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BAGIAN 2

PROSIDING

FORUM STUDI TRANSPORTASI ANTAR-PERGURUAN TINGGI

Kumpulan makalah yang dipresentasikan pada **SIMPOSIUM INTERNASIONAL FSTPT KE-16** di Universitas Muhammadiyah Surakarta, 1 - 3 November 2013 dengan topik:

Ekonomi dan Kelayakan Transportasi
Transportation Feasibility and Economics

Transportasi Barang dan Logistik
Freight and Logistics Transportation

Manajemen Prasarana Transportasi
Transportation Infrastructure Management

Manajemen dan Rekayasa Jalan Raya serta Beban Berlebih
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Pavement Materials, Pavement Design, and Subgrade Characteristics

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FOAMED BITUMEN STRUCTURE

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Abstract

Foamed bitumen is a binder of cold mix asphalt, a road material alternative of the conventional hot mix asphalt. Because of foamed bitumen properties are still not well defined, then the cold mix foamed asphalt performance is not interpreted correctly. It causes any research to unlock the understanding of foamed bitumen properties is necessary. This paper is therefore designed to open one of the important foamed bitumen propertis aspect, i.e. its structure. The foamed bitumen structures are explored based on theoretical study. It is studied in a general context, including foam behaviour, body structure, modulus, and rheology.

It is deduced from the results that foamed bitumen can be included within the general foam family. Foamed bitumen composition, with both wet and dry foam formation, gives an indication that foamed bitumen behaviour complies with expected general foam properties. It can be concluded some general properties that are valid for general foam and which are also valid for characterising foamed bitumen. This includes foam quality categories, structure, modulus, and rheology. Category of Foamed bitumen quality can be approached by wet foam ranges between 52% and 87%, stable dry foam between 87% and 96%, and beyond 96% the dry foam becomes unstable. This quality category is adapted from foam in the general context.

Key Words: foamed bitumen, quality, structure, modulus, rheology

INTRODUCTION

Road pavement materials can be produced using cold mix system. These materials are called by cold mix asphalt (CMA), as an alternative of the conventional hot mix asphalt. If a CMA is generated using binder of foamed bitumen, it is then called by cold mix foamed asphalt (CMFA). In general, CMFA is preferred to implement in field by engineer due to its excellent in context of environmental issues. This material has been widely implemented in Indonesia, e.g. in Pantura road project.

One of the disadvantages of CMFA is that of its properties are still poorly understood by engineers. This is due to the properties of foamed bitumen, as CMFA binder, also has not been well understood. This paper is therefore designed to open one of the important foamed bitumen propertis aspect, i.e. its structure.

THE WAY TO GENERATE FOAMED BITUMEN

Foamed bitumen can be produced by injecting pressurised air and a small quantity of cold water into a hot bitumen phase in an expansion chamber (Figure 1). Soon after spraying into a special container, the bitumen foam expands rapidly to its maximum volume followed by a rapid collapse process and a slow, asymptotic return to its original bitumen volume.

For example, 500g of hot bitumen injected using 10g of cold water (2% of bitumen mass) normally results in foam with a maximum volume around 15-20 times that of the bitumen.

The ratio between maximum foam volume achieved and the volume of original bitumen is termed the maximum expansion ratio. This value is mainly dependent upon the amount of water added (foaming water content), the type of bitumen, and the temperature of bitumen. The foam expansion ratio increases with higher water added. After reaching its maximum volume, the foam dissipates rapidly accompanied by steam gas escaping. The time that the foam takes to collapse to half of its maximum volume is called the half life. In the above example, half life would normally be between 20-30 seconds. After a particular time (around 60 seconds), the foam volume reduces very slowly and asymptotically. During this phase, foam bubbles still survive even though the bitumen has become harder (Figure 2).

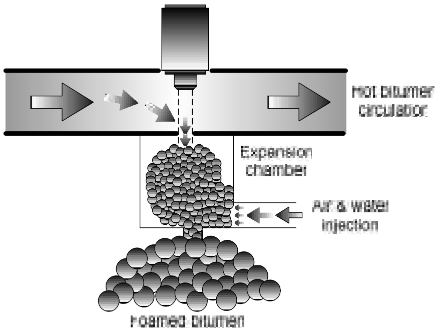

Figure 1 Foamed bitumen produced in an expansion chamber

Figure 2 Appearance of the collapsed foamed bitumen

METHOD OF STUDY

It is actually not easy to develop an understunding of the structure and foamed bitumen properties. There are not many refferences discussing about foamed bitumen structure, modulus and rheology concept. The foamed bitumen structures are subsequently explored based on theoretical study. The theoretical study is an investigation of foam in a general context, including foam behaviour, structure, modulus, and rheology. Foamed bitumen structures are investigated by assuming that this soft material is included on the foam families. Therefore, the structure of foam was studied based upon the related refferences.

DISCUSSION

Discussion of foamed bitumen generating process

Since the foam generation process influences the created foam type and its properties (Weaire and Hutzler, 1999), it is therefore important to understand the dynamic process in generating foamed bitumen. It is developed with some consideration of the foaming process discussed by Jenkins (2000), He and Wong (2006) and Barinov (1990). These steps can be described as follows:

- ***Step 1: Initial position***

When water and air are injected together under high pressure, the water takes the form of large number of small water droplets which directly enter the hot bitumen liquid phase. This situation aids rapid energy exchange. It is noted that the heating process of bitumen causes its nuclei to distribute uniformly in the bulk phase, and heating to temperatures above 100°C is accompanied by its conversion into a true liquid, creating the conditions for diffusion of (asphaltene) surfactant molecules from its bulk to any interfaces which develop (e.g. when foamed).

- ***Step 2: Heat transfer***

Heat transfer from hot bitumen to the cold small water droplet surfaces occurs rapidly when they come into contact in the expansion chamber. Subsequently, the temperature of the water droplet increases whilst temperature of the bitumen decreases.

- ***Step 3: Evaporating and steaming***

As soon as the water droplet reaches a temperature of 100°C, the energy transferred from the hot bitumen exceeds the latent heat of steam, resulting in evaporation of the water droplet surface. In this way, the water evaporating from the droplet generates steam and this results in explosive expansion bubbles due to the presence of internal pressure. It is noted that the amount of water becoming steam is dependent upon the amount of water added and the bitumen temperature. As the water is not sprayed in a single instant, there is probably also condensation occurring during steaming. This indicates that some water potentially still remains in the foamed bitumen.

- ***Step 4: Foam forming***

Water steam is forced into the bitumen liquid phase, causing steam bubbles to be trapped within the bitumen liquid. At this time, wet foam is formed in which small bubbles appear dispersed within the bitumen liquid phase. In this condition, the (asphaltene) surfactant forms an adsorption layer on the bitumen-vapor phase boundary. Due to the bubbles' explosive expansion behaviour, they pressurize the bitumen liquid. In seconds, the bubbles become larger and the bitumen films become thinner, and this results in a dry foam until a state of equilibrium is reached. The foam state may remain as long as the thickness and surface properties of bitumen film can counteract the bubble pressure. It was noted that during this investigation, in which foam was sprayed into a container for 5 seconds, foams grew rapidly. Some bubbles seemed to collapse before the 5 seconds of spraying had finished. However, not all foam bubbles grew and collapsed at the same rate. Sporadically, small bubbles grew up following collapse of large bubbles. When foams reached their maximum volume, they remained stable for seconds before all bubbles ruptured together, which was accompanied by loss of steam. At this time, foam volume therefore dropped dramatically. It is supposed that when foam expanded in the container, the bitumen liquid (including collapsed bubbles) tended to drain to the bottom, whereas the bubbles tended to rise up. This situation results in a foam column transition from a wet condition in the bottom to a dry condition in the top as shown in Figure 3.

- ***Step 5: Foam collapsing***

The collapse of foamed bitumen may be explained by the following three scenarios:

Scenario 1 (Foam collapse caused by external physical contact):

Physical contacts between bitumen films (lamella) and an outside material having lower temperature such as air, aggregate surface or container cause the foam to collapse. Breward (1999) and He and Wong (2006) agreed with this scenario. If this scenario is correct, it means when foamed bitumen is directly sprayed into cold wet aggregate, it then immediately collapses and returns to the original fluid state. Interestingly, when foamed bitumen is sprayed into a cold steel container, it does not collapse; it even grows to reach a maximum volume. It is likely that the heat energy loss is more significant than physical contact with external materials in affecting foamed bitumen ruptures.

Scenario 2 (Foam collapse caused by excessive pressure of expanded bubble):
Foam may collapse if the surface tension (which is a function of viscosity) of the bitumen film is not adequate to withstand the expanded bubble pressure. In this study, when applying foaming water at 5% or 6% (using a bitumen mass of 500 g), some foams were found to burst as they reached maximum volume. This might indicate that the expanded bubble pressure exceeded the surface tension of the bitumen film. Jenkins (2000) agreed with this scenario since, when the elongation of the bitumen for the given (short) loading time is exceeded, the bubble will burst. He and Wong (2006) also supported this scenario since they found that the maximum expansion ratio (ERm) of foam produced using bitumen pen 100 was lower than with bitumen pen 60. This indicates that foam with lower viscosity and relatively low surface tension (pen 100) will be more likely to collapse prematurely before reaching its maximum volume than a higher viscosity foam (pen 60). It is interesting to note that the effect of surface tension on the foam life time may have two different aspects. First, considering the pressure in an expanded bubble, high surface tension of the bitumen film gives a positive effect on the foam life; on the other hand, secondly, considering Plateau border suction, high surface tension of the bitumen film may increase this suction and give a negative effect on the foam life.

Scenario 3 (Foam collapse caused by draining process)
In general foam literature, it is found that foam collapse is caused by the foam draining process (Breward, 1999; Breward & Howell, 2001). The draining process can be caused by gravity, suction between Plateau border and lamella, and capillarity between small and large bubbles. Lamella is thin films forming the faces of the roughly polyhedral bubbles, and Plateau border is the tubes of liquid at the junctions between these films. As the liquid fraction drains out of the foam body, the thin film becomes unstable and then ruptures so that eventually the foam collapses.

Discussion of foamed bitumen family
Considering the process of generating foamed bitumen in the expansion chamber as described previously, foamed bitumen may be composed of air, water vapour (steam), hot bitumen liquid and remaining water. At the beginning, the air and water vapour are trapped as small bubbles in the continuous bitumen liquid phase. The remaining water may be present in the bitumen liquid or else inside the bubbles. This formation gives a ‘wet foam’ condition. The water vapour content then increases rapidly due to the presence of internal bubble pressure, causing the bitumen liquid to form a thin film at the bubbles surfaces. This gives a ‘dry foam’ condition.

The above description indicates that the constituent of air and water vapour forming bubbles with internal pressure represents the gas in general foam literature, and that the bitumen acts as the liquid phase. The volume fraction of remaining water is small compared to that of bitumen liquid and therefore its presence will not alter the general formation of foamed bitumen. Therefore, it can be deduced that foamed bitumen can be included as a member of the foam family. This statement is utilised in this study to develop foamed bitumen characteristics, borrowing knowledge from general foam literature. In asphalt material literature, it is noted that Jenkins (2000) placed foamed bitumen into the polyhedral foam category in terms of bubble-form.

Discussion of foam behaviour

Foams can be found in a wide variety of contexts. They occur in the form of soap froth, fire-fighting foam, the head on a glass of beer, the froth in a washing-up bowl, and many more. Practically, foams are important, for example, in cleaning, dampening explosions and collecting radioactive dust. In these applications, the ability of foam to spread a small amount of liquid over a wide area is important. In any case, it is important to understand the bulk properties of foam and how its constituents affect it. In the case of foamed bitumen, it is desirable to know what properties are most significant in their effect on foamed asphalt mixture performance. The ability of foamed bitumen to spread over a wide area of aggregate surface during mixing process is important.

Foam is a combination of gas and liquid in which the gas bubbles are separated by thin liquid films and the volume fraction of the liquid is small. The principal distinguishing characteristic of foam is the large volume fraction of the discontinuous gas phase so that its density is relatively low. Foam viscosity is found to be relatively higher than its components and dependent on its density. Therefore, the quantity known as 'kinematic viscosity', the ratio between the viscosity and the density, is likely to be more suitable to characterise foam consistency. Foam is also known as a compressible material due to the gas constituent being compressible in nature. Because of the density difference between the gas and liquid in the foam, the liquid fraction (the denser phase) always tends to drain out of the foam body.

The structure of foamed bitumen can be assumed using Schramm (1994) and Breward (1999) definition. Foamed bitumen can be divided into wet and dry foams. Figure 3 shows an example of a foam in a column frame. In this formation, the bubbles tend to rise to the top and the liquid fraction tends to fall due to gravitational effects. Consequently, a transition is created from wet foam (at the bottom) to dry foam (at the top). In two dimensions (Figure 3 left), it can be seen that bubble shapes in wet foam are approximately spherical, while in dry foam, the bubbles are more polyhedral.

Foams are generally characterized according to their quality (Fq) as defined in Eq. 1.

$$Fq = \frac{Vg}{Vg + Vl} * 100 \qquad \text{..} \text{ Eq. 1}$$

where: *Fq* is the foam quality (%), *Vg* is the gas volume, *Vl* is the liquid volume.

The onset of bubble motion (the starting point for wet foam) has been found at a foam quality of 52% (Mitchell, 1971) or 60% (Weaire et al., 1993). The transition between wet and dry foam may be at a quality of 75% (Rankin et al, 1989) or 87% (Weaire et al., 1993). This transition should be at the densest possible spherical bubble packing. Based upon a face-centred cubic system (by calculation), this limit is found to be at 74% quality, which is lower than those quoted by Rankin et al (1989) and Weaire et al. (1993). However, the experimental result may be more accurate due to bubbles being arranged randomly. Stable foam can be observed up to 96% (Rankin et al, 1989), but when the quality exceeds this point the foam becomes unstable. Thus, foam quality gradation and the limits of wet and dry foam can be summarised as shown in Figure 4. It can be deduced that this quality gradation is also valid for characterising foamed bitumen.

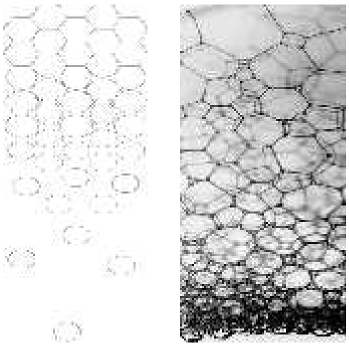

Figure 1 A foam: wet foam (bottom)-dry foam (top) (Schick, 2004).

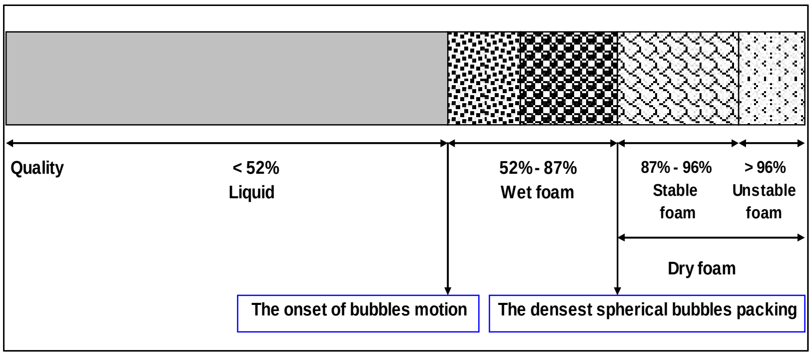

Figure 4 Gradation of foam quality

Discussion of foamed bitumen body structure

Figure 5 illustrates the structure of foam. In a wet foam, gas bubbles are dispersed in the liquid phase and they are separated from each other due to the liquid volume still being large. In a dry foam, the thin films forming the faces of the roughly polyhedral bubbles are called lamella and the tubes of liquid at the junctions between these films are called Plateau borders (named after Plateau). The vertices where the Plateau borders meet are called nodes. Foams may consist of bubbles with a wide distribution of sizes, randomly mixed and arranged. Figure 6 shows a random foam structure. Discussion of foam structure can be found in Weaire and Hutzler (1999).

Foam can only be formed if surface active materials (surfactants) are present. A foam lamella consists of a thin liquid slab stabilized by two amphiphilic adsorption layers. In a wet foam lamella, both adsorption layers are separated by a fairly thick liquid slab (Koelsch and Motschmann, 2005). In an extremely dry foam lamella, the liquid becomes so thin so that molecular forces arise due to the interaction of the two free surfaces. If these forces are repulsive, this culminates in the formation of a stable film of thickness between 10 and 100 Angstroms (1 Angstrom= 10^{-10} m) (Breward, 1999).

It is noted that a molecule of surfactant is amphiphilic by means of both a hydrophobic and a hydrophilic part. At sufficiently high bulk concentrations, the surfactant molecules form micelles in which the hydrophobic 'tails' are surrounded by hydrophilic 'head' (see Figure 7a). Basically, the surfactant molecules prefer to be present at an interface rather than within the body of the liquid. In this case, the tail groups are in the gaseous phase while the head groups remain within the liquid phase (see Figure 7b). This arrangement potentially reduces the surface tension of the interface. However, if the surfactant molecules form micelles, they will not be able to affect the surface tension and hence will not benefit the foam properties.

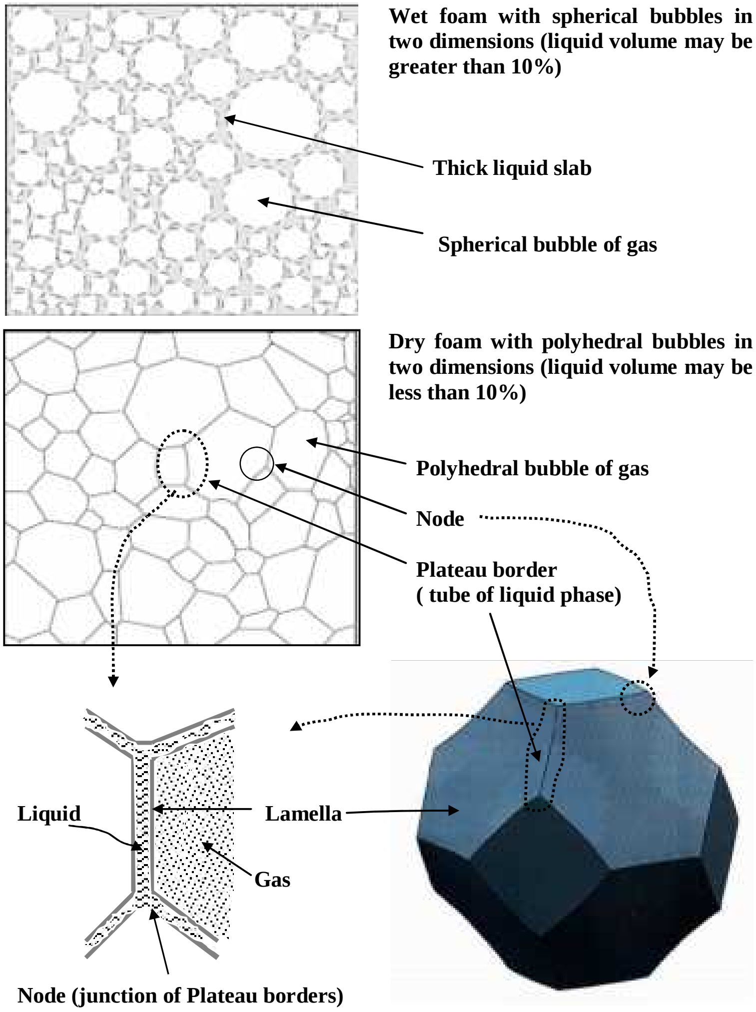

Figure 5 Structure of wet and dry foam

Figure 6 A random foam structure (Breward, 1999)

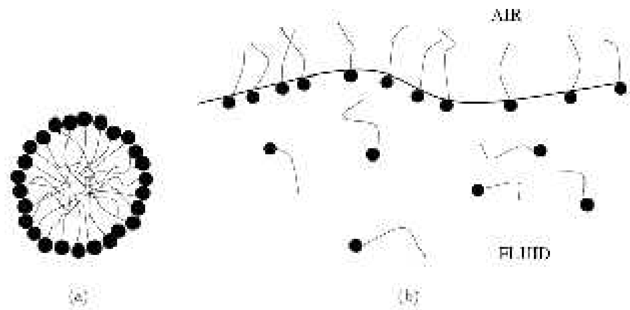

Figure 7 Surfactant molecules (a) forming a micelle within the liquid and (b) at a free surface (Breward, 1999)

Discussion of foamed bitumen modulus

Elastic modulus may be an important property for foam stability, since a stiff film limits bubble rupture (Bauget et al, 2001). Under low applied stress, foam behaves as a solid and displays elastic behaviour that depends upon bubble size and quality. The elastic (shear) modulus is small and depends on foam surface properties. The modulus comes from the surface tension present on the foam film (lamella). As the stress is increased, the foam response becomes increasingly plastic. Beyond a certain yield stress, the foam starts to flow. This foam stress-strain behaviour has been discussed clearly in Weaire and Hutzler (1999) based on many experiments of general foams (see Figure 8 and 9).

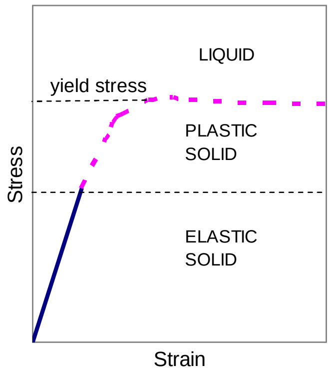

Figure 8 Stress – strain relationship of foam (Weaire and Hutzler, 1999).

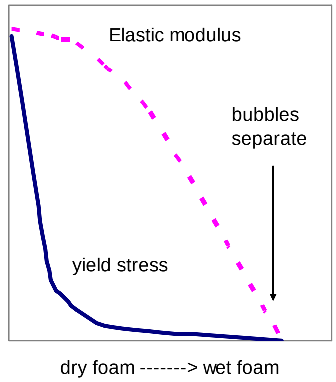

Figure 9 The elastic modulus and yield stress depend strongly on the liquid fraction of the foam

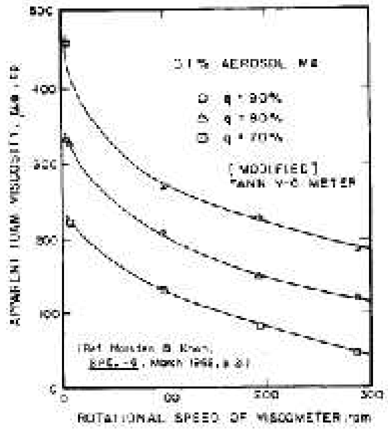

Figure 10 Apparent foam viscosity at various foam qualities (Marsden and Khan, 1966 in Heller and Kuntamukkula, 1987)

Discussion of foamed bitumen rheology

It is not simple to understand the rheology of foam. The flow of a foam differs from that of conventional fluids. Complications include the following three aspects (Heller and Kuntamukkula, 1987). Firstly, the flow characteristics are affected by the size and shape of the channels that confine it due to the presence of bubbles with various sizes. Secondly, compressibility behaviour affects foam flow in tube viscometric measurement. Thirdly, foam drainage during testing can have an impact on the flow characteristics.

In most work related to foam flow experiments, the results of measurements have been analysed in terms of the traditional rheology parameters of fluids. In practice, the term ‘effective or apparent viscosity’ is used to describe foam rheology in order to accommodate the differences between foam and fluid flow. The presence of the compressible bubbles with various sizes affects the flow characteristics, and the measured viscosities are then not true for the absolute values, like in the case of a fluid.

According to the ratio of mean bubble size (r_B) and flow channel size (Rc), foam flow is divided into two types, i.e. macroflow and microflow (Kraynik, 1988). Foam flow through pipes is a typical macroflow, which is characterized by $r_B << Rc$. This type represents bulk foam flow, exhibits a nonlinear correlation (between shear stress and shear rate) and has a slip problem (between foam structure and pipe wall). Investigators generally note the same trends in the variation of apparent viscosity with shear rate, quality and pipe size; however this is not generally true for the absolute values themselves (Heller and Kuntamukkula, 1987). On the other hand, foam flow in a porous medium or in a fine capillary tube is a microflow type, where $Rc \leq r_B$. In this case, the flow can not be related to foam viscosity because the dimension of bubbles is less than or comparable to that of the pore space (Kraynik, 1988).

Studies on foam rheology have been conducted in a number of viscometric devices, including the Brookfield viscometer, and also using a modified viscometric device (Heller and Kuntamukkula, 1987). Major experimental problems in viscosity measurement are (1) the evidence of collapse or rearrangement of the network of foam bubbles on contact with the rotating solid surface of the viscometer device and (2) drainage of the foam liquid during testing.

Most studies agree that the apparent viscosity increases with the gas content and decreases with shear rate (Assar and Burley, 1986). For example, as shown in Figure 10, Marsden and Khan (1966) found that increasing gas content from 70% to 80% and then 90% resulted in increasing the foam viscosity from 130cp to 210 and then 280cp respectively at 100 rpm rotational speed (Heller and Kuntamukkula, 1987). It is clear that foam viscosity is dependent on its density, with viscosity increasing at lower density (increased gas content). Kinematic viscosity may therefore be a suitable property to represent resistance to foam flow. It was also found that the apparent viscosity varied between 50 and 500 cp for aqueous foam having a quality in the range 70-96%. As a comparison, a Brookfield viscosity measurement of bitumen pen 70/100 in the range 140^{o}C to 180^{o}C is typically about 260 to 55 mPa.s (note: 1 mPa.s = 1 cp).

CONCLUSION

It is deduced that foamed bitumen can be included within the general foam family. Foamed bitumen composition, with both wet and dry foam formation, gives an indication that foamed bitumen behaviour complies with expected general foam properties. It can be deduced some general properties that are valid for general foam and which are also valid for characterising foamed bitumen. This includes foam quality categories, structure, modulus, and rheology. Foamed bitumen category are wet foam ranges between 52% and 87%, stable dry foam between 87% and 96%, and beyond 96% the dry foam becomes unstable.

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REFERENCES

Assar, G. R. and Burley, R. W., 1986. *Hydrodynamics of Foam Flow in Pipes, Capillary Tubes, and Porous Media*. In Encyclopedia of Fluid Mechanics, edited by N.P. Cheremisinoff, Vol. 3, pp. 26-42.

Barinov, E.N., 1990. *Formation and Properties of Foams. Leningrad Institute of Construction Engineering.* Translated from Khimiya i Technologiya Topiv i Masel, No. 10, pp. 24-26, October 1990.

Bauget, F., Langevin, D. and Lenormand, R., 2001. *Dynamic Surface Properties of Asphaltenes and Resins at the Oil–Air Interface.* Journal of Colloid and Interface Science 239, 501–508 (2001).

Breward, C.J.W., 1999. The Mathematics of Foam. *PhD Thesis*, St. Anne's College, University of Oxford.

Breward, C.J.W. and Howell, P.D., 2001. *The Drainage of a Foam Lamella*. Journal Fluid Mech. (2002), vol. 458, pp. 379-406, Cambridge University Press.

He, G. and Wong, W. 2006. *Decay Properties of the Foamed Bitumens. Construction and Building Materials,* Volume 20, Issue 10, December 2006, Elsevier, Pp 866-877.

Heller, J.P. and Kuntamukkula, M.S., 1987. *Critical Review of the Foam Rheology Literature*. Ind. Eng. Chem. Res. Vol. 26, No. 2, 1987, pp. 318-325, © 1987 American Chemical Society.

Jenkins, K.J., 2000. *Characterisation of Foamed Bitumen*. Chapter 3, Mix Design Considerations for Cold and Half-warm Bituminous Mixes with Emphasis on Foamed Bitumen, PhD Dissertation, University of Stellenbosch, South Africa.

Koelsch, P. and Motschmann, H., 2005. *Relating Foam Stability and Surface Dilational Rheology*. Langmuir.

Mitchell, B.J., 1971. *Test Data Fill Theory Gap on Using Foam as a Drilling Fluid*. Oil and gas Journal, September 1971, pp. 96-100.

Rankin, M.D., Friesenhahn, T.J., Price, W.R. and Pool, C., 1989. *Lightened Fluid Hydraulics and Inclined Boreholes.* SPE/IADC 18670, New Orleans.

Schramm, L., L., 1994. *Foams: Fundamentals and Applications in the Petroleum Industry*. Advances in Chemistry series 242, American Chemical Society, Washington DC.

Weaire, D., Pittet, N., Hutzler, S. and Pardal, D., 1993. *Steady-State Drainage of an Aqueous Foam*. Physical review letters, volume 71, Number 16, The American Physical Society.

Weaire, D. and Hutzler, S., 1999. *The Physics of Foams*. Oxford University Press. Great Clarendon Street, Oxford OX2 6DP.

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Re: Paper Acceptance for the 16th FSTPT International Symposium

Dear Sir/Madam,

Please kindly let me inform you that the following paper:

FOAMED BITUMEN STRUCTURE
1) Sri Sunarjono (Centre for Transportation Study, Universitas Muhammadiyah Surakarta)
2) Nyamadi (Civil Enggineering, Universitas Muhammadiyah Surakarta)

is accepted for presentation in the 16th FSTPT International Symposium to be held in Muhammadiyah University of Surakarta, Surakarta, Indonesia on November 1, 2013. Furthermore, presentation schedule will be announced in www.fstpt.or.id and www.fstpt-icid.com on October 24, 2013.

Authors are to immediately register their attendance by filling in the registration form as provided in the Local Committee website (www.fstpt-icid.com) and submit the registration form through email address: icid.ums@gmail.com.

Thank you for your kind attention and looking forward to meeting you in Surakarta.

Yours Faithfully,

Sony Sulaksono Wibowo, Ph.D
Chairman