A Comprehensive Treatise of the High Temperature Specification Parameter $|G^*|/(1-(1/\tan\delta\sin\delta))$ for Performance Grading of Asphalts

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Abstract:

The term $|G^*|/(1-(1/\tan\delta\sin\delta))$ has been suggested as one of the best candidates for the replacement of the Superpave specification parameter $|G^*|/\sin\delta$, which has been found to be inadequate in rating polymer-modified binders for high temperature performance grading. This refinement of the Superpave specification parameter evolved through a theoretical derivation based on fundamental concepts. It was shown to be more sensitive to the variations in the phase angle δ than the original Superpave specification parameter. It thus described the unrecovered strain in the asphalt binders more accurately, and hence related to actual field performance data. This article provides a comprehensive treatise of the parameter $|G^*|/(1-(1/\tan\delta\sin\delta))$ giving details of its derivation, salient features that are attributed to its success, comparison with actual field performance data for validation and a one-on-one comparison with the existing parameter $|G^*|/\sin\delta$. It is shown that for all available field data, the parameter $|G^*|/(1-(1/\tan\delta\sin\delta))$ does a better job in correlating with the rutting behavior than the parameter $|G^*|/\sin\delta$ for unmodified as well as modified asphalts. Since it is obtained in the same manner as the parameter $|G^*|/\sin\delta$ through the determination of $|G^*|$ and δ from a stress-controlled or strain-controlled dynamic shear rheometer, it means that no retraining of technicians and staff is required and implementation for the use of this parameter is immediate, thereby saving enormous amount of time and money. This parameter has the further advantage of being in a form easily adaptable to modeling, and thereby directly applicable for pavement design purposes.

Zusammenfassung:

Der Term $|G^*|/(1-(1/\tan\delta\sin\delta))$ wurde als Ersatzung des Superpave Spezifikationsparameters $|G^*|/\sin\delta$ vorgeschlagen, der sich für die Beurteilung von polymerisch modifizierten Bindemittel für hochtempeartuer "Performance Grading" als unzureichend herausgestellt hat. Diese Verfeinerung des Superpave Spezifikationsparameter entstand aus einer theoretischen Herleitung, welche auf fundamentealen Konzepten beruhte. Es wurde gezeigt, dass sie sensitiver auf Veränderungen im Phasenwinkel δ war, als der ursprüngliche origianale Superpave Spezifikationsparameter. Er beschriebt die nicht relaxierten Deformation in den Asphaltenbindern somit genauer und lieferte damit einen Zusammenhang mit aktuellen Feldparametern. Dieser Beitrag gibt eine verständliche Abhandlung des $|G^*|/(1-(1/\tan\delta\sin\delta))$ Parameters, wobei Details seiner Herleitung, wichtige Eigenschaften die seinen Erfolg begründen, Vergleich mit Leistungsdaten für die Validierung und einen eins-zu-eins Vergleich mit bestehendne $|G^*|/\sin\delta$ daten gegeben werden. Es wird gezeigt, dass für alle verfügbaren Felddaten für unmodifizierte und modifizierte Asphalte der Spezifikationsparameter $|G^*|/(1-(1/\tan\delta\sin\delta))$ zur Korrelation des Verschleissverhaltens besser geeignet ist als der $|G^*|/\sin\delta$ Parameter. Da er nach der selben Methode wie der Parameter $|G^*|/\sin\delta$ gefunden wird, d.h. durch die Bestimmung von $|G^*|$ und von δ aus einem spannungskontrollierten oder verformungskontrollierten Scherrheometer, bedeutet dies dass keine Schulung von Techniker und Belegschaft nötig ist und dass die Implementierung für das Benutzen dieses Parameters direkt erfolgen kann, wodurch enorme Zeit und Kosteneinsparung gegeben ist. Dieser Paramter hat den weiteren Vorteil, dass der leicht für das Modellieren angepasst werden kann, und dabei direkt für Zwecke des Bodendesign angewendet werden kann.

Résumé:

Le terme $|G^*|/(1-(1/\tan\delta\sin\delta))$ a été suggéré comme l' un des meilleurs candidats afin de remplacer le paramètre de spécification Superpave $|G^*|/\sin\delta$ qui s'est montré inadéquat au cours de l'évaluation de liants polymériques modifiés lors de performances de montée à hautes températures. Ce raffinement du paramètre de spécification Superpave a évolué grâce à un calcul théorique basé sur des concepts fondamentaux. Il se révèle plus sensible aux variations de l'angle de phase d que le paramètre original de spécification Superpave. Ainsi, il décrit la déformation recouvrée des liants d' asphalte de manière plus précise et ce, en rapport avec les données réelles du champ de performance. Cet article propose un traitement étendu du paramètre $|G^*|/(1-(1/\tan\delta\sin\delta))$ en donnant les détails de son calcul, des caractéristiques marquantes associées à son succès, une comparaison et une confrontation avec les données réelles du champ de performance, ainsi qu' une comparaison directe avec le

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It may be noted that, in the present work, laboratory mixture data was not used for comparison, which is in sharp contrast to the general tendency wherein rheological behavior of the binder is compared with mechanical property data on the mixture and a correlation is sought. The reason for not doing this is because mixture data is far more variable and less reliable than binder data. Without any gold standard amongst mixture data, it is inappropriate to evaluate the efficacy of a new high temperature specification parameter through a comparison with mixture data. As a matter of fact, the correct practice should be to pick the most reliable binder parameter that correlates with field data, and then use it as a standard to find a mixture test that indicates true field performance rather than the other way around. The parameter $|G^*|/(1-(1/\tan\delta \sin\delta))$ that is derived using fundamental concepts and is accurate enough to capture field performance has the potential of being used as a reliable measure for comparison in order to identify the best of the available mixture tests that would closely match field performance. This is certainly advantageous from the viewpoint of future developmental research work.

The other advantage is that the parameter $|G^*|/(1-(1/\tan\delta \sin\delta))$ is obtained in the same manner as the parameter $|G^*| / \sin\delta$ through the determination of $|G^*|$ and δ from a stress-controlled or strain-controlled dynamic shear rheometer. This means that no retraining of technicians and staff is required, and implementation for the use of this parameter is immediate, thereby saving enormous amount of time and money. The parameter can be programmed into the software of the dynamic shear rheometer such that the parameter and the specification temperatures based on the two criteria can be readily obtained without manual calculation.

The parameter $|G^*|/(1-(1/\tan\delta \sin\delta))$ has the further advantage of being in a form easily adaptable to modeling. Thus, if a rheological property relevant to rutting has to be input into any future models for pavement design purposes, the expression for this parameter in the most general form may be used. Equation 17a gives the unrecovered strain per cycle for applied stress σ_o. To obtain the accumulated strain, it is necessary to carry out a summation over the number of cycles as follows. In actual practice, neither the magnitude of the applied stress nor the duration of the stress or the temperature at which the stress is applied may be constant. Hence, the expression for the accumulated strain is written in the most general form as follows:

$$\gamma_{acc} = \sum_{i=1}^{N} \frac{\sigma_{oi}}{|G^*|(\omega_i,T_i)}\left(1-\frac{1}{\tan\delta(\omega_i,T_i)\sin\delta(\omega_i,T_i)}\right) \tag{19}$$

If the magnitude of the applied stress, the duration of the stress and the temperature are constant, then $\gamma_{acc} = N\gamma_{unr}$, and the plot of γ_{acc} versus number of cycles N (or time) is a straight line with a slope given by the right-hand side of Eq. 17a. Equation 19, however, gives an opportunity to input values corresponding to different loading levels, different traffic speeds, and different pavement temperatures for each duration of loading. This is important for pavement design.

DISCLAIMER

The opinions, findings, and conclusions in this document are those of the author and not necessarily of the Federal Highway Administration or other researchrs at the Turner-Fairbank Highway Research Center.

NOTATION

a, $Z(a)$	Spriggs model parameters
$\|G^*\|$	complex shear modulus (Pa or kPa)
J''	loss compliance (1/Pa or 1/kPa)
T	temperature (degrees)
T_{HS}	high specification temperature (degrees)
γ_{unr}	unrecovered (or permanent) strain
δ	phase angle (degrees or radians)
η_o, λ	Spriggs model parameters
σ_o	applied stress during creep loading (Pa or kPa)
ω	frequency of oscillatory motion (radians/s)

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