COMPARISON OF BITUMEN RHEOLOGICAL PROPERTIES BETWEEN 60/70 AND 80/100 GRADE PENETRATION BITUMEN

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ABSTRACT — Conventional bitumen is widely used in most countries where it hardens at the early stages during handling, mixing and in service. The level of performance of service life has a close relationship with the properties of bitumen used in the asphaltic concrete. This rheological weakness of the conventional bitumen has generated an increasing interest in the use of polymer modifiers to enhance properties of conventional bitumen. The study investigated the comparison of bitumen 60/70 and 80/100 penetration grades in terms of physical properties before aging and after aging. Bitumen is thermo-visco-elastic material where temperature and rate of load application have a great influence on their performance. In this the fundamental rheological and mechanical tests were conducted, which include penetration test, softening point, the rolling thin film oven test (RTFOT), and pressure age vessel (PAV). The effects of aging on the rheological and physical properties of bitumen binders were studied by conducting the penetration and softening point test after aging. The results obtained from the laboratory tests conducted shown that, bitumen grade penetration 60/70 is suitable to be apply and use in Malaysia. Based on the test conducted and comparison of the results, it shows that the penetration value after aging grade 60/70 got lower penetration compared to grade 80/100. It has been observed and analyzed that bitumen grade 80/100 has higher penetration value after long aging. It can be concluded that the lowest penetration aging ratio, will led to reduce the degree of aging. In addition, if the penetration after aging (60/70) is lower, the value of softening point will increase. The higher penetration value after aging is not suitable to be used because of the penetration will be higher if the temperature increased. Higher temperature will turn the bitumen soften and this will reduce the stiffness and make the bituminous mixture more susceptible to rutting. Hence, when the temperature is lower, the stiffness will increase and it will reduce the flexibility and tend to fatigue failure.

Keyword: bitumen; aging; deformation; rutting

1. INTRODUCTION

Nowadays, country all over the world have faced big difficulties on maintaining their existing road networks due to high traffic volume, higher axle loads and increased of tire pressure. Most of the main road in Malaysia got system paved with dense graded failed essentially through fatigue cracking. Firoozifar et al, 2011 stated that rheology involves the study and evaluation of the time—temperature dependent response of materials that are stressed or subjected to an applied force. Rheological properties of bitumen consist of age hardening, temperature susceptibility, shear susceptibility, stiffness, penetration, ductility, and viscosity of the bitumen. Cracking and rutting happened to the pavement due to the traffic loading and climate factors; temperature and moisture. According to Abdullahi A,(2007) stated that bitumen under the hot tropical sun, oxidative ageing of asphalt layers leads to the phenomenon of surface down crocodile cracking. Environmental changes between hot and cold temperature over a year had influenced the durability of asphaltic bitumen. Bitumen can be soften when high temperature and it can reduce the stiffness of asphaltic concrete and cause the mix more susceptible to rutting. In contrast, the stiffness of the bitumen can be increase when the temperature is low and it can reduce the elasticity of the asphaltic bitumen, hence it may cause fatigue failure. Thus, cracking on the surface of pavement may develop badly affects the performance of the asphaltic. Hence, high temperature stiffness and low temperature flexibility become significant properties in bituminous mixture respectively to avoid rutting and cracking (Roberts et al., 1990). **Aging** (Oxidation) is caused by **external** to surroundings like the existence of atmospheric oxygen, Ultra-violet radiation from the sun, temperature changes, traffic loadings, and the formation of free radicals (Kanabar,A.,2010)(Lu, X, 2008).

The critical problem that needs to be face is, how to solve rutting and crack problems and which grade penetration bitumen supposed to be used in the highway construction. Thus, the comparison of bitumen rheological properties between 60/70 and 80/100 grade penetration bitumen need to be done.

OBJECTIVES:

The objectives of this research are:

- To **determine of physical properties** of virgin bitumen grade 60/70 and 80/100 by performing physical test; Penetration and Softening Point.

- To understand the **aging mechanism** between bitumen grade 60/70 and 80/100 by performing Rolling Thin Film Oven test and Pressure Aging Vessel test.

- To c**ompare** the penetration and softening point before and after aging between 60/70 and 80/100 grade.

2. LITERATURE REVIEW

2.1 BITUMEN STRUCTURE

Bitumen, also known as asphalt, is a sticky, black and highly viscous liquid or semi solid present in most crude petroleum and in some natural deposits. Bitumen is primarily used in road construction, where it is used as the glue or binder mixed with aggregate particles to create asphalt concrete. It is also commonly used for bituminous waterproofing products, including production of roofing felt and for sealing flat roofs. Major distresses that lead to permanent failures are rutting and fatigue cracking in pavement construction. Bitumen is a visco-elastic material which its rheological properties are very sensitive to the temperature and rate of loading. The bitumen binder properties are always affecting the performance of road pavement properties. It is because the rheological properties and durability of bitumen that not sufficient to resist pavement distresses. In Malaysia the conventional bitumen that most commonly used is 80/100 penetration grade, due to the high traffic load and hot climate. Malaysia is the only ASEAN country that uses more bitumen penetration grade 80/100 compared to 60/70. In warmer region, lower penetration grades are chosen to avoid softening while higher penetration grades are used in colder regions to avoid the incident of excessive brittleness. High penetration grade is used in spray application works

Binder used in this research are 60/70 and 80/100 Grade Penetration Bitumen. According to The Shell Bitumen Handbook (2003), the design of internal structure of bitumen is mostly determined by the chemical structure of the molecular species present. Bitumen becomes predominantly hydrocarbons with small amount of structurally analogous heterocyclic species and functional groups containing sulphur, nitrogen and oxygen atoms (Traxler et al, 1936).

2.2 RHEOLOGY OF BITUMEN

Science that deals with the liquid flow and deformation of matter is called rheology. The rheological characteristics of bitumen at certain temperature are found by the structure (chemical composition) and the physical arrangement of the molecules in the material. Change to the formation, structure or both will result in a change to the rheology. Thus, to understand changes in bitumen rheology, it is necessary to understand how the structure and constitution of bitumen interact to influence rheology. Bitumen also contains trace quantities of metals such as vanadium, nickel, iron, magnesium and calcium, which occur in the form of inorganic salts and oxides or in porphyrine structures. Elementary analysis of bitumen manufactured from a variety of crude oils shows that most bitumen contains:

- Carbon 82-88%
- Hydrogen 8-11%
- Sulphur 0-6%
- Oxygen 0-1.5%
- Nitrogen 0-1%

2.3 THE RELATIONSHIP BETWEEN CONSTITUTION AND RHEOLOGY

Systematic blending of saturates, aromatics, resins and asphaltene fractions separated from bitumen has demonstrated the effect that constitution has on rheology (Griffin R l, 1959). By holding the asphaltene content constant and varying the concentration of the other three fractions, it has been demonstrated that:

- Increasing the aromatics content at a constant saturates to resins ratio has little effect on rheology other than a marginal reduction in shear susceptibility;
- Maintaining a constant ratio of resins to aromatics and increasing the saturates contents softens the bitumen; and
- The addition of resins hardens the bitumen, reduces the penetration index and shear susceptibility but increases the viscosity.

Rheological properties of bitumen depend strongly on the asphaltene content. At continuous temperature, the viscosity of a bitumen increases as the concentration of the asphaltenes blended into the parent maltenes is increased. Though, the increase in viscosity is significantly greater than would be expected if the asphaltenes were spherical, non-solvated entities.

2.4 BITUMEN PROPERTIES

Lesueur (2008) stated that the density of bitumen lies typically between 1.01 and 1.04 g/cm3, depends on the paving grade and crude source. It is a viscous material and also possesses a thermoplastic manner which means up to a certain temperature, it becomes moldable and returns to a solid state upon cooling. It is also insoluble in water. Chemically, they are static material and oxidize slowly. There are two empirical tests used to characterize bitumen which are penetration test and softening point test. For penetration grade bitumen, it is determined by the penetration test which will classify it into several grades namely 60/70, 80/100 or 100/120. Penetration grades greater than 40 are mostly used in road construction.

Bahia et al, (1991) has developed the equation to define the way that consistency changes with temperature which is the penetration index. The equation below is developed for the penetration test temperature at 25°C.

$$PI = \frac{1952 - 500 \log \text{Pen25} - 20\,\text{SP}}{50 \log \text{Pen25} - \text{SP} - 120}$$

The penetration index (PI) indicates temperature susceptibility of bitumen. Typically, PI values are ranging from around -3 (high temperature susceptible bitumen) to around +7 for highly blown low temperature susceptible bitumen. Below is table of several bitumen properties according to American Society for Testing and Materials (ASTM) Standards, which is also applied by British Standards (BS) in BS2000: Part 49.

It is become essential to test the different characteristic grades since the bitumen are manufactured wide diversity. It is feasible to approximate vital engineering properties from the results although they are arbitrary empirical tests, including high temperature viscosity and low temperature stiffness. The use of the penetration test for characterizing the consistency of bitumen dates from the late nineteenth century.

Physical Test (Before Aging)

The main objective of conducting Physical Test before laboratory aging test is to measure the initial physical properties of the bitumen samples. **Penetration Test** and **Softening Point Test** have been conducted to measure the penetration and softening point of all bitumen samples. Basically, these two properties are correlated to each other in terms of hardness and temperature susceptibility of the samples. By comparing the data from Physical Test before and after aging, the degree of bitumen degradation can be obtained. The percentage difference in degradation values will be determined at the end of this project.

BITUMEN PREPARATION

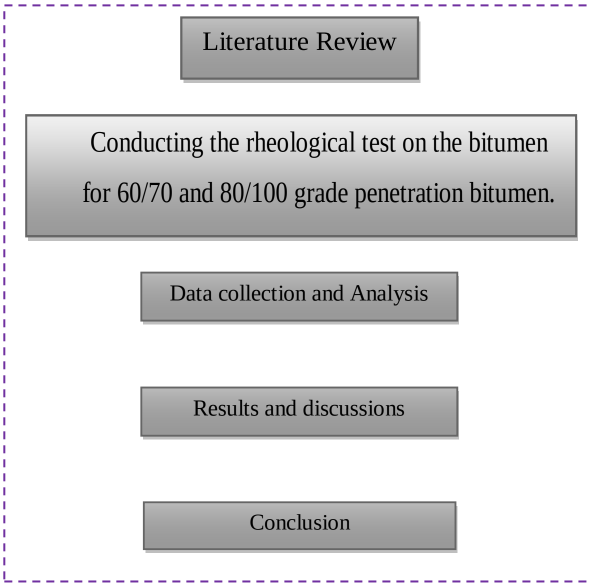
The bitumen has been completely prepared for the project according to the experiment with an appropriate amount. Shown below the production steps as well as the step had been taken during the bitumen process.

Penetration test:

The bitumen must be taken out from the storage by using hot scoop and it must be heated with care (use proper equipment full with safety). Stirring as soon as possible to prevent local over-heating, until it has become sufficiently fluid to pour. Then, pour the sample into sample container to a depth and leave at least 10mm greater than the depth. The container must be covered loosely as protection against dust and it must be cooled down in the atmosphere at temperature between 15°C and 30°C for 1 to 1.5hours before proceed with the experiment.

Figure 3.2a & 3.2b: *the method how to taken out bitumen from it storage*

3, METHODOLOGY



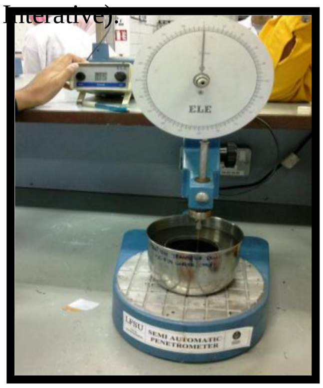
Softening point (Ring and Ball test):

The bitumen must be taken out from the storage by using hot scoop and it must be heated with temperature 75°C and 100°C above the expected softening point. The sample must be stirred to avoid air bubbles and to make sure it completely melt into fluid. Apply grease oil on a metal plate and pour the sample into the ring with sufficient molten sample so it can give an excess above the top of each ring when cooled. Let the sample in the ring cooled for 1 hour, then level the sample in the rings by cutting away the excess with warmed knife.

Penetration Test

BP Bitumen Australia website stated that Penetration Test can be applied on bitumen to determine the consistency of bitumen by measuring the distance that a standard needle will penetrate vertically into a sample (reported in tenths of a millimeter) under specified conditions of:- Loading = 100g, Temperature = 25°C, and Time = 5 seconds

Semi Automatic Penetrometer was adopted for this test The standard procedure of this method is in AASHTO T 49 and ASTM D 5: Penetration of Bituminous Materials (Pavement Interative).



Rolling Thin-Film Oven (RTFO) Test

This laboratory test is very important in providing the best simulation of short-term aging as usually occurred during hot mixing and the placement process (Kanabar, A., 24 2010). Pavement Interactive (2011) website stated that the RTFO test also provides a quantitative measure of the volatiles lost during the aging process. The basic RTFO procedure takes unaged bitumen samples in cylindrical glass bottles and then places these bottles in a rotating carriage within an oven. At high temperature of 163°C, the carriage will rotate at 15 RPM within the oven and ages the samples for 85 minutes. The rotation effects are significant as it continuously exposes the bitumen with heat and air flow as well as slowly mixes each sample. Samples are then stored for use in physical properties tests or to be used for PAV test. The standard RTFO test procedure can be found in AASHTO T 240 and ASTM D 2872 “Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)”.

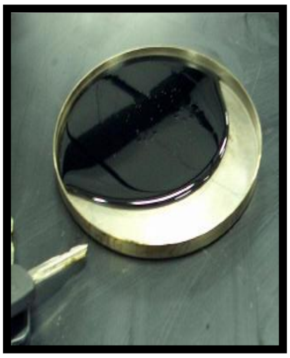
Figure 3: *RTFO Test Machine*

Pressure Aging Vessel (PAV) Test

Pressure Aging Vessel (PAV) tests is most preferred by researchers in order to simulate the long-term aging of bitumen. As stated by Kanabar (2011) earlier, long-term aging occurred whilst in-service of asphalt pavement where the effects of thermal and load-induced loads gradually crack the pavement and causing fatigue failure. The PAV test can age the bitumen sample that simulates the in-service aging over 7 to 10 year period. The bitumen sample will be exposed to heat and pressure during PAV test and the simulated long-term aged bitumen sample can be used for physical property testing (Pavement Interactive, 2011).

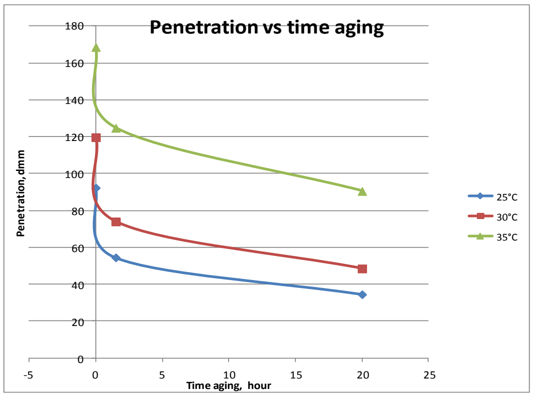
The basic PAV procedure takes RTFO aged bitumen samples and exposes them to high air pressure up to 305 psi (2.10 MPa or 20.7 atm) and heated for 20 hours. The heating temperature, as according to Amit Kanabar (2011), can vary according to different climate simulation. Table shown above is the proposed heated temperature that simulates different climate:-

Temperature	simulation
90°C	Cold climate
100°C	Moderate Climate
110°C	Hot Climate

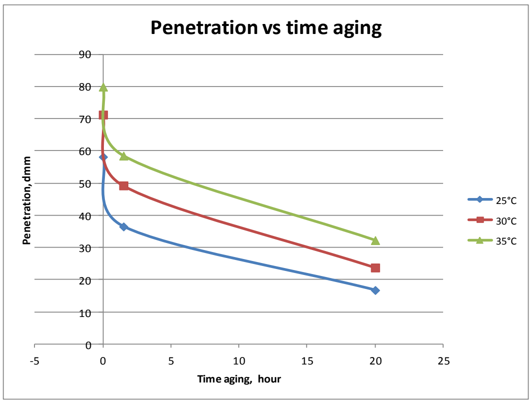


4.RESULT AND CALCULATION

1.Penetration Test Results



Based on **figure 4.3**, it shows that the value of penetration before aging, aging at 1.25 hours and 20hours at three different temperatures. At first, the value of penetration before aging is slightly higher compared to the penetration values after 1.25hours. After 20hours aging, the penetration values has dramatically dropped due to oxidations occurs for long hours.



According to the graph shown, bitumen grade 60/70 has higher value penetration compared to 80/100. At temperature 25°C before aging, the penetration is higher compared to penetration after 1.25hours aging and 20hours aging. After 1.25hours aging, the penetration has decreased into range 35-60 penetration at three temperatures. However, the penetration has dropped when longer aging has applied as per graph shown. The basic cause of the hardening during the Short Term Aging is mainly due to volatilization and oxidation, whereas, oxidation is the major factor for the second stage, Long Term Aging. An important factor that affects the durability of an asphalt concrete is the rate of hardening of the asphalt binder. The causes of hardening of asphalt have been attributed to oxidation, loss of volatile oils, and polymerization (changes in structure). Among all these possible factors, oxidation is generally considered to be the prime cause of asphalt hardening.

2.SOFTENING POINT RESULT

The softening point of every sample has been successfully obtained. Note that 3 sets of experiments have been conducted; the results were recorded in the table 11.0, 12.0 and 13.0. The result shows softening point value before aging and after aging for bitumen grade 80/100 and 60/70.

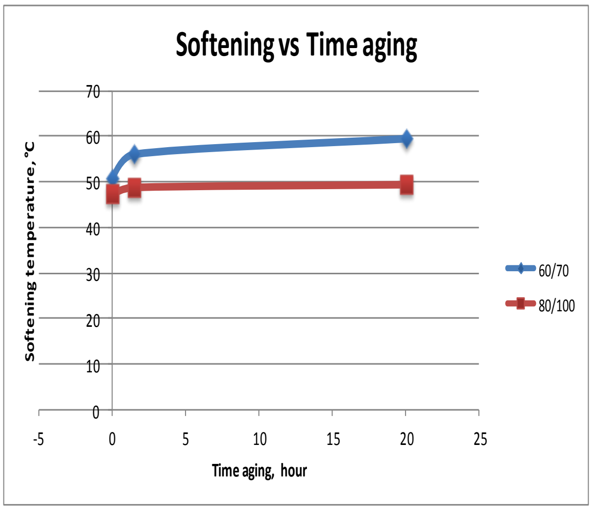
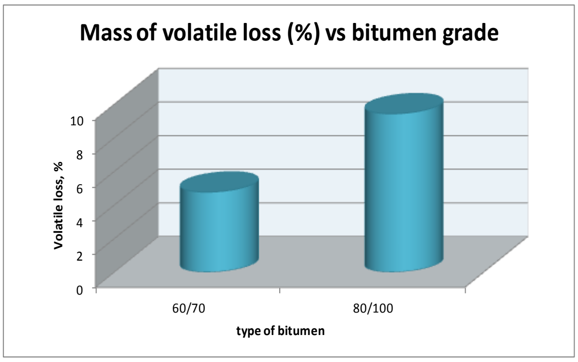


Figure 4.7 shows the value of softening point for bitumen 60/70 and 80/100 before and after aging. Based on the graph above, it shows that the softening point after aging was increased (grade 60/70). The longer time for aging is taken, the higher temperature for the bitumen to reach softening point.

3.Rolling Thin Film Oven Mass Change calculation



Based on the experiment RTFO test, the result indicates that all bitumen samples that were going through RTFO-aged were losing their weights after the aging process. As shown in figure 4.4, bitumen grade 80/100 lost the highest percentage of its volatiles which is 9.42% followed by bitumen grade 60/70 with 4.76% weight reduction. In future, those volatiles lost can be prevented by using antioxidant material that was in the market to slow down the aging process and allow the bitumen to last longer.

5.DISCUSSION

5.1 Physical properties changes and observation

There are some significant differences between virgin bitumen before and after aging. Before aging, the conditions of bitumen are different. The physical condition of virgin bitumen at room temperature bitumen is soft with a density of 1 g/cm3, but at low temperature it becomes brittle and at high temperature it flows like a viscous liquid. However, it is different with condition bitumen after aging. The bitumen is stickier compared to the bitumen before aging and the ability to flow is decreasing. In addition, samples that were aged by PAV produced arrangements of air bubble on it surfaces.

5.2 Softening point test

Softening point data are very essential to verify the penetration data of bitumen. The softening point data must be logical with respect to the penetration data. The relation between softening and penetration is, when bitumen possess low grade penetration, the softening point must be higher. In contrast when bitumen possesses high grade penetration the softening point will be lower. Thus, softening point after aging was conducted, and it shows that the bitumen after aging is much harder compare to the virgin bitumen. The time for the bitumen to turn soften is getting longer compared to the virgin bitumen. In addition, the temperature for the bitumen to reach the soften point also at high temperature.

5.3 Penetration test

From the penetration test after aging, the results indicate that penetration after long aging score the least penetration grade 60/70 at 25°C, 30°C and 35°C with an average value of 16.75dmm, 23.75dmm and 32.25dm followed by virgin bitumen is 58.16dmm, 71.25dmm and 79.92dmm. All the penetration values of the highest and the lowest do not exceed maximum allowable differences as required according to BS2000-49:2007 standard. However, penetration values for bitumen after aging as tabulated in table 8.0 and 10.0 are lower than the penetration values obtained from the virgin bitumen. It is determined that, the bitumen after long aging has the highest degree of hardness as compared to the other sample, while virgin bitumen has the softest degree of hardness in terms of penetration value.

6. CONCLUSION

In conclusion, all the objectives are achieved. The physical tests for both bitumen grades was conducted and successfully obtained the result. The aging mechanism processes were tested by performing RTFOT and PAV test on both bitumen grades. Bitumen ageing is a very complex process resulting in hardening of bitumen and brittle, which contributes deeply to the deterioration of paving applications. In bitumen aging, it consists of two main mechanisms which are; loss of volatiles and oxidation.

The results obtained from the laboratory tests conducted shown that, bitumen grade penetration 60/70 is suitable to be apply and use in Malaysia. Based on the test conducted and comparison of the results, it shows that the penetration value after aging grade 60/70 got lower penetration compared to grade 80/100. It has been observed and analyzed that bitumen grade 80/100 has higher penetration value after long aging. It can be concluded that the lowest penetration aging ratio, will led to reduce the degree of aging. In addition, if the penetration after aging (60/70) is lower, the value of softening point will increase.

The higher penetration value after aging is not suitable to be used because of the penetration will be higher if the temperature increased. Higher temperature will turn the bitumen soften and this will reduce the stiffness and make the bituminous mixture more susceptible to rutting. Hence, when the temperature is lower, the stiffness will increase and it will reduce the flexibility and tend to fatigue failure.

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