observations clearly indicate the expected relative performance of each mix in terms of resistance to creep, hence, rutting resistance. Thus, it is perceived that the polymer modified asphalt would generally provide greater resistance to rutting as compared to conventional asphalt.

There is an almost linear relationship between softening point and permanent strain (*Figure 10*). The excellent correlation between the two parameters further strengthens the idea of using softening point as an indicator to determine the suitability of a particular bituminous binder, especially for the purpose of rutting resistance. Relationships between permanent strain and viscosity as well as permanent strain and dynamic shear are illustrated in *Figure 11* and *Figure 12* respectively. One observation from these relationships is that it is not really necessary to obtain a very high value of viscosity or dynamic shear in order to achieve a high creep resistance (ie. low creep value). Too high a viscosity would reduce workability during mixing and risk that aggregates may not be well coated. Nevertheless, a slight increase in either the viscosity or the dynamic shear of the bituminous binder would significantly increase the creep resistance of the asphalt mix.

4. CONCLUDING REMARKS

The findings from this laboratory study has indicated some of the superior characteristics of polymer modified bituminous binders in comparison to conventional 80/100 pen. bitumen. Various properties and characteristics of the modified binders were investigated with particular emphasis on binder rheology and the visco-elastic properties. Relationships between certain binder properties and asphalt mix performance has also been investigated and established. There is good correlation between certain binder properties and expected performance of the asphalt mix. The use of polymer modified binders in asphalt mixes would continue to be a better choice especially when a high performance type bituminous pavement is required.

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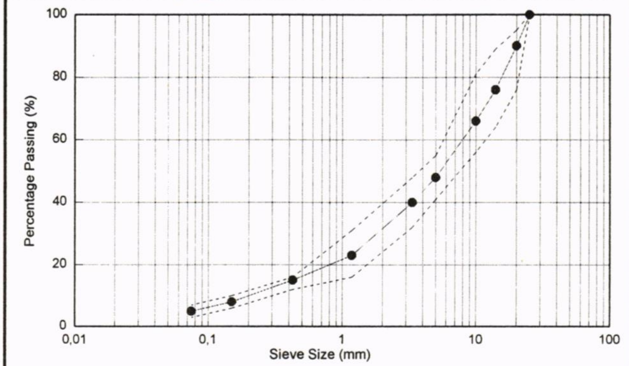

Figure 1 : Gradation Limits for IKRAM 20

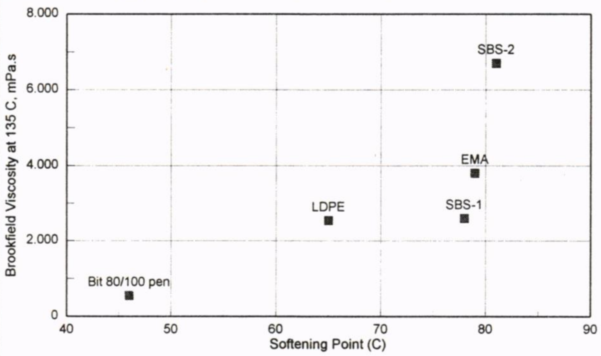

Figure 2 : Viscosity - Softening Point Relationship

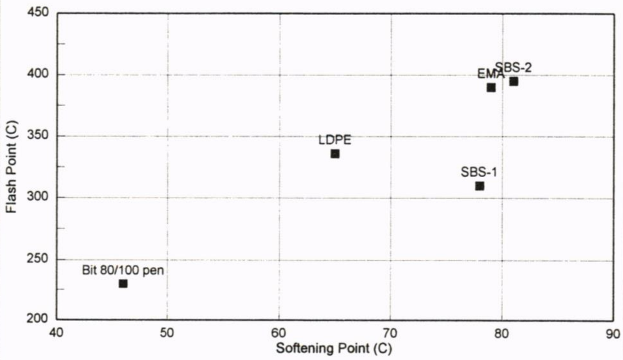

Figure 3 : Softening Point and Flash Point Relationship

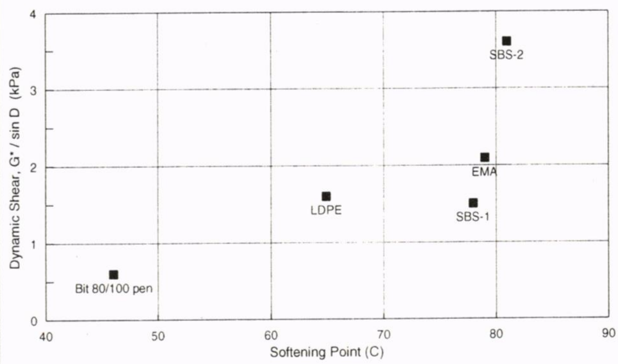

Figure 4 : Softening Point - Dynamic Shear Relationship

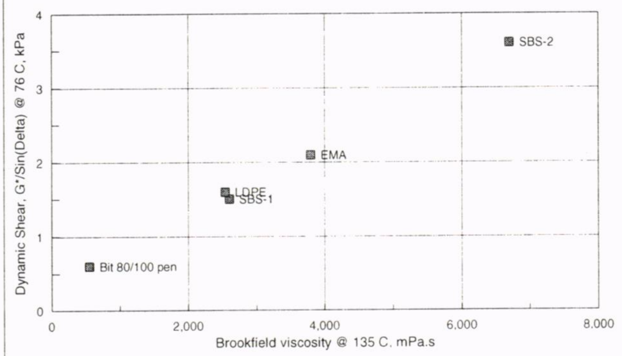

Figure 5 : Dynamic Shear vs Viscosity

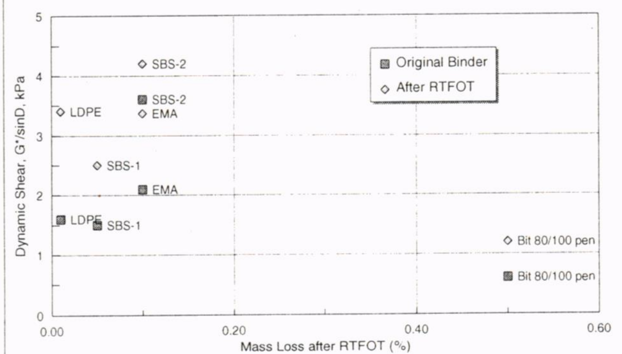

Figure 6 : Effect of RTFOT on Dynamic Shear Characteristics

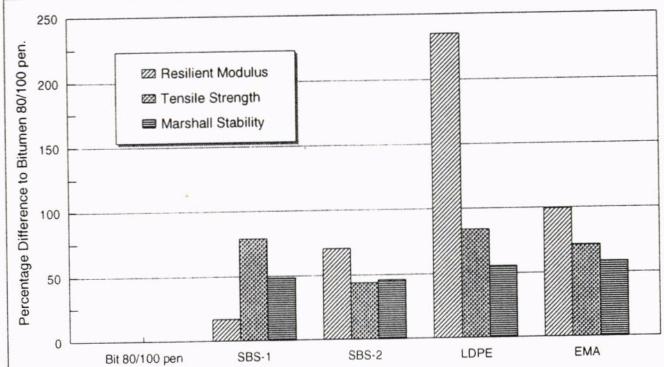

Figure 7 : Percentage Difference as compared to Bitumen 80/100 pen.

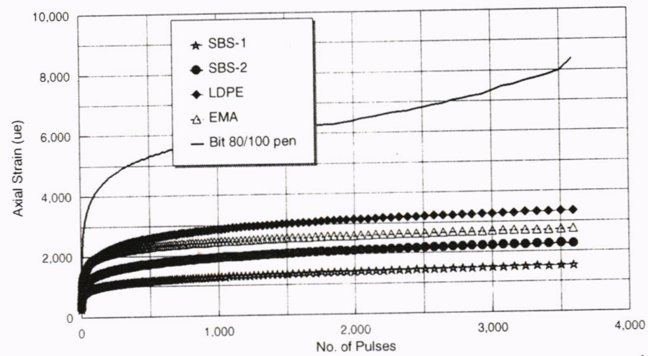

Figure 8 : Static Creep Curves at 40C

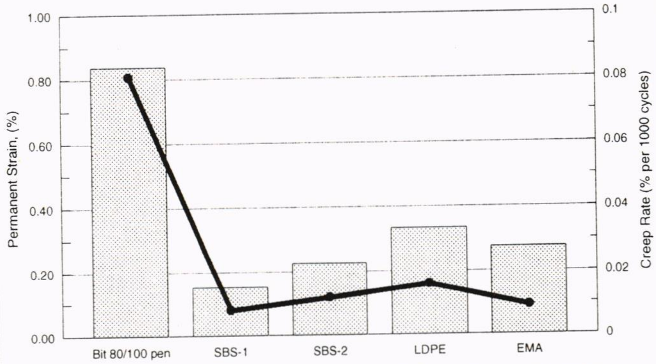

Figure 9 : Permanent Strain vs Creep Rate at 60min. of loading

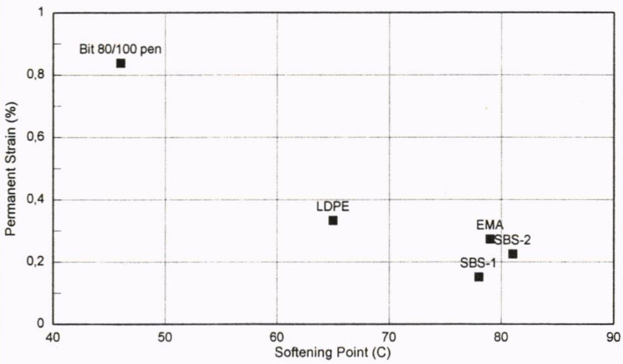

Figure 10 : Relationship Between Permanent Strain and Softening

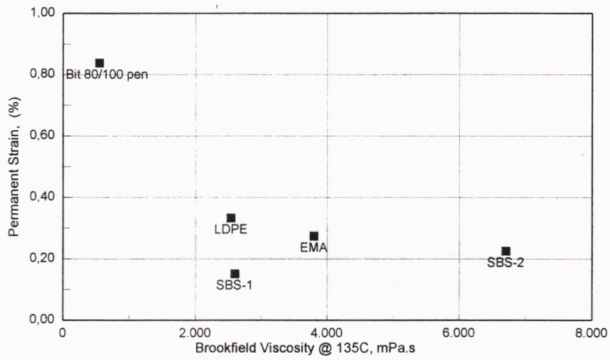

Figure 11 : Permanent Strain and Viscosity relationship

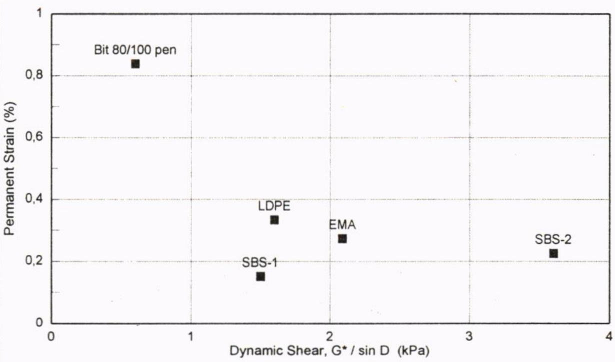

Figure 12 : Permanent Strain - Dynamic Shear Relationship