한국도로학회 논문집
第9券1號 2007年 3月
pp. 57 ~ 67

The New Calculation Model of Film Thickness to Evaluat Asphalt Mixtures

아스팔트혼합물을 평가하기 위한 유효아스팔트 함량의 새로운 계산 모델

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Abstract

Many researches have recently discussed about the film thickness as a good substitute or supplement for VMA or other volumetric criteria in the design procedure. Some researchers have not only proposed the specific number for the recommended film thickness, but also introduced the new calculation procedures or concepts. Each model (index model and the virtual model) has its own advantages and disadvantages in terms of the ability to account for the volumetric properties of the mixture. In this paper, the modified virtual model was proposed to combine advantages from both models. However, it cannot be disregarded the way to determine the appropriate particle shape factors for different sources and sizes of aggregates. In order to evaluate the different calculation methods, mixtures with two aggregate sources and eight gradations were designed based on the dominant aggregate size range (DASR) porosity concept. Superpave indirect tensile test (IDT) and asphalt pavement analyzer (APA) test were used to describe the performance of mixtures. Test results indicated that the virtual model, which is the same to the modified virtual model for sphere 1:1 case, is better than the conventional standard model to define the range of the film thickness to have better performance of asphalt mixtures.

Keywords : voids in mineral aggregate, film thickness, dominant aggregate size range, modified virtual model

요 지

최근 아스팔트 혼합물의 VMA 혹은 그 외 다른 체적요소의 기준값을 대체하기 위해 유효아스팔트 함량(film thickness)에 대해 논의되어 왔다. 이들 중 일부는 유효 아스팔트 함량의 기준값을 제안하였으며, 일부는 새로운 개념 또는 계산 방법을 포함하는 새로운 모델을 즉, 인덱스 모델(index model) 또는 가상 모델(virtual model)을 소개하였다. 각각의 모델은 아스팔트 혼합물의 체적특성을 설명하는데 있어서 형상, 크기 등 골재의 체적특성을 정량화하는 방법을 이용한다. 본 연구에서는 인덱스 모델과 가상 모델의 장점을 결합한 개선된 가상 모델(modified virtual model)을 제안하였다. 개선된 가상 모델을 기존의 두 가지 모델과 비교평가하기 위하여 DASR 개념에 근거하여 제작된 총 8개의 혼합물을 대상으로 IDT 시험과 APA 시험을 수행하였다. 시험 결과, 아스팔트 혼합물의 공용성과 유효 아스팔트 함량의 관계를 계산함에 있어서 본 연구에서 제안된 가상 모델은 기존의 모델들에 비해 더 적절함을 알 수 있었다.

핵심용어 : 골재 간극률, 유효 아스팔트 함량, 아스팔트 혼합물 체적요소, 인덱스 모델, 가상 모델

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1. INTRODUCTION

After introducing firstly the VMA requirement by MeLoed(1) in 1950' s, minimum VMA requirement was also adopted by the Superpave mixture design procedure. This has been widely used for a criterion to produce the proper mixture based on the Superpave specification. However, some recent studies show that it is sometimes difficult to achieve minimum VMA itself(2, 3, 4). The mixtures which meet VMA criteria cannot assure good performance. On the other hand, the mixtures which don' t meet VMA criteria can perform better(5).

Some researchers recommended the film thickness as an alternate or supplement for mixture design characteristics(3, 4, 6, 7). Although several researchers suggested the specific average film thickness to ensure the durability of mixtures(4, 8, 9), it was also pointed out that the film thickness is difficult to define(9). Radovskiy mentioned that "…to calculate an average film thickness, the surface area is determined by multiplying the surface area factors by the percentage passing the various sieve sizes. However, they could not find the background research data for the surface area factors in the literature." (10)

Nukunya et al.(2) suggested the alternative concept of the conventional film thickness, called as the effective asphalt film thickness. They calculated this based on the effective volumetric properties instead of the original procedure.

Recently Heitzman(11) recommended using the new calculation procedures; index model, and virtual model. The former was based on the mixture volumetric properties on 2-D surface to calculate the surface area. In addition, it also included the surface area and volume factors to consider different particle shapes. The latter firstly developed the polydispersed particle system(12). This was utilized for concrete materials by Carboczi and Bentz(13). Finally, Radovskiy has finalized the concept for asphalt mixtures. Heitzman(10) called this as virtual model because it counts for 3-D model. To cover 3-D aggregate having the same surface area, asphalt content should be more than 2-D aggregate(11). However, virtual model doesn't count for particle shape unfortunately.

2. Previously Developed Film Thickness Calculations

2.1 Conventional standard model

Conventional method for calculating film thickness is based on the surface area factors mentioned in Hveem mix design procedure(14), and using the following equation:

$$FT = \frac{Vb_{eff}}{SA \times W_{agg}} \times 1000 = \frac{Pbe}{SA \times Ps \times Gb} \times 1000 \qquad (1)$$

Where FT = film thickness (microns), V_{beff} = effective volume of asphalt binder (l), SA = surface area of the aggregate (m^2/kg), W_{agg} = weight of aggregate (kg), Pbe = percent of effective asphalt binder, Ps = percent of aggregate by mix weight, and Gb = specific gravity of asphalt binder.

The surface area is determined by multiplying the factor by the percentage passing for each sieve size and totaling for all sieve sizes. This is significantly affected by the smaller sieve sizes, but not by mineral filler gradation (smaller than 0.075mm). In addition, multiplying by the percent passing means that each value represents all particles smaller than that sieve. The determination of surface area does not consider of the specific gravity of the aggregate.

2.2 Index model

Index model to calculate film thickness proposed by Heitzman(11) is a simple procedure. Based on the basic information of materials, which are weight and volume of asphalt and aggregate, etc, the theoretical surface area of each aggregate particle is calculated by using particle geometry (Equation 2). After getting the sum of surface area for each sieve size, it is substituted to Equation 1, and then it will be the following equation:

$$SA_{(i)(n)} = \frac{0.0012 * Pc_{(i)} \times (Ps_{(i)(n+1)} - Ps_{(i)(n)}) \times SAF_{(i)(n)}}{Gsb_{(i)} \times (D_{(n-1)} + D_{(n)}) \times VF_{(i)(n)}} \quad (2)$$

$$FT = \frac{Pbe}{\sum SA_{(i)(n)} \times Ps \times Gb} \times 1000 \quad (3)$$

where, $SA_{(i)(n)}$=surface area for the i^{th} source retained on the n^{th} sieve, $Pc_{(i)}$=percent of the i^{th} source by aggregate weight, $Ps_{(i)(n)}$=percent of the i^{th} source retained on the n^{th} sieve by source weight, $SAF_{(i)(n)}$= surface area factor for the particle from the i^{th} source on the n^{th} sieve, $D_{(n)}$=sieve size of the n^{th} sieve, and $VF_{(i)(n)}$=volume factor for the particle from the i^{th} source on the n^{th} sieve.

The shape factors (volume factor and surface area factor) convert the volume and surface area from a uniform sphere to the desired particle shape. Therefore, they represent the degree of the elongation of particles. The dimensions for spherical and cubical shape are changed to account for a particle to randomly pass through a square opening. The volume of spherical and cubical particles retained on the same sieve has approximately equal volume. Table 1 presented the volume and surface area factors derived from the geometric calculations.

Table 1. Particle Shape Factors.

Particle Shape	Volume Factor	Surface Area Factor
Sphere 1:1(basic geometry)	1.0	1.0
Sphere 2:1	2.5	2.0
Sphere 3:1	4.0	3.0
Cube 1:1	1.0	1.2
Cube 2:1	2.0	2.1
Cube 3:1	3.0	2.9

Although the three pairs of volume and surface area factors allow the mix designer to distinguish among coarse-aggregate, coarser fine-aggregate, and finer fine aggregate, there are no established test procedures to determine these values(11). The index model is a logical sequence of calculations to determine the surface area of each aggregate particle. Since it accounts for the gradation, specific gravity, and particle shape of each aggregate source between aggregate sources, the resulting surface area is a better approximation of the true surface area. However, it measures film thickness with the simplification that the surface area coated by the asphalt binder is a flat surface, not 3-D particles, and each particle is separately and uniformly coated. This is significant because a flat surface reduces the coated volume from a 3-D shell thickness to a 2-D thickness. Heitzman(11) mentioned that as the ratio of particle diameter to film thickness gets smaller, the impact of converting the surface area from a shell to plane surface increases. Therefore, the computed 2-D film thickness is significantly larger than the 3-D binder shell thickness.

2.3 Virtual model

Heitzman(11) rearranged Radovskiy’ s approach(10) to account for the 3-D volume of each particle and for the spatial relationship between particles in the mixture. This was originally derived by Lu and Torquato(12), and introduced for concrete materials by Garboczi and Bentz(13). This theoretical particle distribution is based on spheres. The spatial relationship can account for differences in air voids of the mixtures. However, this model has the primary restriction that it cannot account for different particle shapes. Equation to calculate the film thickness of the virtual model is originally as follows:

$$Va = (1 - Vs)\exp\left[-(a_1 t + a_2 t^2 + a_3 t^3)\right] \quad (4)$$

where, Va = air voids, Vs = (1-VMA)(1-Vext), volume fraction of aggregate having diameter greater than t, Vext = volume fraction of aggregate having diameter smaller than t, t = film thickness, a_1, a_2, a_3 = coefficients. This can be modified for convenience.

$$a_1 t + a_2 t^2 + a_3 t^3 = \ln\left(\frac{1 - Vs}{Va}\right) \quad (5)$$

Coefficients a_1, a_2 and a_3 are :

$$a_1 = 6q\frac{m_2}{m_3} \quad (6)$$

$$a_2 = 12q\frac{m_1}{m_3} + 18q^2\frac{m_2^2}{m_3^2} \quad (7)$$

$$a_3 = 8q\frac{1}{m_3} + 24q^2\frac{m_1 m_2}{m_3^2} + 16q^3\frac{m_2^3}{m_3^3} \quad (8)$$

where $q = Vs/(1\text{-}Vs)$, m_1 = the mean diameter of the aggregate particles, m_2 = the mean of diameter squared, and m_3 = the mean of diameter cubed:

$$m_1 = \sum\left(\frac{D_{(n-1)} + D_{(n)}}{2} \times \frac{Ns_{(n)}}{\sum Ns_{(n)(i)}}\right) \quad (9)$$

$$m_2 = \sum\left[\left(\frac{D_{(n-1)} + D_{(n)}}{2}\right)^2 \times \frac{Ns_{(n)}}{\sum Ns_{(n)(i)}}\right] \quad (10)$$

$$m_3 = \sum\left[\left(\frac{D_{(n-1)} + D_{(n)}}{2}\right)^3 \times \frac{Ns_{(n)}}{\sum Ns_{(n)(i)}}\right] \quad (11)$$

where, $Ns_{(i)(n)}$=number of aggregate particle from the i^{th} source retained on the n^{th} sieve:

$$Ns_{(n)(i)} = \frac{\dfrac{Pc_{(i)}}{100} \times \left(\dfrac{\dfrac{PsD_{(i)(n-1)} - Ps_{(i)(n)}}{2}}{Gsb_{(i)}}\right)}{\dfrac{\pi \times \left(\dfrac{D_{(n-1)} + D_{(n)}}{2}\right)^3}{6}} \quad (12)$$

Once the coefficients (a_1, a_2, and a_3) are determined in terms of the particle moments (m_1, m_2, and m_3), the average shell film thickness, t is calculated by using Equation 5. Note that the total percent binder is based on total mixture weight, and the percent binder absorbed is based on total aggregate weight.

2.4 Modified virtual model

As mentioned before, although the index model account for different particle shapes, it does not account for different compaction levels (i.e., air voids). On the other hand, the virtual model can account for the latter, not for the former one. To take advantages from both models, the modified virtual model is proposed. The purpose of the modified model accounts for particle shape factors within the virtual model.

The modified shape factor is inserted into the particle moment coefficients. The surface area is a quadratic function, and the volume is a cubic function of diameter. Therefore, to get the similar effect with the shape factors from the index model (Equation 2), a square root of surface area factor per the unit cubic root of volume factor are added to Equations 9 to 12 to calculate the average diameter of the particle. Since the surface area and volume factors were derived from the representative surface area and volume for each particle shape, these factors are directly used instead of using the surface area and volume themselves. One example of equations is rearranged as below:

$$m^3 = \sum\left[\left(\frac{\sqrt{SAF_{(i)(n)}}}{\sqrt[3]{VF_{(i)(n)}}} \times \frac{D_{(n-1)} + D_{n)}}{2}\right)^3 \times \frac{Ns_{(n)}}{\sum Ns_{(n)(i)}}\right] \quad (13)$$

The new particle moments (m_1, m_2, and m_3) were substituted into Equations 6 to 8, and then the film thickness from the modified virtual model is calculated from Equation 5. Kandhal et al.(9) applied sphericity coefficients for irregular shape particles to calculate surface area: coefficient 1 for sphere, 0.806 for cube, and 0.874 for cylinder. Sphericity values relate the surface area of the non-spherical shape to a spherical shape on the basis that both particles have equal volume. If comparing between the modified shape factors and sphericity coefficients, a spherical shape factor 0.806 for cube is slightly more cubed than cube 3:1 for the modified shape factor in this study, and a spherical shape factor 0.874 for cylinder is slightly more cylindrical than sphere 3:1 for the modified shape factor.

3. Parametric Study for Different Models

From the previous and this research, four models were proposed. Although Heitzman(11) did some sensitivity study of the standard, index, and virtual model, the sensitivity analysis for all of them including the modified virtual model are presented because a different mixture is used and also has possibility to show a little different trend.

3.1 Variation of specific gravity of aggregate

First of all, to address the sensitivity of the specific gravity of aggregates, five specific gravities from 2.3 to 2.7 were applied to each model. FL-Good gradation and mixture which will be introduced later were used for the basic mixture. Figure 1 shows that film thickness increases as the specific gravity increases. This analysis is based on the assumption that all other variables are fixed except for the specific gravity of aggregates. Although the index model and virtual model account for the specific gravity of aggregate, in fact, the surface area calculation of the standard model does not consider of it. However, Figure 1 shows that the standard model also increases, because the specific gravity is already considered to calculate the effective binder content which is one of variables in the standard model. Generally the index model estimated more *FT* than the standard and virtual models. The difference between the index and virtual models increases as the specific gravity increases, because the index model accounts for 2-D plane surface instead of 3-D in the virtual model. As the specific gravity increases, the result shows that the virtual model may be showing the less FT than the standard. However, since this result is based on the fixed variables (i.e., Gmm, *Pb*) except for the specific gravity of aggregates and not from measured values, some of them shows the minus asphalt binder absorption that is not possible. To reduce these effects, a new *Pbe* and *Pb* are calculated from the revised mixture properties in Equations 14 and 15.

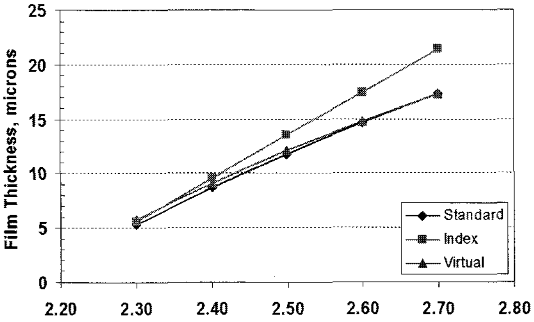

Figure 1. Sensitivity of FT to aggregate specific gravity.

$$Pbe_{(i)} = \frac{Pbe_{(0)}}{\left(\frac{(1-Pbe_{(0)}}{Gbe_{(0)}} \times Gsb_{(0)}\right) + Pbe_{(0)}} \qquad (14)$$

$$Pb_{(i)} = Pbe_{(i)} \times \frac{Pb_{(0)}}{Pbe_{(0)}} \qquad (15)$$

Figure 2 presents the result after applying the new *Pb* and *Pbe* from Equation 14 and 15. All models show that film thicknesses decrease as the specific gravity (*Gsb*) of aggregate increases. Heitzman(11) reported that the index model shows the same film thickness for different *Gsb*, although the standard model decreases as *Gsb* increases. Because he applied different surface area factors as part of the calculation for the index model as *Gsb* changes. Therefore, using fixed surface area factors, the new *Pb* and Pbe are reduced as *Gsb* increases on the equal material volume basis and film thickness decreases. The virtual model exhibits more sensitive than others. Since it accounts for 3-D, changes in *Gsb* directly affect to shell film thickness of aggregates. This is the one of possibility that the conventional film thickness may be overestimated(10). The modified virtual model should follow the virtual model with the shape factor 1:1 in Figure 2 and 3.

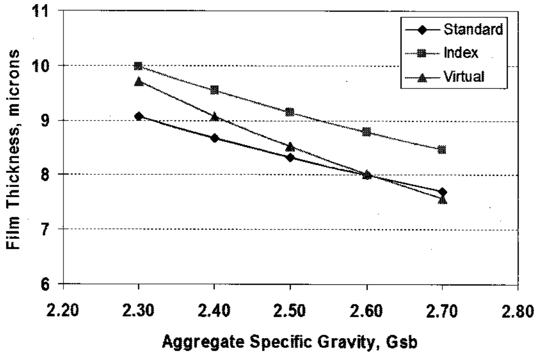

Figure 2. Sensitivity of FT to aggregate specific gravity on equal material volume basis.

3.2 Variation of particle shape

As defined earlier, the standard model and virtual model do not account for aggregate shape. However, the index model is able to account for the shape factor by its nature. The advantage of the modified virtual model is the ability to account for particle shape with 3-D model. Figure 3 presents film thicknesses for all models in terms of different particle shape factors defined in Table 1. For this comparison, only shape factors (*SAF, VF*) were varied in gradation as same as used in the study of *Gsb* variation before. As mentioned before, the standard model and virtual model do not show any changes as varied in shape factors. The index model and modified virtual model exhibit that the film thickness increases as the anisotropy of particle increases. The index model presents that the film thickness of spherical shape particles is higher than cubical shape particles, because a cubical shape needs to have more surface area to achieve the same particle volume. The film thickness within the same shape (sphere or cubic) increases as the anisotropy of particle increases.

However, the modified virtual model shows that the film thickness of cubical shape particles is a little higher than spherical shape particles. Since the virtual model is based on the case of 3-D spherical systems and the radial distribution function(12), the application of cubical shape is not appropriate in terms of the assumption of this model. Therefore, only spherical shape factors can be applied for the modified virtual model. However, spherical shape factors in Table 1 are also based on anisotropy (or elongated) shape of the particle. Therefore, by using Equation 13, the characteristic of anisotropy of the particle is considered as a sphere with the same volume and surface area in Table 1.

However, as the most important issue here is that a

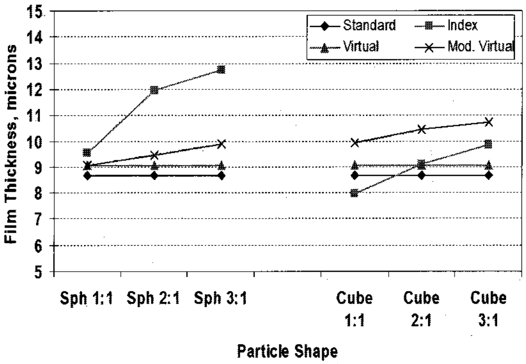

Figure 3. Sensitivity of FT to aggregate shape factors.

shape factor should be selected in order to describe for different types and sources of aggregates. Recently Masad(15, 16) has tried to analyze the form, angularity, and texture of coarse aggregates, and angularity and form of fine aggregates by using the Aggregate Imaging System. This might be very useful to quantify and convert from aggregate characteristics to shape factors for further studies.

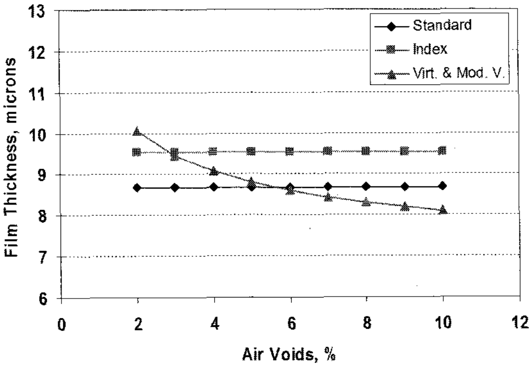

Figure 4. Sensitivity of FT to the degree of compaction.

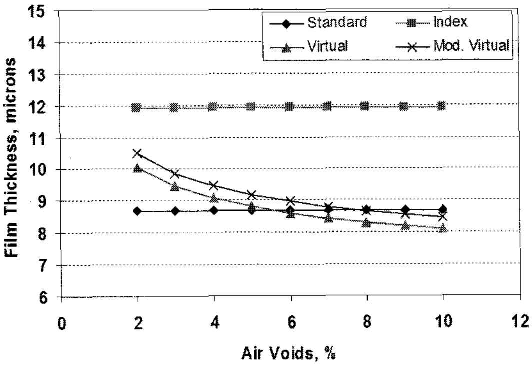

Figure 5. Sensitivity of FT to the degree of compaction with sphere 2:1 shape factor.

3.3 Variation of the degree of compaction

Since the standard model assumed that the sum of the volume of all asphalt films is equal to the total volume of effective binder, asphalt shell in this model may not overlap one another. In addition, the procedure to calculate the film thickness of the index model does not have a variable of air voids. However, throughout the mixing, compaction processes, aggregates are forced closer together. Accordingly, the distance between the nearest surfaces of particles may be much smaller than an average thickness of asphalt shell. The virtual model is able to account for this, and if wanted, the aggregate particles smaller than shell film thickness can be considered to embedded in shell film. In order to calculate Vext, the initial film thickness is assumed to be a certain value and then Vext can be calculated by using Fuller’ s equation and so on(10). Since the detailed gradations of the mineral fillers were not known, the fixed percentage of passing 0.010 mm sieve based on the percent passing of 0.075 mm sieve instead of using Fuller’ s equation.

Based on the design volumetric property of the mixture, air voids was decreased from 4 to 2 percent, and increased from 4 to 10 percent. As expected, the standard and index models do not show any changes in terms of air voids in Figure 4. The virtual and modified virtual model show that the film thickness decreases as air voids increases. Therefore, the virtual and modified virtual model can present the film thickness varying on air voids in terms of different compaction levels(11). It may be explained that decreasing air voids makes the internal air voids pockets more disconnected and the film thickness more increased to resist aging of mixture.

Figure 5 shows that the same sensitivity analysis to Figure 4, but with the shape factor of sphere 2:1. Since the index model accounts for the shape factor, it shows higher film thickness than one for sphere 1:1, but it shows a constant value through out different air voids. However, the modified virtual model presents slightly higher film thickness than the virtual model with changes as air voids changes. Therefore, the modified virtual model accounts for the particle shape and the compaction level in terms of the film thickness.

4. Effect of gradation and performance

In order to know the effect of gradation on the film thickness, four gradations for each aggregate source (Florida limestone and Georgia granite) were prepared and tested for laboratory performance. Gradations were designed by the Dominant Aggregate Size Rage (DASR) porosity concept for two gradations (FL-2-Bad, FL-3-Bad, and GA-2-Bad, GA-3-Bad) to have bad performance and for other two gradations (FL-Good, FL-48, and GA-Good, GA-48) to have good performance(5). The conceptual meaning of the DASR porosity is that a mixture, which has the DASR porosity below 50% for interactive aggregate sizes based on its gradation and mixture volumetric properties, performs better. To simplify the calculation of the film thickness, JMF and combined *Gsb* were considered instead of multi-gradations and *Gsb*' s for each aggregate source. All gradations were fine-graded 12.5 nominal maximum aggregate size (NMAS) mixtures.

Figure 6 shows film thicknesses based on different methods compared to the DASR porosity for different mixtures. Because of different sensitivities of each method, they showed different values as well as ranges of film thicknesses. For the standard model, mixtures having porosity below 50%, which may perform better, were positioned between 8 and 9 microns of film thickness. This confirms the NCAT study that recommended an asphalt film thickness of at least 8 microns in order to ensure mixture durability(9). However, two mixtures of standard model performed badly, even though the film thicknesses were located between 8 and 9 microns of film thickness. For the index model, most of them were spread out from 9 to over 11 microns. The modified virtual model presented that all mixtures with porosity below 50% were within from 8.6 to 9.8 microns except for one which is FL-3-Bad. It had performed worse than FL-G and FL-48, but not so bad such as GA-2-Bad and GA-3 Bad. Therefore, the modified virtual model seems to be the best model in terms of the DASR porosity analysis. It should be noted that all model used sphere 1:1 of shape factors to simplify the cases.

Table 2. Designed volumetric information.

Gradation	AC (%)	G_{mm}	G_{sb}
FL-2-Bad	5.2	2.336	2.413
FL-3-Bad	7.2	2.306	2.425
FL-48	6.5	2.324	2.408
FL-Good	6.6	2.311	2.400
GA-2-Bad	4.7	2.553	2.745
GA-3-Bad	4.7	2.561	2.746
GA-48	4.6	2.578	2.758
GA-Good	4.8	2.579	2.770

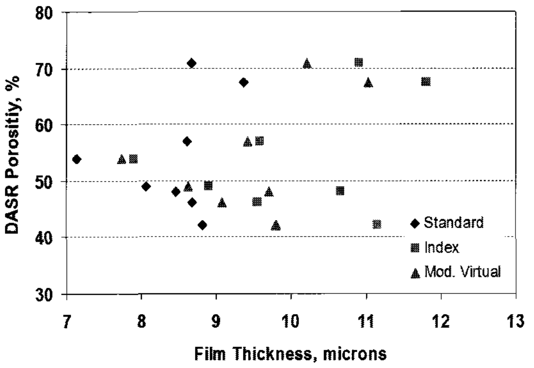

Figure 6. Film thicknesses vs. DASR porosity for designed mixtures.

The Superpave indirect tension test (IDT) was used to evaluate the mixtures' resistance to cracking(17, 18). Instead of the creep compliance itself, the creep compliance rate which is supposed to present the damage rate was plotted with the film thickness in

Figure 7. The standard model shows that lower rate mixtures had 8 to 9 micron of film thicknesses. However, the modified virtual model exhibited better relationship between the creep compliance rate and the film thickness. The minimum creep compliance rate occurs at about 9 microns of film thickness. It increases as the film thickness below 9 microns decreases, and also as the film thickness above 9 microns increases.

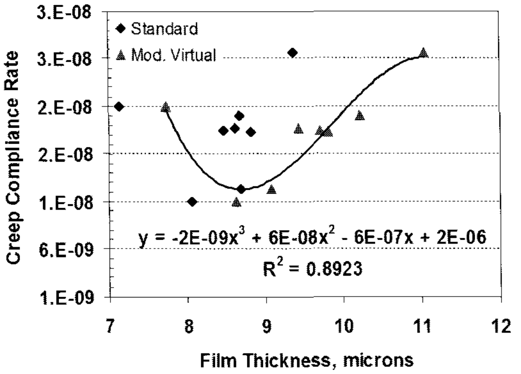

Figure 7. Creep compliance rate compared to Film thicknesses.

The energy ratio*(ER)*, which is defined as the dissipated creep strain energy*(DCSE)* threshold of a material*(DCSEf)* divided by the minimum *DCSE* (*DCSEmin*) needed, is calculated from IDT results as follows⁽¹⁹⁾.

$$ER = \frac{DCSE_f}{DCSE_{\min}} \tag{16}$$

The $DCSE_{\min}$ is a function of material properties and the pavement structure.

$$DCSE_{\min} = \frac{m^{2.98} D_1}{A} \tag{17}$$

where, *m* and D_1 are the creep compliance power law parameters. Parameter "*A*" accounts for the tensile stresses in the pavement structure and the tensile strength of the material.

$$A = 0.0299 \times \sigma^{-3.10}(6.36 - S_t) + 2.{}^{8}46 \times 10 \tag{18}$$

where, σ is the applied tensile stress, *St* is the tensile strength.

Therefore, *ER* can be calculated directly once the creep compliance parameter (*m*-value and *D1*), and also tensile stress and tensile strength are known. For this comparison, tensile stress was assumed to be same as 150 psi.

Figure 8 presented the *ER* result which reflects the creep compliance rate as well as *DCSE* of the mixture. Although the *ER* did not show the good relationship, it may be enough to state that the modified virtual model has higher *ER* values between 9 to 10 microns of film thickness, while the standard model has higher *ER* between film thickness 8 to 9 microns.

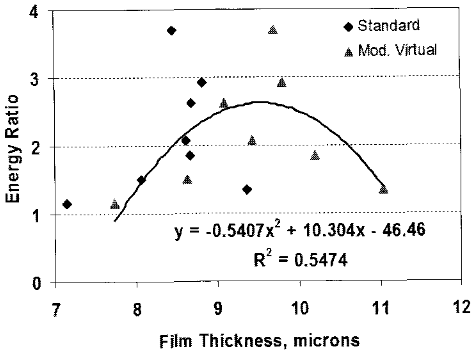

Figure 8. Energy ratio compared to Film thicknesses.

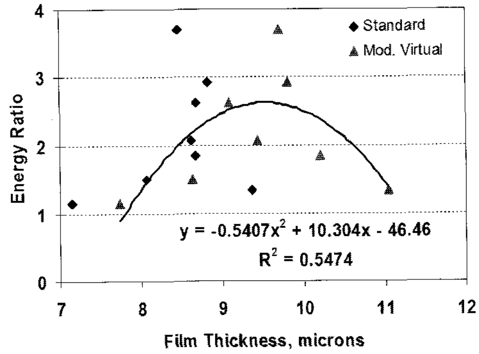

Figure 9. Differential rut depth compared to Film thicknesses.

In order to evaluate rutting performance, the asphalt pavement analyzer (APA) test was simulated. The final profiles were measured by the new measurement system (contour gauge) developed by Drakos(20). The new measurement system was implemented to record the entire surface profile of the specimen. Figure 9 shows the relationship between rut depth from APA test and film thicknesses from the standard and modified virtual models. Although mixtures with film thickness between 8 to 9 microns from the standard model shows large variation in APA result, for the modified virtual model, film thicknesses of mixtures with lower rut depth were around 9 microns. Therefore, it is confirmed that more film thickness might have more rutting.

5. SUMMARY AND CONCLUSIONS

Many researches have addressed the importance of the film thickness in terms of the asphalt mixture performance and durability, and recommended it as a good substitute or supplement for VMA or other volumetric criteria in the design procedure. However, the conventional calculation method for the film thickness has been questionable to address to be an effective property, specifically in terms of the surface area calculation.

Recently some researches have introduced new concepts to calculate the film thickness. Heitzman(11) has summarized the standard method, which is the conventional method, and developed the index model. The virtual method was introduced to asphalt materials by Radovskiy(10). The index model accounts for different particle shape factors, and the virtual model accounts for different air voids on 3-D surface of particles. In this paper, the virtual model was modified to overcome its shortcoming that it cannot account for particle shape factors. The modified virtual model developed here is successfully able to account for particle shape factors as well as air voids of a mixture. However, in order to apply the new model to real aggregates, the correspondence between aggregate characteristics such as texture, angularity, and elongation, and particle shape factors is required.

Based on the film thickness of different methods, several mixtures designed by the DASR porosity concept were explored in terms of the laboratory performance and mixture properties. In general, the modified virtual model presented better relationship between the film thickness and the mixture performance. For creep compliance rate, the minimum value has about 9 microns of film thickness. The better mixtures in terms of the *ER* have film thicknesses between 9 and 10 microns. According to APA test, a mixture with about 9 microns of film thickness showed better rutting performance. As expected, a mixture with lower film thickness has less rutting in APA test. Since film thicknesses from the standard model were not varied much and most of them had 8 to 9 microns of film thickness, it was difficult to distinguish between mixtures that showed different performance.

In conclusion, the modified virtual model is more valuable in terms of taking the advantages from both the index model and the virtual model. The further research is required to specify the aggregate shape factors. The modified virtual model, which is the same as the virtual model with sphere 1:1 of shape factor, was compared to the standard model in terms of the laboratory test results. The modified virtual model is able to distinguish better performance mixtures by the film thickness.

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접 수 일 : 2007. 2. 22
심 사 일 : 2007. 2. 22
심사완료일 : 2007. 3. 6