What You Need to Know About Bitumen Rheology

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THIS paper intends to compile a number of fundamental descriptions concerning the science of bitumen rheology. Understanding bitumen rheology is a major concern since the mechanical properties of binders are closely linked to the service behaviour of actual flexible pavements.

Rheology involves the study and evaluation of the flow and permanent deformation of time-temperature dependent materials, such as bitumen, that are stressed (usually shear stress or extensional stress) through the application of force. The word rheology is believed to originate from the Greek words "ρεω", which can be translated as "the river, flowing, streaming", and "λογοο" meaning "word, science" and, therefore, literally means "the study of the flow" or "flow science" [1].

In the Rheology Bulletin, Morrison [2] translated the word rheology as, "Rheology is the study of the flow of materials that behave in an interesting or unusual manner. Oil and water flow in familiar, normal ways, whereas mayonnaise, peanut butter, chocolate, bread dough, and silly putty flow in complex and unusual ways. In rheology, we study the flow of unusual materials". The rheology of bitumen can be defined as the fundamental measurements associated with the flow and deformation characteristics of bitumen.

Therefore, understanding the flow and deformation (rheological properties) of bitumen in an asphalt mixture is crucial for pavement performance. Asphalt mixtures that deforms and flows too readily may be susceptible to rutting and bleeding, while those that are too stiff may be exposed to fatigue and cracking.

The study of bitumen rheology is not a new field and has been extensively studied all over the world. It is so well established that the most famous rheology tests on bitumen was started in 1927 at the University of Queensland in Brisbane, Australia (Figure 1). Professor Thomas Parnell initiated "the pitch drop" experiment, a test that consists of a bituminous-like pitch, slowly dripping out of a funnel at room temperature.

This test is considered as the longest rheology experiment and, up to the present time, only eight drops have fallen. The pitch has an estimated viscosity of approximately 230MPa.s [3]. Considerable efforts have been undertaken by bitumen and paving technologists over the last five decades to study the rheological properties of bitumen [4]. Nevertheless, the study of bitumen rheology is not widespread in Malaysia.

The rheological properties of bitumen are measured using conventional tests including softening point, viscosity (at 65°C and 135°C), elastic recovery (at 25°C by using a ductilometer), storage stability (penetration point, softening point), flash point and tests after thin film oven ageing (softening point, viscosity, elastic recovery). However, these measurements are insufficient to properly describe the rheology and failure properties that are needed to relate bitumen properties to asphalt mixture performance. The reliability of the tests is also often questionable. In addition, these tests do not quantify the time-dependent response of the binder and are not suitable to measure the rheological properties of modified binders.

Nowadays, the rheological properties of bitumen are usually determined using an oscillatory type testing apparatus known as a dynamic shear rheometer (DSR). This method was initially introduced during the Strategic Highway Research Program (SHRP) in 1993. The DSR is a very powerful tool used to determine the elastic, viscoelastic and viscous properties of bitumen over a wide range of temperatures and frequencies, often using the testing configuration shown in Figure 2.

Normally, the rheological properties of bitumens are presented in terms of complex modulus (stiffness) and phase angle (viscoelastic) master curves. Other equipment such as a bending beam rheometer (BBR) and a direct tension test (DTT) are used to measure the rheological properties of bitumen at very low temperature. However, these tests are not particularly relevant in our country's climatic condition. The rheological data of bitumens is presented in the following forms.

- ***Isochronal Plot:*** An equation or a curve on a graph representing the behaviour of the system at a constant frequency (time of loading). For example, curves of complex modulus as a function of temperature at constant frequency are isochrones [6].
- ***Isothermal Plot:*** An equation of a curve on a graph representing the behaviour of a system at a constant temperature. For example, curves of complex modulus as a function of frequency at constant temperature are isotherms [6].
- ***Black Diagram:*** A graph of complex moduli versus phase angles. The frequencies and temperatures are eliminated from the plot, which allows all the dynamic data to be presented in one plot without the need

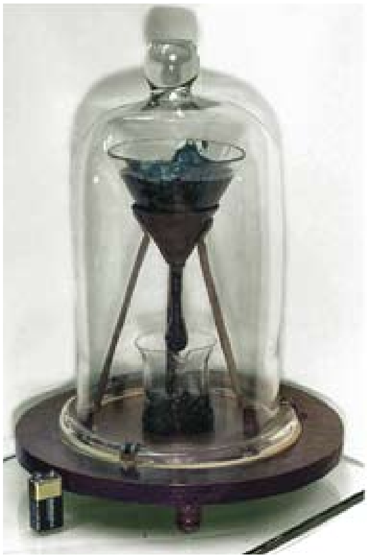

Figure 1: Pitch drop experiment [5]

Figure 2: Dynamic shear rheometer (DSR)

to perform the time-temperature superposition principle (TTSP) manipulations on the raw dynamic shear data [1].

- ***Cole-Cole Diagram:*** A graph of loss moduli as a function of storage moduli. This plot provides a means of presenting the viscoelastic balance of the bitumen without incorporating frequencies and/or temperatures as one of the axes [1].
- ***Master Curves:*** It is found that there is a relationship between temperatures and frequencies (times of loading) which, through time-temperature shifts, can incorporate measurements done at different temperatures to fit into one overall continuous curve at a reduced frequency. The curve, known as a master curve, represents the binder behaviour at a given temperature over a wide range of frequencies [1].

Recognising that testing is generally laborious, time consuming and expensive, and require skilled operators, rheological models can be taken as a valuable alternative tool to quantify the rheological properties of bitumens [7]. In general, all the models are able to satisfactorily predict the rheological properties of bitumen in the linear viscoelastic (LVE) region.

In the 1950s and 1960s, nomographs were used to represent the rheological properties of bitumen. However, nomographs become obsolete with time due to the invention of computational techniques and were replaced by mathematical and mechanical element approaches. The advantage of the latter is that elements might be relatable to structural features. Figure 3 shows an example of the complex modulus and phase angle master curves predicted by means of the rheological model.

As mentioned before, the DSR rheological data of bitumen is obtained in the frequency domain. According to the theory of viscoelasticity, by using specific mathematical inter-relationship equations, one LVE function can be converted into another LVE function even though they emphasise different information [8]. For instance, the rheological data in the frequency domain can be converted into other functions in the time domain.

The use of data interconversion equations is really useful compared to conducting several tests simultaneously. Many computer programs, such as the Interactive Rheological Software (IRIS), the Non-linear Regularization (NLREG) and the Rheology Analysis (RHEA) are commercially available. The RHEA, for example, is available to simplify the process involved in the construction of master curves.

The rheological properties of bitumen can normally be improved with the addition of modifiers such as fillers, extenders, polymers (natural and synthetic), fibres, oxidants and anti-oxidants, anti-stripping agents and hydro-carbons. For example, the use of polymer modified bitumens (PMBs) helps improve its rheological properties over a wide range of temperatures and times of loading. The stiffness modulus and elasticity values of PMBs are significantly increased. They are more resistant to rutting, abrasion, cracking, fatigue, stripping, bleeding and ageing at high temperatures and brittle fracture at low temperatures.

There are many reasons why the smoothness of rheological data is disrupted. For example, the presence of highly crystalline bitumens, structured bitumen with high asphaltenes content, high wax content and highly modified bitumens can result in inconsistencies in the rheological properties of binders. This material is termed thermorheologically complex [9].

In summary, the rheological property of bitumen is an important parameter and reflects the actual flexible pavement performance. It is, therefore, recommended that this study be included as part of our paving standards as this exercise is widely practised among developed countries. ■

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