한국도로포장공학회지
第3券 2號 2001年 6月
pp. 91 ~ 102

개질 및 비개질 아스팔트 바인더의 새로운 고온등급 연구

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

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Abstract

On the basis of several experiments performed, Bahia et al. (1998) concluded that the current Superpave PG-grading system failed to characterize grading specification of all modified binders. This conclusion motivates us to investigate the correct grading system suited for modified asphalt binders. The main concept of this development is originated from the relationship between rut depth and binder properties at high temperatures. A new grading system for modified asphalt binders suggested here somewhat resembles to the unmodified binder grading one developed by Huh et al. (2000). Thus, this investigation will provide a unified single theoretical equation of high temperature grading that can apply both to modified and unmodified binders, and will check its effectiveness with the laboratory and the field rut data reported by independent studies. Successful results observed may allow to construction of a correct grading system in the near future.

Keywords : *Theory of Binder Grading, Modified and Unmodified Asphalts, Viscosity, Penetration, Superpave PG-grading*

요 지

Bahia et al. (1998)은 여러 실험을 통하여 현재의 수퍼페이브 공용성 등급체계로는 모든 개질바인더의 등급을 규정화할 수 없다는 결론을 맺고 있다. 이러한 결론은 개질아스팔트 바인더에 적합한 올바른 등급체계를 개발하도록 동기를 부여한다. 본 개발의 중요개념은 고온에서의 소성변형깊이와 바인더성질 사이의 상관관계로부터 시작된다. 여기에 제안된 개질아스팔트 바인더를 위한 새로운 등급체계는 Huh et al. (2000)이 연구한 비 개질바인더의 등급체계와 다소 동일하다. 따라서 본 연구는 개질과 비개질바인더 둘 다에 공히 적용 가능한 단일 고온등급 이론식을 제공하고, 독립적 연구에 의해 발표된 실험실 및 현장 소성변형 데이터를 이용하여 제시된 식의 효용성을 점검한다. 이로 인해 관측되는 성공적인 결과는 가까운 장래에 정확한 등급체계를 정립할 수 있는 가능성을 시사해준다.

핵심용어 : 바인더등급이론, 개질 및 비개질 아스팔트, 점도, 침입도, PG 등급

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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 modified binders. In this respect, Bahia et al. (1998) who originally provided the theory and the methodology of the PG-grading of asphalt binders during Strategic Highway Research Program (SHRP) in USA had recently investigated the very question. They found two types of binders that behaved differently in property measurements: one was the simple binder that satisfied the assumptions made in the PG-grading system; that was a binder holding a wide linear range, non-thixotropy, isotropic homogeneity and independence of sample geometry. The other was the complex binder that violated one or more of the PG-grading assumptions just mentioned. Here, the simple binder indicated the unmodified asphalt, while the complex binder usually represented the modified asphalt that was used for extreme cases (i.e., high volume traffic in warm regions and grades being considered in many cold regions).

By this observation, Bahia et al. (1998) concluded that the current PG-grading failed to characterize all modified binders, because it was based on simplifying assumptions that could not be reliably extended to the complex behaviors.

Stuart and Mogawer (1997) also claimed in the Superpave validation study of asphalt binders and mixtures that the current PG-grading system could not correctly evaluate the order of rut-resistance for modified binders.

Even for the unmodified binder cases, Huh et al. (2000) claimed that the high temperature PG grading was not correctly constituted to produce the right grading. That was, the upper PG-grade number for unmodified binders could be deviate from the true value.

All these evidences make one be suspicious about validity of the current Superpave PG grading. Thus, the purpose of this investigation lies in examining the current theory and proposing a new unified one both for modified and unmodified binders.

2. THEORY AND DEVELOPMENT

Pavement rutting is often described by the well-known empirical equation, where rut depth is expressed in the term of number of wheel passes;

$$h = \alpha \cdot N^{\beta} \qquad (1)$$

where h and N are a rut depth and a number of wheel passes, and α and β are two parameters relating to material properties.

Recently, Huh & Nam (1999) and Kim et al. (2000) reported the empirical relationship between rut depth and binder properties obtained from Eq. (1). It is written as:

$$h = \frac{d}{\eta_o^{k\beta}} \cdot N^{\beta} \qquad (2)$$

where η_o is a binder zero shear viscosity (or absolute viscosity), k is a power-index parameter, and d is a constant independent of binder viscosity.

For comparison of rut performance among different binders, Eq. (2) can be divided into two special types: one is rut depth at a fixed number of wheel passes, and the other is number of wheel passes at a fixed rut depth. The former case is used popularly over the latter, and is chosen here for development of a grading theory.

Also, two special cases are evolved from Eq. (2): one is the simplified version and the other is the rigorous one. These two cases will be discussed below.

2.1 Simplified High-Temperature Grading Theories

The parameters, k and β, in Eq. (2) are assumed to be constant in the simplified version. Then, Eq. (2) can be written as

$$\mathrm{Ln}(h_N) = \mathrm{Ln}(d \cdot N^{\beta}) - k\beta \cdot \mathrm{Ln}(\eta_0) \qquad (3)$$

where h_N is the rut depth at a fixed number of wheel passes.

For most of rutting tests, note that β varies with binder viscosity. Hence, Eq. (3) is usually an approximation to Eq. (2). Huh et al. (2000) have shown that all grading presently available (penetration, viscosity, and performance grading) are constructed on the basis of Eq. (3). Also, this simplified equation turns out to work reasonably well for unmodified asphalt binders, but shows substantial error for modified ones. Thus, to find a new unified grading theory that works both for the unmodified and the modified asphalt binders, more rigorous analysis of Eq. (2) is necessary. Before a rigorous grading equation is suggested, it is worth to explore how the simplified equation (3) becomes a basis for all grading presently available.

2.1.1 A Viscosity Grading Equation

The relationship between rut depth and binder absolute viscosity shown in Eq. (3) simply indicates the theory of the present viscosity grading. In other words, if a binder absolute viscosity is known, the rut depth can be defined by the equation. Thus, comparing viscosity among binders by the rule of Eq. (3) implies comparing of rut depth among mixtures made of each binder under the condition of fixed aggregate effects (aggregate kind, size, distribution, shape, surface texture, etc.). This is the current viscosity grading.

2.1.2 A Penetration Grading Equation

In the literature (Welborn et al. (1966)), the empirical relationship between penetration depth and binder absolute viscosity is well established. That is,

$$\mathrm{Ln}(L) = \mathrm{Ln}(c) - m \cdot \mathrm{Ln}(\eta_0) \qquad (4)$$

Combining Eqs. (3) & (4) and eliminating the absolute viscosity yield to the relationship between rut depth and penetration depth:

$$h_N = a \cdot L + b \qquad (5)$$

where a and b are constants changing with number of wheel passes, and L is the penetration depth. Equation (5) represents a theoretical basis of the present penetration grading. That is, comparing the penetration depth among different binders just means comparing rut depth among different mixtures made of each binder with the fixed aggregate effects, as shown in Eq. (5). However, this grading is essentially similar to viscosity grading, because penetration depth is related to binder absolute viscosity by Eq. (4). Hence, either grading can be applied for straight asphalt binders, but measurement is simpler in the penetration than the viscosity testing.

2.1.3 A New Performance Grading Equation in a Simplified Version

To develop a performance grading equation in the simplified version, one has to find a material parameter to be used in the relationship between the rut depth and the parameter. Asphalt binders are known to be a viscoelastic material. Thus, the adequate parameter must be a viscoelastic one instead of viscosity. The required parameter found is $G^*/\sin\delta$. Logical background of using this parameter is explained in the section 2.1.4.

Now a functional relationship is required between the rut depth and the viscoelastic parameter $G^*/\sin\delta$ to form a new performance grading equation. For this purpose, Eq. (3) is used by substituting the viscoelastic parameter ($G^*/\sin\delta$) in the place of the viscosity (η_o); that is,

$$Ln(h_N) = Ln(d\ N^{\beta}) - k\beta Ln\left\{\frac{G^*}{\sin\delta}\right\} \quad (6)$$

Equation (6) is a new grading equation, which is different from the current Superpave PG-grading, developed by Bahia and Anderson (1995). Their equation is something like

$$h_N = \frac{f}{G^*/\sin\delta}$$
$$\text{or} \quad Ln(h_N) = Ln(f) - Ln\left\{\frac{G^*}{\sin\delta}\right\} \quad (7)$$

The major difference between Eq. (6) and (7) is that the slope $k\beta$ in Eq. (6) changes with number of wheel passes, while that in Eq. (7) is fixed to be one. Since $k\beta$ is usually different from one, serious error could be evolved if one uses Eq. (7) to grade asphalt binders. For example, in the Superpave PG-grade validation study, Bonaquist and Mogawer (1997) have shown that $k\beta$ is not one, but 0.318.

In a simplified grading theory, Eqs. (3), (5), and (6) represent a viscosity, a penetration and a new performance grading. All equations are based on Eq. (3) that is a special case of Eq. (2). Either one of the three equations can be used, but the new performance grading is the best one. They can be used effectively to grade the unmodified straight asphalt binders, but may fail for modified binders due to simplified assumptions (fixed k and β) made in derivation of Eq. (3). The more rigorous equation will be discussed in the section 2.2.

2.1.4 A Viscoelastic Parameter and Its Effect

The storage (G') and the loss modulus (G'') in the dynamic shear test represent the elastic and the viscous property of a given material. Combination of these two moduli is the complex modulus ($G^* = G' + iG''$), and its magnitude becomes

$$|G^*| = \sqrt{G'^2 + G''^2} \tag{8}$$

$|G^*|$ is usually written as G^* hereafter without the absolute sign for convenience, and is proved to be identical to shear stress (τ) in shear flow by Cox and Mertz (1958). That is,

$$G^* = \eta^* \cdot \omega = \eta \cdot \dot{\gamma} = \tau \tag{9}$$

where η^*, ω, η and $\dot{\gamma}$ denote a complex viscosity, a frequency, a shear viscosity and a shear rate, respectively. The complex modulus (G^*) is usually measured at a fixed frequency ($\omega = 10$ rad/sec) and 60℃ for rutting such that it simply represents viscosity multiplied by a constant:

$$G^* = 10 \cdot \eta^* = 10 \cdot \eta = \tau \tag{10}$$

According to Eq. (10), change of the complex modulus directly implies change of the shear viscosity. This means that the complex modulus alone displays the viscous property, not the viscoelastic one. Hence, for representation of viscoelasticity, it should be modified properly.

Comparison of the elasticity among different binders does not imply a direct comparison of G'. Rather, it is determined by the relative magnitude of G' compared to G'' or G^*. This relative amount of G' to G'' or G^* is usually expressed by $\tan\delta (= G''/G')$, $\sin\delta (= G''/G^*)$, or $\cos\delta (= G'/G^*)$, where δ is a phase shift angle. These are three parameters denoting viscoelasticity of a given material. They are not independent, but rather interrelated each other: that is, $\sin\delta = (1 - \cos^2\delta)^{1/2}$, and $\cos\delta = (1 - \sin^2\delta)^{1/2}$ and $\tan\delta = \sin\delta / \cos\delta$.

Now, to obtain a viscoelastic parameter from the complex modulus, it is sufficient to combine the complex modulus to one of the three parameters just mentioned. Among several possible combinations, physically acceptable one is turned out to be $G^*/\sin\delta$. This is the viscoelastic parameter turned out to be identical to the one obtained in performance grading (PG-grading).

The combined parameter can represent change of either viscosity or viscoelasticity depending on the value of $\sin\delta$. When $\sin\delta$ is equal to one (negligible elastic modulus compared to loss modulus in definition), $G^*/\sin\delta$ becomes the complex viscosity parameter (η^*) multiplied by the fixed frequency of $\omega = 10$ rad/sec:

$$\frac{G^*}{\sin\delta} = G^* = 10 \cdot \eta^* \tag{11}$$

This is demonstrated in Fig. 1 by plotting the data of $G^*/\sin\delta$ versus η^*, reported by Hanson et al. (1995) for unmodified binders. Some scattering is observed in the figure, but there is no doubt for existence of the relationship indicated by Eq. (11). Here, some scattering and the slope of 0.5453 instead of 10 may be due to presence of some elastic effect in certain binders, measuring inaccuracy and using different frequencies other than 10 rad/sec.

Equation (11) indicates that change of $G^*/\sin\delta$ is nothing but change of η^*. In this case, Eq. (6) becomes the form of Eq. (3) working for the unmodified asphalt binders at

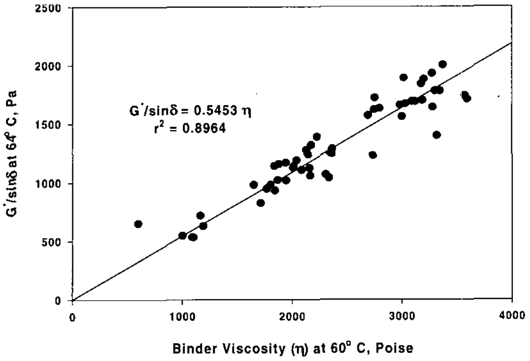

Fig. 1. Relationship between $G^*/\sin\delta$ vs. η for original asphalt binders

high temperatures, which are totally viscous.

When $\sin\delta$ is less than one with significant elastic modulus present relative to loss modulus, that is,

$$\sin\delta = \frac{G''}{G^*} = \frac{G''}{\sqrt{G'^{\,2} + G''^{\,2}}} < 1 \qquad (12)$$

then $G^*/\sin\delta$ becomes greater than $G^*(=\eta^*\omega = 10\eta^*)$. This increased parameter value essentially manifests viscoelastic effect in material deformation:

$$\frac{G^*}{\sin\delta} = \frac{10\cdot\eta^*}{\sin\delta} > G^* = 10\cdot\eta^* \qquad (13)$$

Daly and Negulescu (1997) have shown that viscoelasticity of a given binder can be increased with either addition of an elastic material (crumb rubber, rubber powder, SBS, SBR, etc.) or reduction of material temperature. The former case is demonstrated in Fig. 2, which shows how $\sin\delta$ decreases with addition of the powdered rubber content. The initial $\sin\delta$ value of one at 64℃ meaning the binder to be a viscous material gradually decreases with addition of rubber content implying increase of visco-elasticity.

A single binder can become either viscous or viscoelastic with variation of temperature. Temperature response of binders is demonstrated in Fig. 3. In the figure, when temperature decreases starting from 64℃, $\sin\delta$ of a binder initially at the value of one decreases gradually indicating increase of viscoelasticity. Note that

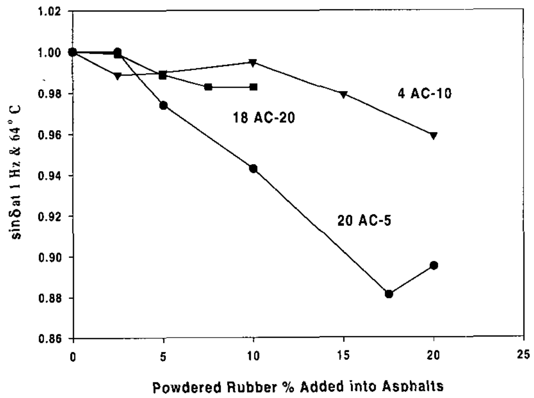

Fig. 2. $\sin\delta$ with powder rubber content added in asphalt binders

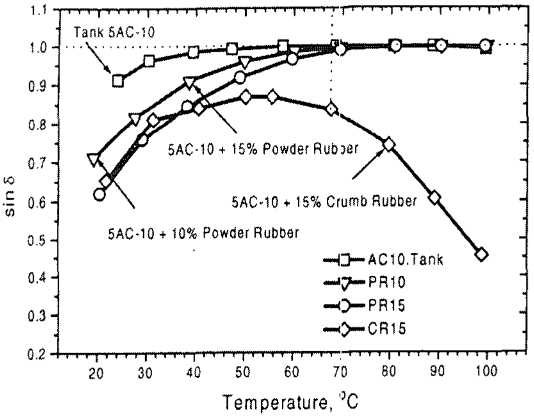

Fig. 3. $\sin\delta$ of the rubber-modified binders changing with temperature

Tank 5AC-10 (the original binder without any rubber content) is in viscoelastic at low temperatures and becomes viscous above 50°C. Raising temperature makes the viscoelastic behaviour be the viscous one. This is true even for some of the modified binders with added rubber content. This viscous binder at high temperature may correspond to the one with the simple behaviour in the classification of Bahia et al. (1998).

However, other modified binders like 5AC-10 +15% Crumb Rubber never become viscous and, instead, viscoelastic throughout all temperature ranges studied. This demonstrates that some modified binders can show different deformation behaviors at high temperatures (50°C above), independently from unmodified binders. It is believed that this viscoelasticity is responsible for the complex behaviour of a modified binder in the classification of Bahia et al. (1998). In this case, the viscous grading theory based on binder viscosity (Eq. (3)) or penetration depth (Eq. (5)) may not work. More rigorous grading theory should be applied.

So far, justification of using $G^*/\sin\delta$ as a viscoelastic parameter has been explained in detail. Also, it has been shown that the parameter could vary with elasticity and temperature of binders. This concludes that $G^*/\sin\delta$ represents a viscous parameter as well as a viscoelastic one depending on the value of $\sin\delta$, while an absolute viscosity (η_o) or a penetration depth (L) manifests only a viscous parameter. Thus, $G^*/\sin\delta$ becomes a more general material parameter to be used in a high temperature binder grading.

2.2 A New High-Temperature Grading Equation

In the simplified form of Eq. (2), k and β are assumed to be constant, but here, in the rigorous form, k and β are treated not to be constant. However, for fixed aggregate effects, k is also fixed such that β only varies with binder viscosity. Then, Eq. (2) turns into the following form:

$$\mathrm{Ln}\left\{\frac{h_N}{N^{\beta}}\right\} = \mathrm{Ln}(d) - k \cdot \mathrm{Ln}(\eta_o{}^{\beta}) \qquad (14)$$

The rut depth expression in Eq. (14) is still based on the viscosity parameter (η_o), even though it is a more rigorous equation than Eq. (3). As mentioned earlier, behaviors of modified binders cannot be described by viscosity parameter alone, but rather they are governed by the viscoelastic parameter, $G^*/\sin\delta$. The more proper equation is formed by replacing the viscosity parameter (η_o) in Eq. (14) with the viscoelastic one ($G^*/\sin\delta$). That is,

$$\mathrm{Ln}\left\{\frac{h_N}{N^{\beta}}\right\} = \mathrm{Ln}(d) - \mathrm{k} \cdot \mathrm{Ln}\left\{\frac{G^*}{\sin\delta}\right\}^{\beta} \qquad (15)$$

Equation (15) is the most rigorous equation used for grading rut-resistance of the modified as well as the unmodified asphalt binders. Note that β is a variable changing with binder viscosity. Remember that the number of wheel passes (N) is fixed in Eq. (15).

3. ANALYSIS AND DISCUSSION

3.1 Simplified Equations

King et al. (1992) qualitatively studied the effect of asphalt grade and polymer concentration on high temperature performance of pavement rutting by using the French LCPC wheel tracking device. Material preparation, test conditions, and measured rut data may be referred to their paper. Aggregate type, shape, size, gradation, air void, load, frequency, and test temperature are all fixed in their experiments to consider only effect of penetration depth (L), viscosity (η), and viscoelastic stress ($G^*/\sin\delta$) of given asphalt binders on rut depth. These data are listed in Table 1 together with two parameters of Eq. (1), α and β , estimated from regression of the rut data provided.

Table 1. Properties of Neat Asphalts and French LCPC Rut Depth Data.

Penetration Grade	40/50	60/70	80/100	180/200
Binder Viscosity at 60℃ & 1/s, Poise	8,540	3,830	2,245	700
$G^*/\sin\delta$ at 30℃ & 1 Hz, Pa	801,000	646,000	487,000	---
Number of Cycles	French LCPC Rut Depth, mm			
300	2.5	3.0	3.5	5.0
1000	3.3	3.9	5.4	9.3
3000	3.8	4.9	10	---
10000	4.8	8.6	14	---
Estimated Parameter	Regression of Rut Data by $h = \alpha N^{\beta}$			
α	0.993	0.501	0.410	0.29
β	0.167	0.301	0.386	0.5
r^2	0.995	0.990	0.990	1.0

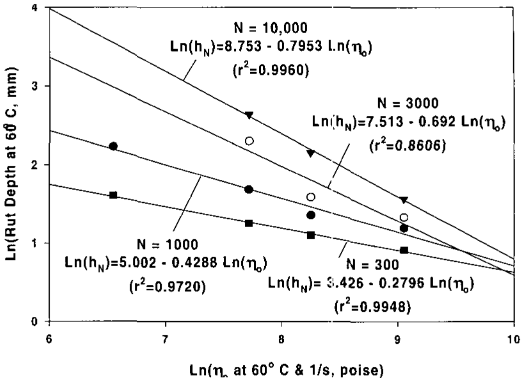

Fig. 4. Rut depth vs. binder absolute viscosity for unmodified asphalts

Figure 4 demonstrates a plot of binder viscosity versus rut depth in the logarithmic scale for unmodified original binders. The data are taken from Table 1. As shown in the figure, the slope and the intercept change with number of wheel passes, but, at the fixed wheel passes, successful prediction of the data by Eq. (3) is well observed. Remember that Eq. (3) works at a fixed number of wheel passes, and this fixed number can be arbitrary assigned in the slope and the intercept parameter. This indicates that the rut depth at a fixed number of wheel passes in the term of viscosity, Eq. (3), works well for unmodified binders at a high temperature, 60℃.

Same trend as the viscosity case is observed both for the penetration depth (L) represented by Eq. (5) and the performance parameter ($G^*/\sin\delta$) described by Eq. (6). The data in Table 1 are used to prove validity of those two equations, Eqs. (5) and (6). The successful curve-fittings are shown in Figs. 5 and 6. These cases indicate that the relationship of rut depth in the term of either a penetration depth or a performance parameter works well for unmodified

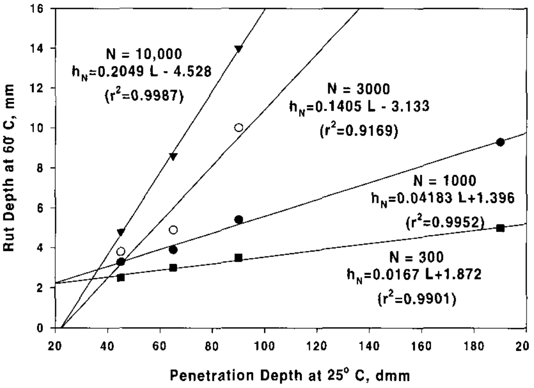

Fig. 5. Rut depth versus penetration depth for unmodified asphalts

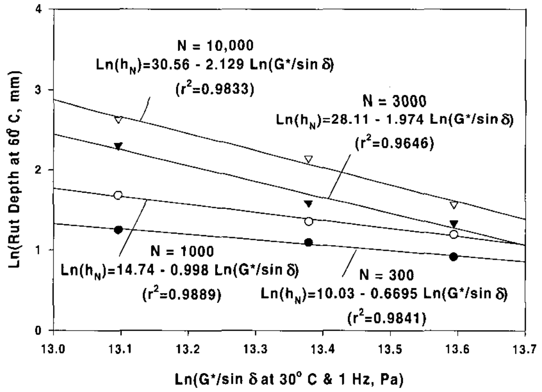

Fig. 6. Rut depth vs. binder $G^*/\sin\delta$ unmodified asphalts

binder cases.

The above evidences verify that either one of the three equations, Eqs. (3), (5), and (6), can be applied to the high temperature grading of unmodified binders that are totally governed by the viscous behavior, not viscoelasticity. However, the penetration grading is the most simple one to be used because of simplicity of measurement. The unified form of the three grading equations seems to rely on the following linear equation:

$$Y = aX + b \qquad (16)$$

where a and b are the slope and the intercept, and meanings of X and Y are shown below according to different grading methods defined.

Grading	Y	X
Penetration	h_N	L
Viscosity	$\mathrm{Ln}(h_N)$	$\mathrm{Ln}(\eta_0)$
New Performance	$\mathrm{Ln}(h_N)$	$\mathrm{Ln}(G^*/\sin\delta)$

Another rutting data used for validatation of grading equations developed here were obtained from Bonaquist & Mogawer (1997), and the corresponding binder properties were from Stuart & Izzo (1995). The rut data were generated by performing accelerated pavement tests at FHWA Pavement Testing Facility located on the ground of the Turner-Fairbank Highway Research Center. This work is designed to be Superpave validation study for polymer-modified asphalt binders showing a viscoelastic property as well as unmodified binders showing a viscous property. Two accelerated loading facility (ALF) equipments were used to simulate the effects of heavy vehicle loading on full-scale test pavements. Pavement rutting data obtained from such tests and their binder properties are listed in Table 2 together with two regression parameters of Eq. (1), a and b, for reference.

Now, the rut data in Table 2 are used to test validity of Eqs. (3), (5), and (6).

Figures 7, 8, and 9 represent the corresponding regression results, and clearly demonstrate that the simplified equations (Eqs. (3), (5), and (6)) fail to express the rut behavior of mixtures made of modified binders.

Table 2. Total Pavement Rut Depth Measured by Accelerated Loading Facility (ALF)

Lane	Lane 5	Lane 7		Lane 8		Lane 9		Lane 10	
Test Site	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
PG-Grade	58-28	82-22		76-22		58-34		64-22	
Gradation	SM-3B	SM-3B		SM-3B		SM-3B		SM-3B	
$G^*/\sin\delta$ (Pa) at 60℃, ω=2.25 r/s	1.08	11.39		8.39		0.53		2.10	
Absolute Viscosity 60℃, dPa.S	1,195	58,774		12,714		665		2,644	
Penetration 25℃, dmm	113	47		55		172		73	
Wheel Passes	Accelerated Loading Facility (ALF) Rut Test Data at 60℃, mm								
N = 1000	18.8	12.2	8.2	10	9.6	26.0	30.3	16.6	16.2
N = 5000	---	17.9	11.0	12.5	11.0	---	---	26.4	28.0
N = 10000	---	20.1	18.1	13.9	15.2	---	---	32.8	36.9
Parameters	Regression of Rut Data by $h=\alpha N^{\beta}$								
α	1.003	2.775	1.589	1.618	1.627	0.809	1.397	2.271	1.567
β	0.424	0.213	0.252	0.243	0.237	0.509	0.443	0.289	0.342

3.2 A Rigorous Equation

By using Eq. (14), regression is performed for the rut data in Table 2 to check whether the rigorous equation works better or not compared to the simplified equations, and the result is shown in Fig. 10. Any visible improvement is not made in the figure compared to Fig. 7 of a simplified case. This is believed due to usage of the viscosity parameter instead of viscoelastic one for the modified binders included. Note that the regression equation in the rigorous form does not change with number of wheel passes such

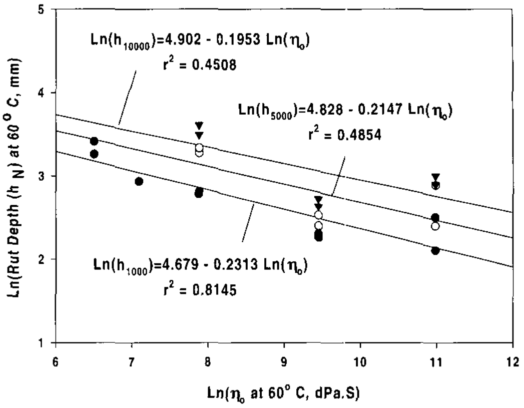

Fig. 7. Rut depth vs binder absolute viscosity for modified asphalts.

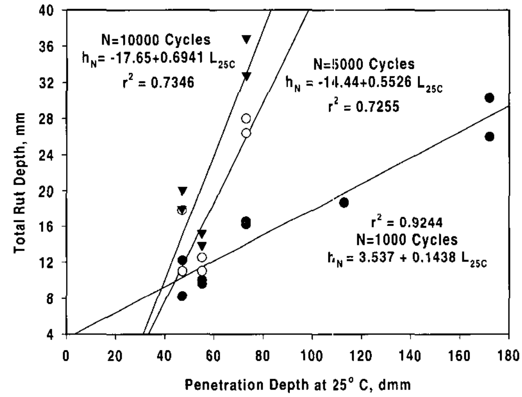

Fig. 8. Rut depth versus penetration depth for modified asphalts.

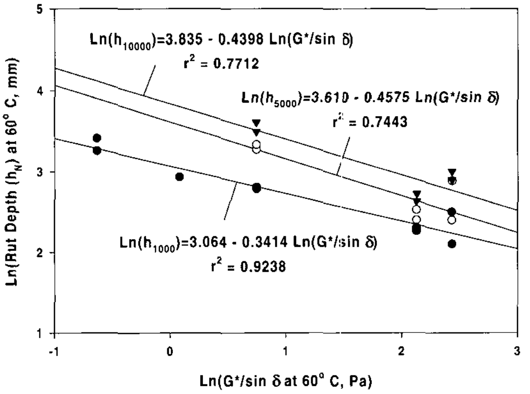

Fig. 9. Rut depth vs. binder $G^*/\sin\delta$ for modified asphalts

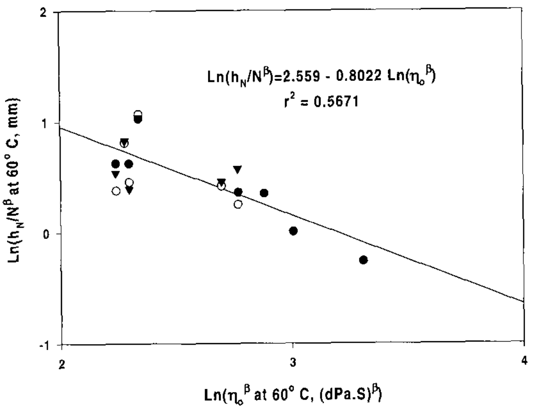

Fig. 10. The plot of Ln(h_N/N^{β}) vs. Ln($\eta_o{}^{\beta}$) for modified asphalt binders

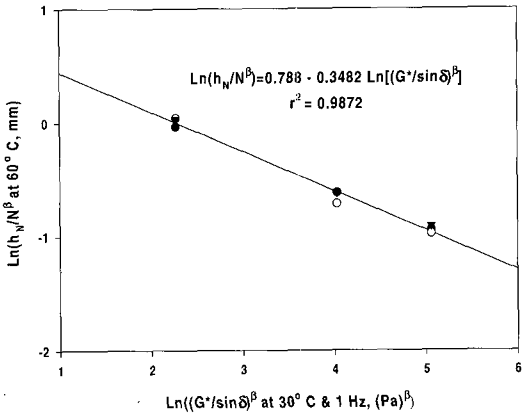

Fig. 11. Relationship between Ln (h_N/N^{β}) and Ln ($G^*/\sin\delta)^{\beta}$ for neat asphalts

that all rut data in different wheel passes can be expressed into a single equation.

Finally, Eq. (15) is tested for the same rut data in Tables 1 (rut data for unmodified binders) and 2 (rut data for modified and unmodified binders) to examine any difference from those results obtained by simplified equations in the previous section. These regression results are exhibited in Figs. 11 and 12. Satisfactory outcome in those figures relative to Figs. 4, 5, 6, 7, 8, 9, and 10 prove good validity of Eq. (15) for high temperature grading of both modified and unmodified binders. This means that a rigorous equation with a viscoelastic parameter, Eq. (15), is the proper grading equation, which agrees with theories derived.

4. CONCLUSIONS

It has been shown that current grading methods (penetration, viscosity, and performance grading) fail to provide proper grades for

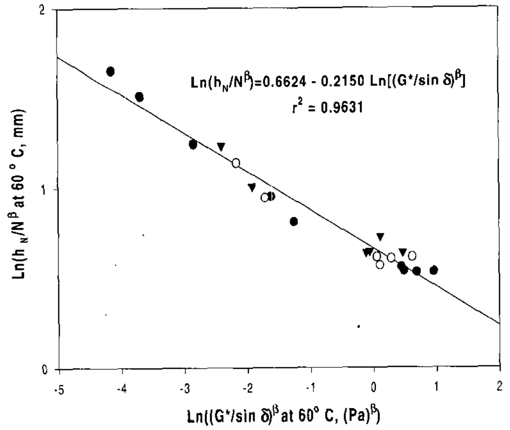

Fig. 12. Plot of Eq. (17) for full-scale field rut depth for modified binders.

modified binders. To resolve the problem, first, a viscoelastic parameter has been defined to cover both viscous and viscoelastic properties. Using this parameter in place of viscosity in the rut depth expression, a new grading theory both for modified and unmodified asphalt binders has been suggested. The laboratory wheel tracking data and the full-scale accelerated field test data are utilized to prove effectiveness of the equation. Successful prediction of those data by the equation promises construction of a new unified high temperature grading both for modified and unmodified binders in the near future.

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(접수: 2001. 1. 13)