An Approach to Characterization of High Temperature Deformation Resistance of Asphalt Concretes using S_D and FCWT

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Abstract: A test technique for characterizing strength of asphalt concrete against compressive and shear deformation was developed using a uni-axial static loading at high temperature (60°C). Considering a tire with a circular imprint, standing on the hot asphalt pavement, the round edge and flat bottom create shear stress and compressive stress, respectively. A loading head, which has round edge and flat bottom center, was used to apply a vertical (uni-axial) static load on top center of a bitumen mixture specimen to create dimple-shape depression before failure at 60°C. The property obtained in this test is the strength against deformation, or the deformation strength designated as "S_D," under the compressive and shearing combined pressure. The S_D showed high correlation with the well-known rut testing results, such as wheel tracking test and asphalt pavement analyzer (APA) test. The R^2 values between S_D and the rut depths of the WT or APA at 60°C were observed from 0.77 to 0.95 or higher. This paper introduces the test procedure and shows characteristics of S_D in relation to the field rut performance of the asphalt materials based on the results of the field-circular wheel tracker (FCWT), a simple accelerated loading facility in actual field condition. Results indicated that the S_D, with the limited FCWT works, is an engineering property providing a reasonable estimation of the rut potential of asphalt mixtures at high temperatures, even though it is measured by static loading test at 60°C.

KEY WORDS: Asphalt pavement, rutting, deformation strength, APA, FCWT, Kim Test

1 ITRODUCTION

The most pronounced distress of asphalt pavement is rutting and resistance of asphalt mixture against rutting is not easy to estimate by a simple laboratory test. There are several static strength tests for asphalt mixtures, and those include Marshall Stability (MS), Hveem stabilometer value (ASTM D1560), indirect tensile strength (ITS), compressive strength (ASTM D1074), immersion compressive strength (ASTM D1075), etc. Most of these test procedures are relatively simple; however, the measured properties are known to have a little correlation with rut resistance in the pavement (Li 2001).

Several studies were made on this issue to recommend the simple performance test (SPT) for permanent deformation estimation of bitumen mixtures (Witzack et al. 2002, Hafez 1997). Their recommendations are not acknowledged as legitimate procedures due to lack of correlation with rut performance. Therefore, there is a need for developing a simple strength test method that can measure an engineering property of asphalt mixture for estimating rut resistance in laboratory.

Rather, the rut potential is evaluated by repeated loading tests, such as wheel tracking

(WT), asphalt pavement analyzer (APA) and, in a larger scale, accelerated loading facility (ALF) (Kandhal and Cooley 2003, Skoke et al. 2002, Brown and Gibb 1996, Sosnovske et al 1994, Bonaquist 1998, Stuart and Mogawer 1997). A field-simulated circular wheel tracker (FCWT) was developed as a semi ALF (Kim et al. 2006). Even though those are well-established techniques, their equipments are expensive and some procedures are rather complex to follow.

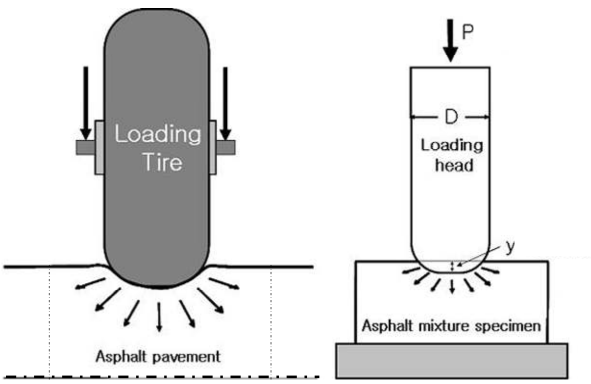
If the deformation of a limited area where the load is directly contacted is properly measured in accordance with the applied load on a bitumen mixture at high temperature, a strength value measured thereby will give better correlation with rutting parameters. Based on this hypothesis, a new approach for measuring deformation resistance of asphalt concrete is introduced in this paper. To take the deformation into consideration for strength calculation, the peak load and the deformation at the peak are measured in this approach. A strength value is calculated using the developed equation and designated as “deformation strength” or “$S_{D,}$” and the test procedure is called “Kim Test.” The objective of this study is to evaluate the correlation of S_D with rut parameters of FCWT test and to show feasibility of the developed approaches as tools for estimating rut tendency of asphalt mixes.

2 DEFORMATION STRENGTH

When a wheel, which has a circular tire imprint, is standing on asphalt pavement, mainly the circular spot underneath the imprint will have to suffer the stress which is effective in a limited area (Figure 1). The resistance against this spot stress will be bearing strength of the mixture in the limited area. In this case, the immediate surrounding body behaves as a confining barrier of shear movement. Therefore, instead of applying load to the whole cross sectional area, a load application to the limited area (Figure 1 (b)), will be more appropriate for simulation of this situation.

Adopting this hypothesis, a static load was applied at the top center of specimen as shown in Figure 1 (b). However, because the imprint of wheel is not flat, a round edge loading head was used to create a dimple on the specimen at a high temperature, i.e., 60°C. The resistance against this dimple is not simply bearing strength, but is called deformation strength (Kim et al 2002a,b,c, Kim et al 2004, Doh et al. 2007, Kim et al. 2008, Kim et al 2010].

Figure 2 shows a 2-D state of stresses by an S_D test, in which the loading head contacts the mixture in a dimple-shape deformation resembling a bowl. The depth of this bowl is y at the peak load P as shown in a load-deformation curve obtained from a test as shown in Figure 3.



(a) (b)

Figure 1. Schematics of (a) tire loading and (b) loading head for S_D test.

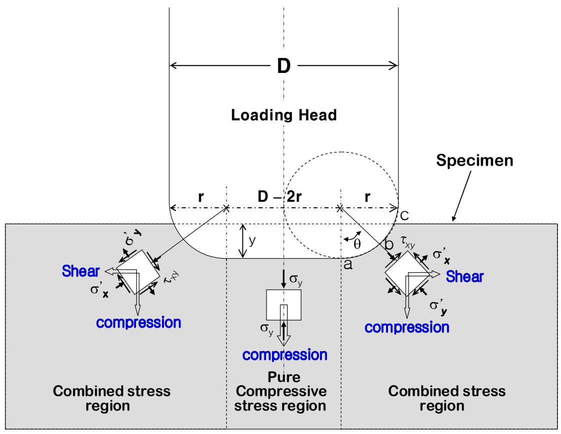


Figure 2. States of stresses in a specimen under pressure through a loading head.

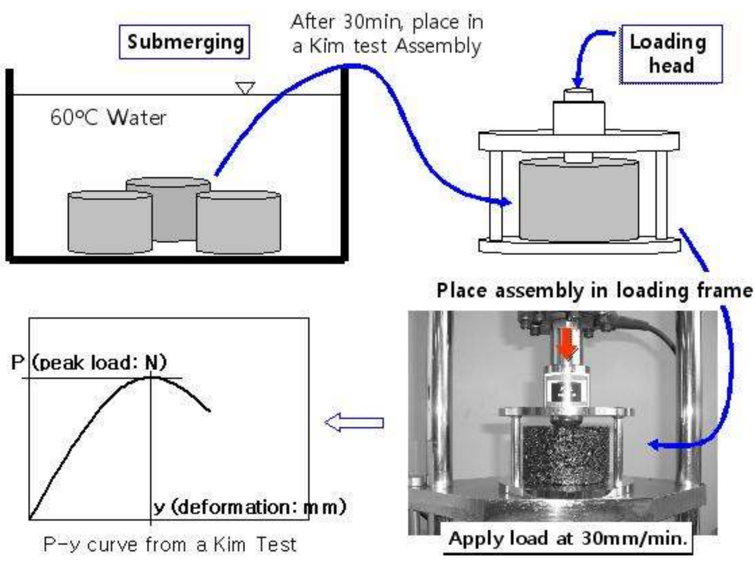


Figure 3. Kim Test procedure for measuring S_D.

The S_D was calculated by dividing P by the dimple area projected to the surface, i.e. $S_D = P/(D-2r+2x)^2/4$, where $A = (D-2r+2x)^2/4$. The loading head diameter (D) and radius (r) of round edge were found to be important variables in sensitivity analysis of S_D and optimum values of D and r were determined as 40㎜ and 10㎜, respectively. Since x is a function of r and y, and D=40 and r=10, the A becomes $\pi[D-2(r-\sqrt{2ry-y^2})]^2/4$ = $\pi[10+\sqrt{20y-y^2})]^2$, making S_D,

$$S_D = \frac{0.32P}{[10+\sqrt{20y-y^2})]^2} \quad (1),$$

where, S_D = deformation strength in pressure unit (MPa), P = maximum load (N) at failure, y = vertical deformation (㎜) for $y < r$. For $y \geq r$, then $y = r = 10$.

A tire wheel loading induces compressive and shear stresses which are considered to be the primary cause of rutting on the asphalt pavement (Brown, S. F. and Gibb 1996). When a two-dimensional stress condition is considered, the shear stress is created by the round edge of tire and the vertical compressive stress is induced by the flat bottom when a load is applied through a tire to the heated asphalt mixture. When a load is applied using a steel round-edged loading head with a diameter of D and radius of r for round bottom edge (Figure 2), similarly, the shear stress is induced by the round edge and the compressive stress by the flat bottom.

If the deformation which is induced by the shear and compression is measured and properly integrated into calculation of an engineering property, the property will be an analogy of the material's endurance level against rutting (Kim et al 2002a,b,c, Kim et al 2004, Doh et al. 2007, Kim et al 2010). Therefore, the S_D test uses a loading head which has a round edge and flat bottom face at the center. Applying a load through this loading head, the stress region in a specimen is divided into two groups as shown in two-dimensional stress states in Figure 2. The stress underneath the flat face is in pure compressive stress (normal stress σ_y) state, and the stress in the areas other than the flat bottom is in a combined stress state (shear stress, τ'_{xy}, and normal stresses, σ'_x, and σ'_y).

3 EXPERIMENTAL PROGRAMS

3.1 Materials

Two maximum size aggregates and four binders were used to prepare the dense-graded asphalt mixtures. The aggregate gradation is dense grade, and the four binders include a base asphalt of penetration grade of 60-80 or PG 64-22 (AP5), a PG 76-22 (PG76) and two laboratory-blended modified binders. A recycled low-density polyethylene (RLDPE) and a CRM (crumb rubber modifier) were used for modified binder. The content of each material, selected based on earlier studies (Kim et al. 2004, Kim et al. 2002d), are shown in Table 1. A total of 8 mixtures (2 aggregates x 4 binders) were prepared by Korean mix-design guide with a target air void of 4 % for surface course mixtures using 75 gyrations using a Superpave Gyratory Compactor (SGC).

Table 1. Description of binders used in this study

Abbreviation	AP5[a]	R10	RL6	PG76	Note
Modifying Materials	None	CRM [b]	Recycled LDPE	SBS	
Content (%) by wt. of binder	0	10	6	3	

Note: [a]: pen 60-80 control, [b]: Crumb rubber modifier.

3.2 Kim Test and FCWT Test

It is recommended to prepare the specimen for S_D using a SGC rather than Marshall Compactor. Cored specimens both from a laboratory-made slab and from an existing asphalt pavement are acceptable for S_D test as long as the top and bottom surfaces are flat. The specimen of 100 ㎜ in diameter and 63 ㎜ in height is prepared with air void of 4% using a gyratory compactor.

To apply a vertical load through the loading head precisely at the center of the specimen, the mold (Figure 4) was developed. The specimen is submerged into water at 60℃ for 30 minutes, and then removed before being placed on a loading frame in which a load is applied at the speed of 30㎜/min. A load and deformation curve, as shown in Figure 3, was obtained and the peak load P and the vertical deformation y at P were read and S_D was calculated by Equation (1) for each specimen.

For the purpose of comparison of the S_D data with field rut data, a field-simulated circular wheel tracker (FCWT) was developed as shown in Figure 5 (Kim et al 2006). Each of four mixtures was placed in 2 sites in 8 faces of hexagon, facing each other in opposite site, as shown in Figure 6. Approximately 172kg of each mixture was used to place in two sites at the depth of 50㎜ using roller compactor. A lab pug mill mixer was used to mix 86kg of hot-mix asphalt mixture in one batch.

One period of test run 72 hours, 4-5 hours per day during hot summer day time. The test for 13㎜ aggregate mixture run in June and the test for 19㎜ run in July. The surface temperature of the site was 53°C on the average. FCWT running started at 11:00am when the surface temperature reaches near 50°C and ended 4:00pm. The running speed of FCWT was 9rpm to simulate approximately 5km/hr of wheel speed.

Rut depth was measured every hour while the wheel was stopped. Three specimens were made from randomly collected sample of each mixture during the paving day. Three cores were taken from each site near wheel path after finishing test. Kim Test was performed to measure S_D of sampled-mixture specimens and cored specimens.

Figure 4. Kim Test mold.

Figure 5. Field-simulated circular wheel tracker

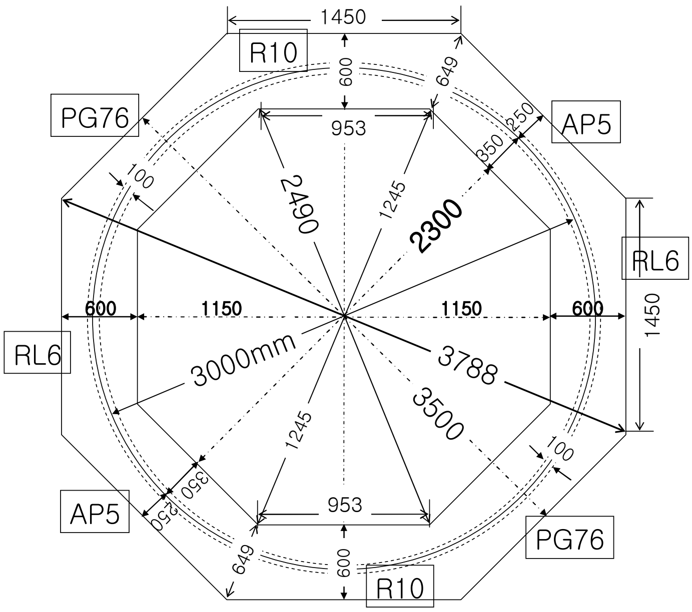


Figure 6. Dimension and arrangement of mixtures in FCWT site

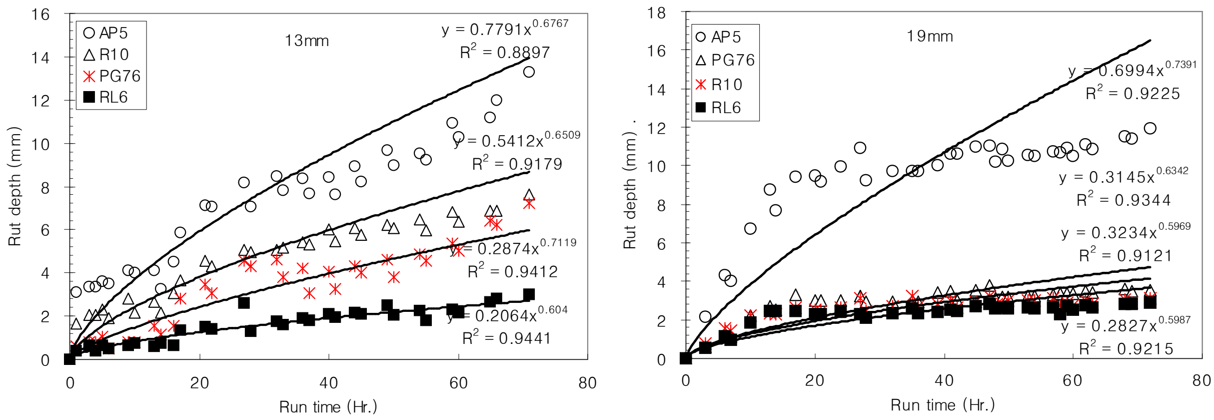
4 RESULTS AND DISCUSSIONS

4.1 Material Testing Results

Table 2 shows the S_D data for each mixture and the mixture rut-performance data from FCWT for two size aggregate mixtures. In general, lab-made specimens showed higher deformation strength (S_D) values than those of cored specimens, suggesting that there must be less compaction and some damage during coring process. In general, 19 ㎜ aggregate mixtures showed somewhat higher S_D and shallow FCWT rut depth, indicating that the mixture with higher S_D shows shallower rut depth in FCWT test.

Table 2. Kim Test for lab-prepared specimen and cored specimen and FCWT test results

Max agg. size	Mixture of granite agg.	Lab specimen		Cored specimen		FCWT final Rut depth (㎜)
		Air void (%)	S_D (MPa)	Air void (%)	S_D (MPa)	
13 ㎜	AP5	4.02	3.21	8.73	1.929	13.29
	R10	3.79	3.48	7.50	2.773	7.60
	PG76	4.13	4.25	8.43	3.154	7.02
	RL6	3.88	4.65	7.62	2.807	3.01
	Mean	3.96	3.90	8.07	2.84	7.74
19 ㎜	AP5	4.05	3.286	6.97	2.809	11.96
	PG76	3.90	4.419	6.55	4.297	3.54
	R10	4.51	3.986	5.84	3.297	3.15
	RL6	4.57	4.074	5.73	3.635	2.86
	Mean	4.26	3.94	5.38	3.48	5.38



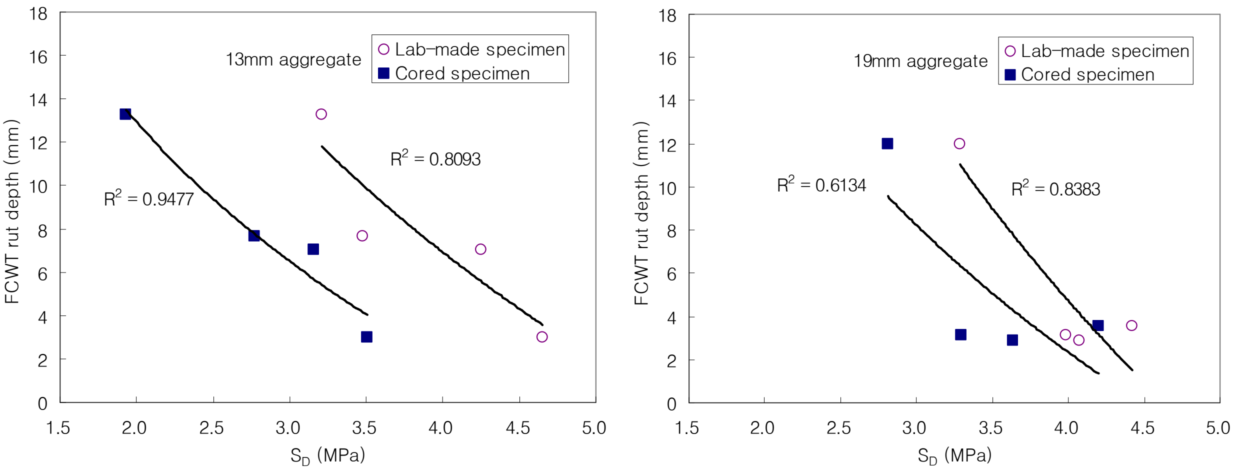
(a) (b)

Figure 7. FCWT test results for granite mixtures for (a) 13㎜ and (b) 19㎜

4.2 Correlation Analyses

For further investigation, regression analyses were performed on the FCWT rutting data and the S_D data to see if any significant correlation exists between two properties. Since the mean S_D of lab-made specimens is significantly higher than that of cored specimens, two data were dealt separately.

FCWT rut data were used for the dependent variable and the S_D value of each binder as the independent variable in the regression model. The best-fit regression curves for 13㎜ and 19㎜ mixtures by specimen type is shown in Figures 8. Coefficient of determination values (R^2 values) are ranged from 0.61 to 0.94. Since R^2 value is 0.8021 on the average, it is possible to state that S_D is a property which is highly related with rut resistance of the asphalt mixtures. Adopting this test for estimating rutting of asphalt mixtures, it is possible to take advantage of simplicity of procedure, affordability of equipment and saving of time. The S_D was adopted as one of the standard variables in Korean asphalt mix-design guide in 2009 (Guide… 2009) and tentatively used together with Marshall Stability.



(a) (b)

Figure 8. Relationship of rut depth by FCWT and S_D for (a) 13 ㎜ mixture and (b) 19 ㎜ mixture

5 CONCLUSIONS

This study is an attempt to use a static strength test for estimation of permanent deformation of asphalt mixture. The important observation from this study is that the mixture with higher deformation strength (S_D) exhibited lower rut depth in field-simulated circular wheel tracking (FCWT) test, with considerably high R^2 values ($R^2 > 0.80$). This result suggested that the S_D be the strength property controlled by mixture's resistance against rutting. Since, such a high correlation was found in regression analysis, it is concluded that S_D can be characterized as an engineering property which has high relation to permanent deformation of asphalt mixture. The S_D test can possibly be considered as a procedure for estimating the rutting potential of asphalt mixtures.

A possibility of using S_D as a tool of predicting rut potential is very high as shown in this study. However, it has shown good correlation of rut potential of dense-grade asphalt mixtures only. The S_D was adopted as a standard variable for asphalt mix-design criteria of dense-graded asphalt mixtures in Korea in 2009.

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