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RHEOLOGICAL PROPERTIES OF CELLULOSE FIBRE MODIFIED BITUMEN

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Abstract

Fibres have been extensively used to increase rheological properties of engineering materials for a long times. It is well known that modified bitumen considerably increases reheological properties of bitumen used within bituminous pavements suffering from different kinds of distresses like low temperature cracking, rutting, fatigue, etc,. Cellulose fibre, which forms three dimentional reinforcements within the bitumnen, is also alternative modifier for bitumen and highway materials. The prime role of the bitumen modifier is to increase resistance of asphalt to permanent deformation at high road temperatures without adversely affecting the properties of bitumen or bituminous materials.

The aim of this work is to assess of reoloji of cellulose fibre modified bitumen. So standart test methods, which are penetration, softening point and viscosity tests, were used for determination of the modified bitumen, to which a certain percentage of cellulose fibres were added. It was observed that the cellulose fibre- modified bitumen presents considerable higher resistance to penetration, softening point and viscosity values hence tensile properties which have a significant effect on the reheological properties of bituminous mixture.

Keywords: Bitumen Enhancement Modified Bitumen, Viscosity, Cellulose Fibre Modified Bitumen and Permanent Deformation.

1. Introduction

During the last decades there have been dramatic increase in traffic volumes, axle load, and tire pressures on the bituminous pavements suffering from different kinds of distresses as low temperature cracking, rutting, fatigue, etc, therefore the binder should be stiff enough to resist rutting, flexible at low temperature to avoid thermal cracking, and should have time independent properties as well as good fatigue and stripping resistances. Permanent deformation is a one of major mode of failure in flexible pavements consisting of both rutting and shoving, which is more severe in hot climates where the stiffness of the mixture is further decreased with the increase of the pavement temperature [1,2]. Additionally, the different behavior bituminous pavement at intersection is related to the more complex stresses imposed at the pavement surface layer by the braking and turning movements of heavy loaded trucks. Therefore, continuous increase in the volume of commercial vehicles applies substantially greater stresses to the road surface and has resulted in bituminous mixtures failing to reach their expected design life. In order to prevent these failures occuring, bitumen enhancement offers a solution, which may meet the pressure coming from the axle load. As bituminous mixtures consist of two important components, which are bitumen and aggregate. Despite the bitumen occupying a small percentage of the component; it plays a vitaly important role in mix performance. The bitumen is responsible for the visco-elastic properties of all bituminous materials. The proportion of any induced strain in a bituminous material that is attributable to viscous flow, i.e. non-recoverable strain increases with both loading time and temperature [3]. It is commonly accepted that bitumen setting up a bond between aggregates plays a major role in the durability and performance of bituminous mixtures. So modification of bitumen used has always been a subject for enhancing rheological properties of bitumen i.e., decrease temperature susceptibility, enhance elasticity and increase viscosity and shear susceptibility [1,4,5]. Binder adhesion properties and resistance to oxidation are the main reasons causing rapid ageing and low

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temperature cracking [2]. The use of modified binders offers a solution to reduce the frequent maintenance of asphalt pavements and provide much longer service life [6,7] and offers a variety of benefits by enhancing the rheological properties of bitumen. The prime role of the bitumen modifier is to increase resistance to permanent deformation at high road temperatures without adversely affecting the bitumen properties [8], which are achieved by either stiffening the bitumen or increasing its elastic component. Within the last fifty years, many researchers have been experimenting with modified bitumen by adding variety of additives, such as asbestos, polymer, special fillers and different fibres to improve bitumen properties [1,9,10]. The common task of bitumen modification has been to reduce the susceptibility of binder stiffness [11] supporting bitumen stability in temperature changes and loading time giving high cohesive strength at elevated temperatures [12], combined with high elasticity at low temperatures. The other important criteria to be considered is not to loose existing properties of bitumen. The primary objective of this research was to determine whether homogeneously dispersed cellulose fibers improve the penetration, the softening Point and viscisity of the bitumen. So the work aims to assess reological properties hence resistance to deformation of effect of cellulose fibre modified bitumen.

2. Materials and method

2.1. Laboratory preparation of cellulose fibre modified bitumen

In order to accommodate adequate fibre distribution within the bitumen, the mixing process considered very important stage in the procedure. Since the cellulose fibre is water loving and susceptible to moisture, forming a uniform fibre distribution is an obstacle within the bitumen composition. Fibre with moisture tends not to disperse and gathers as a ball within the bitumen therefore prevents enhancement of the bitumen-fibre- matrix. In order to avoid this problem, the fibre was kept in an oven for one-hour at 100 ^{o}C and then added to the mixture to encourage uniform dispersion. An apparatus was developed to assure adequate distribution of cellulose fibre within the bitumen. In ten minutes mixing procedure an adjustable speed mixer was used as the fibre was being added. In order to prevent the air void remained within the mix because of the mixing procedure the mix was put in an oven at 135 ^{o}C for 30 minutes before testing was carried out. During the period in the oven the air voids evaporated due to the Newtonian behaviour of bitumen at high temperature. Than the samples were prepared for testing.

2.2. Fibre distribution within the fibre-bitumen mixture

In order assure whether the mixing process accommodate an adequate fibre distribution, the sample prepared was observed under a microscope. The mixture put in a plastic cup was kept within liquid nitrogen to feeze the samples, which makes bitumen very brittle and easy to break, the sample than broken by a sharp metal piece and placed under a microscope to examine its texture. The texture also showed that there were no air voids, which may affect an accurate measurement, in the mixture. The medium fibre, which was used in the work, has an even fibre distribution compared to the coarse fibre which is gathering in a certain point of the texture. The cross - section of the coarse fibre has a thicker fibre shape, which may prevent bitumen penetration into the fibre within structure. Table 1. Shows the fibre type and composition.

Table 1. The Cellulose fibre properties used within the mix

Number	Type of fibre	Composition
1	**Fine** (>1.60 mm)	25 µm to 1.60 mm
2	**Medium** (<1.60mm&>3.36mm)	25 µm to 2.50 mm
3	**Coarse** (>3.36 mm)	25 µm to 5.50 mm

3.0. Rheological Properties and Testing Procedure

The bitumen rheoloji is more widely used as elastic modulus, which has a prime role of effecting the pavement performance. So determination of bitumen rheoloji is vitally important for bituminous pavement design and performance. In order to determine the rheologicaI properties of the fibre-modified bitumen, the empirical tests, which are included: Penetration, Softening Point (R&B),Viscosity, Ductility.

3.1. Bitumen used

200 pen bitumen was chosen for the tests carried out. The properties of the bitumen are given in Table 2.

Table 2. The bitumen properties used in the tests

Property	Test method	Grade/200 pen
Penetration at 25 ^{0}C	BS 2000: Part 49	200±30
Softening point ^{0}C (min)	BS 2000: Part 58	33
Softening point ^{0}C (max)	BS 2000: Part 58	42
Loss on heating for 5h at 163^{0}C (a) Loss by mass % (max) (b) Prop in penet. (max)	BS 2000 Part 45	 0.5 20

3.1.1. Penetration Test

The penetration test, which is an empirical test, was carried out in accordance with [13]. The penetration value at 25 ^{0}C is often used to indicate the grade of bitumen which is categorised and named using this grading system. It is well known that bitumen hardening in terms of penetration lead to crack development in asphalt pavements when the penetration of bitumen (25 ^{0}C) falls below 20 serious pavement cracking may occur. High resistance to cracking may occur when a mixture is well designed and properly compacted and the penetration of the bitumen is well above 30.

The above conclusions are supported by other studies. Obviously, other factors Such as bitumen film thickness, bitumen temperature susceptibility, bitumen ductility, air void content, age of pavement, traffic and climatic conditions also influence this general relationship between penetration and cracking. Figure 1. shows the penetration results for the fibre-bitumen mixes (fine, medium and coarse) with different fibre concentrations from 0.2 to 1.0 %. It also presents that the cellulose fibre additives have a significant decrease with the fibre additive, which leads of increasing bitumen consistency hence resistance to deformation. There is also a good correlation in terms of fibre size respectively fine, medium and coarse fibre addition. Fine and coarse fibre additives follow a parallel trend compared to the medium fibre additive. This may be a reason that fine fibre contains a significant dust content which might prevent interconnection among the fibre particles, so it is difficult to determine an optimum fibre content with the Penetration test method.

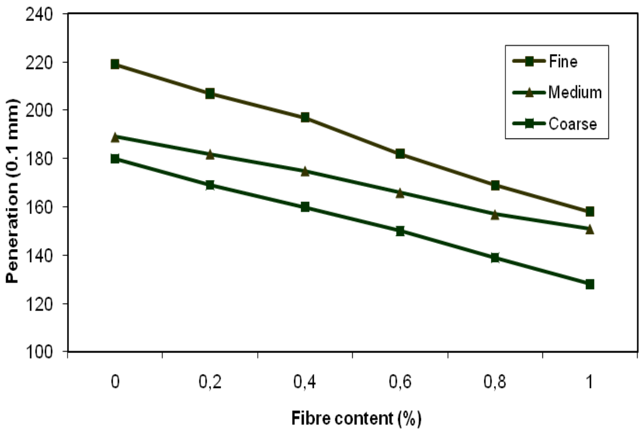

Figure 1. Penetration and fibre content.

3.1.2. Softening Point (Ring & Ball) Test

The Softening Point test (Ring and Ball) was carried out accordance with [14]. Bitumen softens gradually upon heating and does not possess a narrow melting softening point. In order to determine the softening point, the Ring &Ball test is the most commonly used method. Softening point can be related to the temperature susceptibility of bitumen at high temperature changes. At high surface temperature, bitumen has less resistance to internal shear force. Therefore it can not resist an applied force. An increase in softening point is an increase in resistance to deformation and temperature effects. Figure 2 presents a good correlation as it is on the penetration test in Figure 1 that there is a significant increase with the fibre addition in softening point test results, which represents more realistic method of measuring the fibre concentration compared to Penetration test, so it is clear that the fibre modified bitumen may have a good deformation resistance/ internal shear force at high temperatures. Figure 3 indicates that the both penetration and R&B tests have a paralel trend with the medium fibre addition. The both test methods also indicate almost the same amount of increase occurring. 1.0 percent fibre addition, which is equvalent about 25 % increase on penetration and softening point.

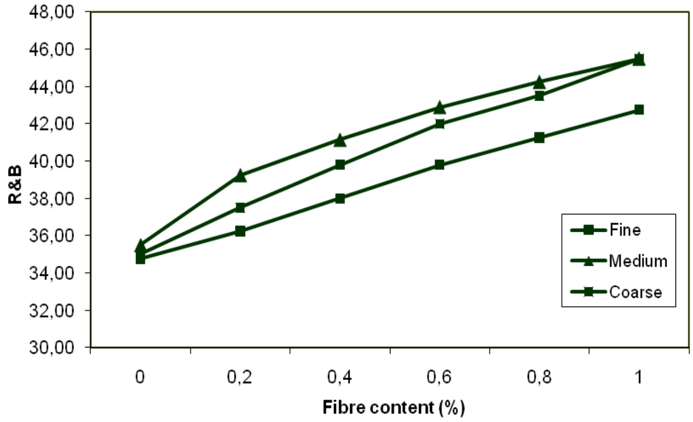

Figure 2. Softening Point and fibre content

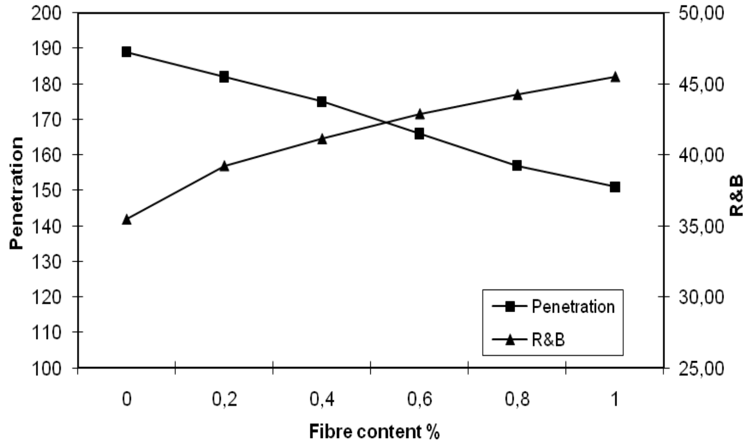

Figure 3. Relationship with Penetration and Softening point (medium fibre)

3.1.3. Viscosity

Viscosity is a fundamental characteristic of bitumen and determines how it will behave at elevated temperatures. It is simply at any given temperature, the ratio of shear stress to shear strain rate. At high temperatures such as 135 ^{0}C (275 ^{0}F) bituminous mixtures behave as a simple Newtonian liquid; that is the ratio of shear stress to shear strain rate is constant. At low temperature, the ratio of shear stress to shear strain rate is not constant and bitumen behaves like a non-Newtonian liquid [15]. Asphalt bitumen viscosity has an influence on the performance of HRA pavements. During hot summer days when the surface temperature is near 60 ^{0}C (140 ^{0}F). A low viscosity at 60 ^{0}C can induce flushing and or rutting. This is especially true for mixes that have relatively high bitumen content.

For determination of the viscosity, efflux viscometers such as the standard tar viscometer (STV) have been used as it is used the UK for many years. They determine an empirical viscosity i.e. the time of flow for a measured amount of bitumen to flow through an orifice of standard size at a controlled temperature. Such devices may be used for penetration grade bitumen, but the temperature used need to be high. The STU was originally designed for cut-back bitumen at 60 ^{0}C [16]. At this temperature, penetration-grade-bitumen would not have reached an appropriate viscosity level to evaluate. So the test was altered to measure cellulose fibre modified penetration grade bitumen. The test temperature was increased to 80 and 100 ^{0}C. An attempt to increase the temperature to 120 ^{0}C was failed because the water controlled heating . Another attemt of measuring the viscosity of the bitumen by ICI Cone Plate Viscosity Test, which was originally devoloped for measuring of viscosity of paints, later adapted by the bitumen industry to determine the viscosity of resins, bitumen, hot melts and similar products, damaged the fibres within the mix and prevent keeping an appropriate modified bitumen thicknes, in which the fibre distribution and texture must be intact. [17] conducted a study indicating that the viscosity of fiber reinforced asphalt binders is increased by the addition of fibers, as Figure 4 presents that the cellulose fibre additives have a signiticant effect in the viscosity of bitumen. There is a constant increase with fibre addition. It appears that the coarse fibre causes a greater increase than the medium and fine fibres. The fine fibre additive has the smallest effect. This may be because the fine fibre contains a significant dust content that has a smooth surface, so it prevents a good interconnection and texture, which helps of working fibres together within the bitumen. The work indicates that cellulose fibre additives have less effect at highest temperature. With an increase of temperature, the bitumen becomes more liquid so that the fibre looses its bond or grip with the bitumen. Figure 5 presents a good correlations that there are similar trends on the penetration, softening point and viscosity test results with the fibre addition, so the cellulose fibre modified bitumen may have good resistance to shear force hence durability with hot temperatures. Figure 8 shows the changes of viscosity with different temperatures, which follows almost the same trend with the fibre additives. However, the test carried out at 120 ^{0}C shows no fibre effect within the bitumen because of its Newtonian behaviour at certain temperature.

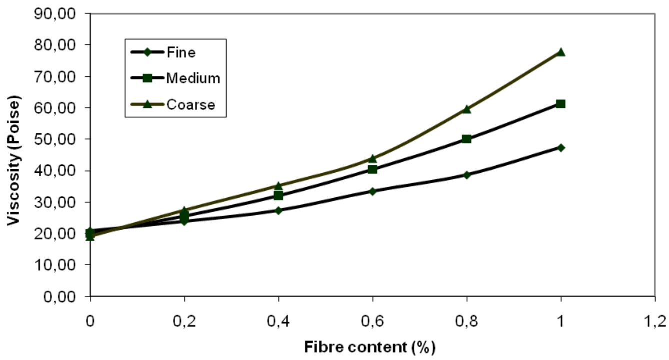

Figure 4. Viscosity and Fibre content at 100 ^{0}C (200 pen)

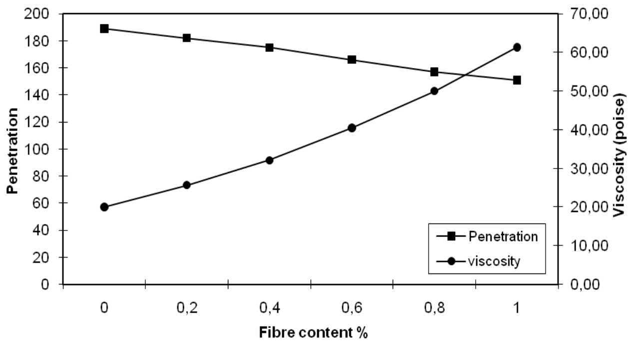

Figure 5. Relationship with penatration and viscosity (at 100 ^{0}C, medium fibre)

4.0. Determination of Stiffness Modulus of Bitumen

The stiffness modulus of bituminous materials is considered to be a very important mechanical and performance property, which is a measure of the load-spreading ability of bituminous layers and controls the level of traffic induced tensile strain that is responsible for structural deformation occuring in due time. The fundamental method to measure the stiffness modulus of bitumen is based on shear deformation. In order to accommodate the large amount of data for shear stress and temperature effects, various authors have proposed master curves and temperature susceptibility correlation [18,19]. The stiffness of asphalt binder plays a critical role in rut resistance of asphalt binders, which means the stiffer binder presents less strain hence plastic deformation. As Figure 6 presents a good correlation between stiffness and strain properties of the fibre modified bitumen. The fibre addition considerably contributes to stiffness hence the strain properties which is vitally important criteria to keep on stable on hot weather conditions and heavy load applications which lead a rapid pavement failures, such as permanent deformation, flushing, rutting etc [17]. So the modified fibre may contribute of meeting the life span of pavement designed.

5.0. Discussion of Performance Assessment of Cellulose Fibre Modified Bitumen

Bitumen, as is a visco-elastic material, plays a prominent role in determining many aspects of road performance effected by wariety of different elements. For example, a bituminous mixture needs to be flexible enough at low service temperatures to prevent pavement cracking and to be stiff enough at high service temperatures to prevent rutting in different loading conditions in varying climatic environments. So enhancing the bitumen properties may considerable contributute to the performance of bituminous pavements failing mostly before reaching expected design life.

As is shown in figures 1, 2, 4, the cellulose fibre modification causes a continuous increase and increase in viscosity and softening point and decrease in penetration, which represents bitumen consistency, plays a vital role in determination of bitumen rheology, hence the pavement performace at heavy load applications causing a rapid failure on the pavement. In addition, softening point test result could be related to the temperature succeptibiliy of bitumen at high climatic conditions at which bitumen has poor resistance to internal shear force, so it can not resist to an applied force. So the fibre addition represent a significant contribution to the internal shear force, hence possible bleeding might be prevented by the modification.

Due to the nature of bitumen, visco-elastic material which is not viscous or elastic, behaves differently in different temperatures and urn into a Newtonian liquid which is not preferable at certain design condition of the bituminous materials. So proper viscosity grade selection appropriate to prevailing temperatures must be chosen. Knowledge of the viscosity of bituminous materials is he key element of controlling of manufacture and constraint having major impact on durability. As the test results, Figure 4, presents a considerable increase with the addition of the fibre modification and different size of fibre concentrations on viscosity of bitumen, so the fibre modification follows the same trend with the softening point, Figure 2, hence it has a great deal of enhancement on the pavement performance.

It can also be seen from the Figure 6 and 7, the modification also reduces temperature susceptibility of the bitumens, as indicated by increased stiffness modulus that increase of stiffness leads to a better resistance of ruting, permanent deformation and stable pavement with heavy loading at higher climatic conditions. It is widely accepted that [17] stiffer materials leads less strain occurance hence longer deformation resistance since the total strain during loading period and the permanent strain is reduced greatly with the fibre addition, which revealed that the resistance to permanent deformation can be significantly improved for bituminous materials containing cellulose fibres.

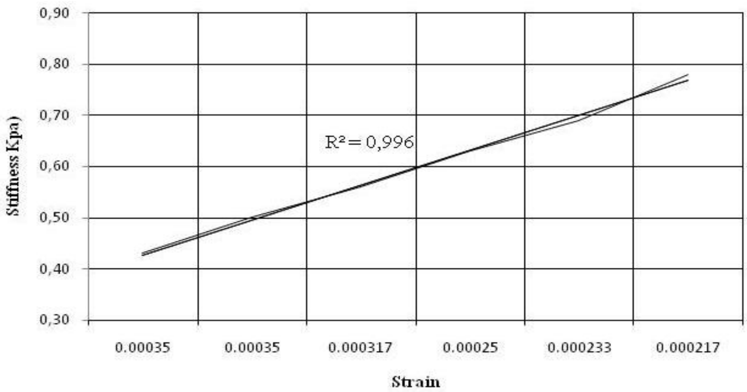

Figure 6. Relationship between stiffness and strain relationship with different fibre addition (0.0, 0.2, 0,4, 0,6, 0,8 and 1.0 %) [20]

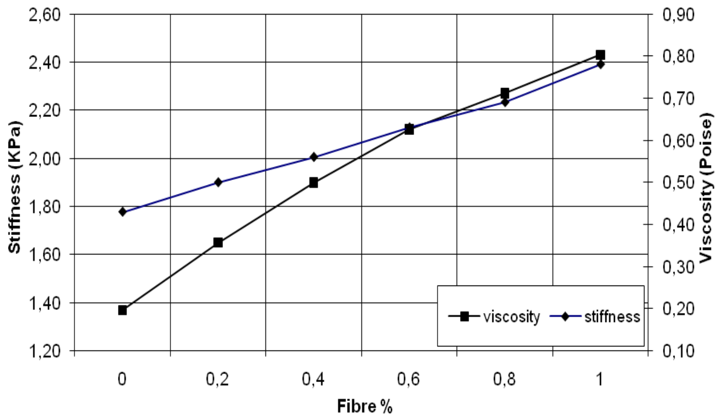

Figure 7. Relation with the fibre content and Viscosity (poise) and stiffness [20]

6. Conclusion

Based on the findings from the study the following conclusions could be drawn;

- The fibre addition changes the reological properties of bitumen depending on fibre addition at elevated temperature. The addition of fibre presents better performance after 0,4%, this means after certain percentages the three dimensional reinforcements works properly within all texture of the mix.
- Experimental results indicate that the viscosity of the fiber reinforced asphalt binders is increased by the addition of fibers, especially when the fiber concentration is medium and coarse.
- Increasing the stiffness of the bitumen is also likely to increase the dynamic stiffness of the asphalt hence improving the load spreading ability of the material and increasing the structural strength. Increasing the elastic component of the bitumen will improve the flexibility of asphalt which is important where high tensile strains are present.
- It is apperent that the three dimensional structure of fibre within the mix plays an important role on the stress transfer mechanism. Stiffer bitumen presents less strain hence higher resistance of permanent deformation.
- The most common pavement distress include: permanent deformation, fatigue cracking, stripping, fretting, and reflective cracking. So better controlling of stress/strain properties will contribute of preventing all distress occuring on a pavement.
- Rheology of the binder is widely interpreted as the elastic modulus, which has a propfound effect on pavement performance regarding resistance of deformation and rutting properties. So the cellulose fibre addition into bitumen is offering a three dimensional effects and considerable contribution on the rheological parameters, which are the profound criterias in bituminous mix design procedure.
- Stiffer materials leads less strain occurance hence longer deformation resistance since the total strain during loading period and the permanent strain is reduced greatly with the fibre addition, which revealed that the resistance to permanent deformation can be significantly improved for bituminous materials containing cellulose fibres.

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