개질 및 비개질 아스팔트바인더의 새로운 고온등급 연구

A Study of New High Temperature Grading for Modified and Unmodified Asphalt Binders

허정도* · 조규태** · 남영국***

1. INTRODUCTION

Polymer-modified asphalt binders are gradually used more in the domestic pavements as well as those of foreign countries. However, there are main concerns whether the current Superpave PG-grading system can be applied or not to those cases of modified binders. In this respect, Bahia et al. (1998) has recently investigated suitability of using the PG-grading for modified binders. They found that the current PG-grading failed to characterize grading specification of all modified binders. Stuart and Mogawer (1997) also claimed that the Superpave PG-grading system could not correctly evaluate the order of rut-resistenace for modified binders.

These evidences make one be suspicious about validity of the current Superpave PG-grading system. Thus, the purpose of this investigation lies in proposing a new grading theory for modified and unmodified binders to resolve problems evident in the present grading system.

2. THEORY AND DEVELOPMENT

Recently, Huh & Nam (1999) and Kim et al. (2000) reported the relationships between rut depth (h) and binder properties. It is written as:

$$h = \frac{d}{\eta_o^{k\beta}} \cdot N^{\beta} \qquad (1)$$

where ho is a binder zero shear viscosity, k and b are power-index parameters, and d is a constant independent of binder viscosity, and N is a number of wheel passes.

There exist two types of grading theory evolved from Eq. (1); the simplified version and the

* Research Director, Dream Techs Co., 627-10 Pajang, Suwon, 440-855, S. Korea.
** Doctoral Student, Dept. of Civil Eng., Univ. of Inchon, Inchon, 402-749, S. Korea
*** Professor, Dept. of Civil Eng., Univ. of Inchon, Inchon, 402-749, S. Korea

rigorous one. These two cases will be discussed below.

2.1 Simplified High-Temperature Grading Theories

If k and b are assumed to be constant in Eq. (1), then

$$Ln(h_N) = Ln(d \cdot N^{\beta}) - k\beta \cdot Ln(\eta_o) \quad (2)$$

where hN is the rut depth at a fixed number of wheel passes. This equation corresponds to the present viscosity grading. Binder grading based on Eq. (2) works reasonably well for unmodified asphalt binders, but some errors are detected for modified binders due to the assumption of the fixed b.

In the literature (Welborn et al. (1966)), the empirical relationship between rut depth and penetration depth is well establised. That is,

$$Ln(L) = Ln(c) - m \cdot Ln(\eta_o) \quad (3)$$

Combination of Eq. (2) and (3) yields to the penetration grading equation;

$$h_N = a \cdot L + b \quad (4)$$

where a and b are constants changing with wheel passes, and L is a penetration depth.

To develop a performance grading equation, one has to find the viscoelastic parameter corresponding to the viscosity (ho) in Eq. (2). The most favorate one that agrees with the physical condition is G*/sind. This parameter is inserted in place of viscosity in Eq. (2); then

$$Ln(h_N) = Ln(d \cdot N^{\beta}) - k\beta \cdot Ln\left\{\frac{G^*}{\sin\delta}\right\} \quad (5)$$

Equation (5) is different from the current PG-grading equation, which is;

$$h_N = \frac{f}{G^* / \sin\delta} \quad (6)$$

The power index kb in Eq. (5), is not the value of one, while it is fixed to be unity in Eq. (6). This fixed value of one in Eq. (6) makes error in grading asphalt binders by the current PG-grading. Detailed explanation maybe referred to Huh et al. (2000). Even equation (5) is applicable only for unmodified binder cases due to the assumption made for k and b to be constant in Eq. (1).

2.2 A Rigorous High-Temperature Grading Theory

Here, k and b are not constant. However, for a fixed aggregate kind, k is usually constant such that b only changes with binder viscosity. Then, Eq. (1) turns into the following form;

$$Ln\left\{\frac{h_N}{N^{\beta}}\right\} = Ln(d) - k \cdot Ln(\eta_o{}^{\beta}) \quad (7)$$

This is a more rigorous viscosity-grading equation than Eq. (3). However, for unmodified binder cases, Eq. (3) is sufficient to represent viscosity grading. Hence, Eq. (7) is not needed in reality. However, for modified binders, a rigorous viscoelastic equation is needed instead of Eq. (5). This is formulated by replacing the viscosity (ho) in the rigorous viscosity equation, Eq. (7), with G*/sind. That is,

$$\mathrm{Ln}\left\{\frac{h_N}{N^\beta}\right\} = \mathrm{Ln}(d) - k \cdot \mathrm{Ln}\left\{\frac{G^*}{\sin\delta}\right\}^\beta \tag{8}$$

Equation (8) is a general grading equation used for rating rut-resistance of modified as well as unmodified asphalt binders.

3. ANALYSIS AND DISCUSSION

3.1 Simplified Equations

King et al. (1992) qualitatively studied the effect of asphalt grade and polymer concentration on the high temperature performance of pavement rutting by using French LCPC wheel tracking device. Their data are used to plot G*/sind versus rut depth in the logarithmic scale for unmodified binders.

As shown in Fig. 1, at the fixed wheel passes, successful prediction of the data by Eq. (5) is well observed. That is, Eq. (5) works well for unmodified binders at a high temperature, 60oC.

Another rutting data for validatation are obtained from Bonaquist & Mogawer (1997). Their data are used to test validity of Eq. (5) for modified binders. Figure 2 represents such a plot and the regression result of the data by Eq. (5). The figure demonstrates that the simplified equation, Eq. (5), fails to express rut behavior of the modified binder case.

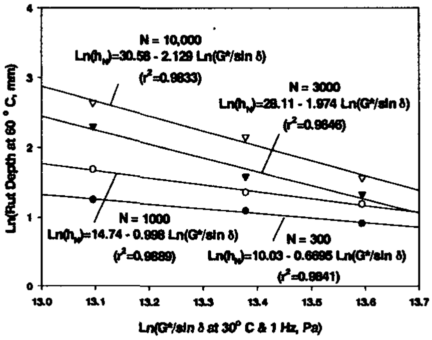

Fig 1. Rut depth vs. binder G*/sin δ for unmodified asphalts

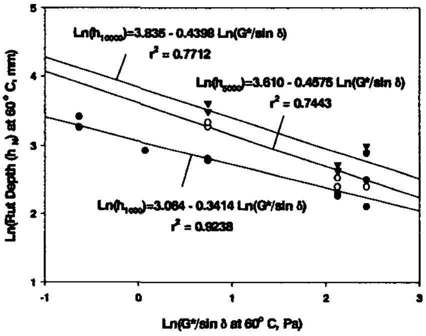

Fig 2. Rut depth vs. binder G*/sin δ for unmodified asphalts

3.2 A Rigorous Equation

By using Eq. (7), regression is performed for the field rut data of Bonaquist & Mogawer (1997), and the result is shown in Fig. 3. Improvement is evident compared to Fig. 2, but some data scattering is unavoidable due to usage of the equation with viscosity for viscoelasticity involved.

Finally, Eq. (8) is tested for the same rut data of Bonaquist & Mogawer (1997). The regression result is exhibited in Fig. 4. Satisfactory result in the figure, compared to Figs. 2 and 3 prove validity of Eq. (8) for high-temperature grading of both modified and unmodified binders. This certifies a rigorous equation with a viscoelastic parameter, Eq. (8), to be the proper grading formula.

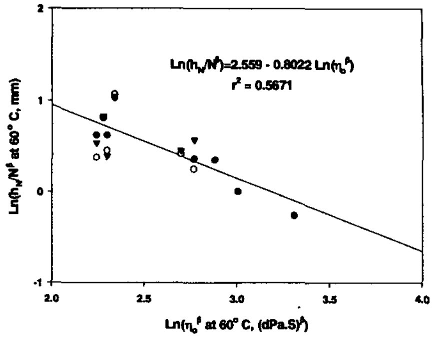

Fig 3. The plot of $\ln(h_N/N^{\beta})$ vs. $\ln(\eta_0{}^{\beta})$ for modified asphalt binders.

4. CONCLUSIONS

It has shown that current grading systems (penetration, viscosity, and performance grading) fail to estimate proper grading of modified binders. To resolve the problem, a theoritical equation of a new high temperature grading system is developed for both unmodified and modified asphalt binders. Successful predicton by the equation promises construction of a correct high temperature grading system.

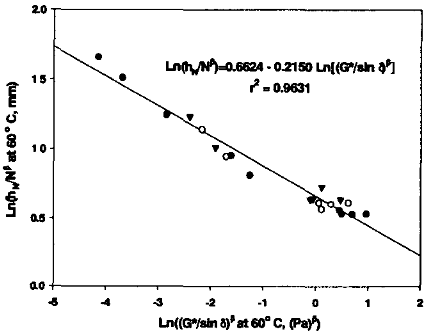

Fig 12. Plot of Eq.(17) for full-scale field rut depth for modified binders.

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