HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 39(2) pp. 195-199 (2011)

PERFORMANCE EVALUATION OF BITUMENS AT HIGH TEMPERATURE WITH MULTIPLE STRESS CREEP RECOVERY TEST

K. ADORJÁNYI, P. FÜLEKI

István Széchenyi University, Department of Transport Infrastructure and Municipal Engineering
9026 Győr Egyetem tér 1, HUNGARY
E-mail: adorjany@sze.hu
E-mail: fulekip@sze.hu

The paper evaluates performance properties of paving grade, hard and modified binders with multiple stress creep and recovery tests (MSCR) at +60 °C. The dynamic shear rheometer measurements were made on Rolling Thin Film Oven Test aged samples at three stress levels. The delayed viscoelastic response was evaluated with recoverable strain and the resistance to permanent deformation with non-recovered compliance. Close relationship presented between average recoverable strain and non-recoverable compliance at different stress levels. The performance parameters have been compared with specified requirements.

Keywords: bitumen, creep and recovery, dynamic shear rheometer, multiple stress creep and recovery test

Introduction

In the frame of Strategic Highway Research Program (SHRP) Superpave (Superior Performing Asphalt Pavements) which was started in USA in 1987 new performance related properties were defined and related test method were introduced among others for bitumen. The performance behaviour of bitumen was defined with viscoelastic properties measured with dynamic shear rheometer. The resistance to permanent deformation at high temperatures was specified with parameter $G^*/\sin\delta$ (complex shear modulus/sin (phase angle)). Later it has been shown by several authors that this parameter was not always adequate with performance in the road pavement especially in case of modified bitumen. During revision of binder Superpave specification for replacing this parameter the Multiple Stress Creep Recovery Test (MSCR) has been developed by D'Angelo at al [2]. This test method has been introduced as AASHTO TP 70-2 test method, and the MSCR parameters were used for binder M 320-09 binder specification [1, 3]. The paper discusses the application of MSCR measurements for evaluation of typical binders used in road pavement construction in Hungary and compares the obtained parameters with AASHTO Performance-Graded Binder Specification.

Laboratory test method

The MSCR tests were performed according to AASHTO TP 70-07 specification, with DSR at 0.1 kPa, 3.2 kPa and 6.4 kPa stress levels on 25 mm diameter specimen and 1 mm gap at temperature of +60°C on RTFOT aged samples. At each stress level 10 cycles were applied with 1 s creep phase and 9 s recovery phase. The strain was measured at 0.1 s steps, and there was no relaxation time between stress levels. The samples were tested through 3x10 cycles at three stress levels the time (t), shear stress (τ) and shear strain (γ), were recorded and the non-recoverable creep compliance (J_{nr}) was calculated. The delayed viscoelastic response of the binder was evaluated with recoverable strain and the permanent deformation with non-recoverable compliance [1, 2]. The adjusted strain at the end of creep phase of each cycle:

$$\gamma_1 = \gamma_c - \gamma_0, \tag{1}$$

where:

γ_1 – the adjusted strain value at the end of creep phase of each cycle, (t=1 s),

γ_0 – the strain value at the start of creep phase of each cycle, (t=0 s),

γ_c – the strain value at the end of creep phase of each cycle, (t=1 s).

The recoverable strain at each cycle is:

$$\gamma_{rec} = 100\cdot(\gamma_1 - \gamma_{10})/\gamma_1, \quad (2)$$

where:

γ_{rec} – the recoverable strain at each cycle,

γ_{10} – the adjusted unrecovered strain value at the end of recovery phase of each cycle (t=10 s) can be given as:

$$\gamma_{10} = \gamma_r - \gamma_0, \quad (3)$$

where:

γ_r – the strain value at the end of recovery phase of each cycle (t=10 s).

Substituting (1) and (3) into (2) the percent recovery at each cycle can be expressed as

$$\gamma_{rec} = 100\cdot(\gamma_c - \gamma_r)/(\gamma_c - \gamma_0). \quad (4)$$

The average percent recovery for ten cycles at stress level of τ is

$$\bar{\gamma}_{rec}(\tau) = \frac{1}{10}\cdot\sum_{1}^{10}\gamma_{rec}(\tau) \;. \quad (5)$$

where:

$\gamma_{rec}(\tau)$ – the recoverable strain at each cycle at τ stress level.

The percent difference in recovery between two given stress levels ($\tau_1<\tau_2$) is

$$\Delta\bar{\gamma}_{rec}\% = \frac{100}{\bar{\gamma}_{rec}(\tau_1)}\cdot\left[\bar{\gamma}_{rec}(\tau_1) - \bar{\gamma}_{rec}(\tau_2)\right] \quad (6)$$

Fig. 1 illustrates the definitions of strains at each cycle.

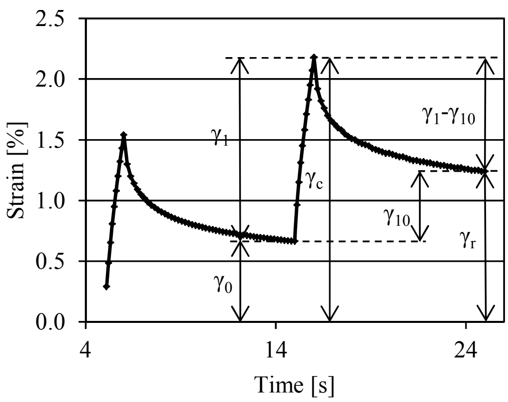

Figure 1: Strain diagram of creep and recovery

The assessment of permanent deformation was made with average non-recoverable compliance, at stress levels of τ=0.1 kPa, 3.2 kPa and 6.4 kPa as follows:

$$\overline{J_{nr}}(\tau) = \overline{\gamma_{10}}(\tau)/\tau \;. \quad (7)$$

Percent differences in average non-recoverable compliance between 0.1 kPa and 6.4 kPa, 0.1 kPa and 3.2 kPa, 3.2 kPa and 6.4 kPa were calculated as

$$\Delta\overline{J_{nr}}\%(\tau_1 - \tau_2) = 100\cdot[\overline{J_{nr}}(\tau_1) - \overline{J_{nr}}(\tau_2)]/\overline{J_{nr}}(\tau_1) \;. \quad (8)$$

Tested binders

For performing MSCR tests 6 different types of bitumens were used which are typically applied in Hungary in hot asphalt mix production. The bitumen types as well as values of needle penetration, ring and ball (R&B) softening point measured on pure samples are given in *Table 1.* The number in brackets after the bitumen type sign refers to sample number of bitumen.

Table 1: Types, penetration and softening point values of tested bitumens

Bitumen type	Penetration at 25°C, 0.1 mm	R&B softening point, °C
Hard B 15 (3)	17	70.5
Polymer modified PmB 10/40-65	24	67.0
Polymer modified PmB 25/55-65	48	66.2
Paving grade B 35/50 (2)	35	56.0
Paving grade B 50/70 (3)	56	51.0
Paving grade B 50/70 (4)	60	48.8

Discussion of test results

For each of three stress levels the average percent of recovery of ten cycles was determined according to AASHTO TP 70-07. *Fig. 2* demonstrates that the paving grade bitumen shows considerable larger creep strain and lower recovery than the modified bitumen.

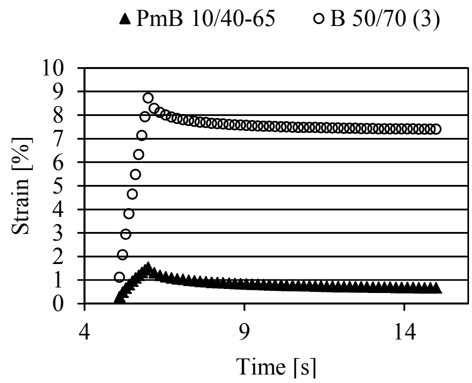

Figure 2: Plot of creep and recovery phase of paving grade bitumen B 50/70 (3) and modified bitumen PmB 10/40-65 at 1st cycle of 0.1 kPa stress level

The rate of strain value increases and shows change at the start of each stress level. For paving grade bitumen B 50/70 (4) most part of the strain (13500%) was developed at the largest stress level (6.4 kPa) over 315 s test duration (see *Fig. 3*).

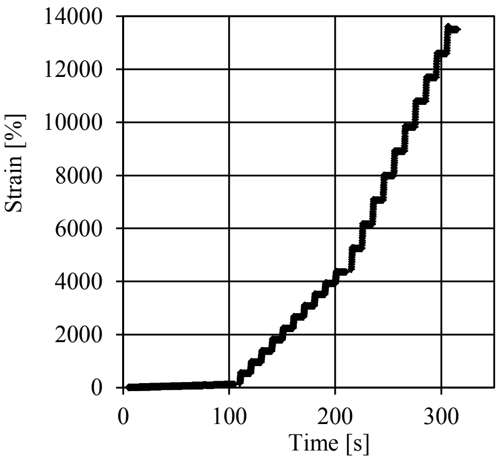

Figure 3: Strain value versus time for bitumen B 50/70 (4) during whole test

While the average recoverable strain of PmB 10/40-65 modified bitumen and of hard B 15 (3) bitumen doesn't depend on the stress level, binders with higher penetration show lower recoverable strains. The distinction between two B 50/70 binders can also be detected here where the differences in recoverable strains are 40–50% depending on stress levels (*Fig. 4*).

The plot of average unrecovered strain determined from ten cycles for each stress level is illustrated on *Fig. 5*. The lowest values of average unrecovered strains have the hard bitumen B 15 (3) and the PmB 10/40-65, while B 35/50 (2) and PmB 25/55-65 binders show almost the same values. Despite the same penetration grade the two B 50/70 binders coming from different distilleries show difference in average unrecovered strains.

Percent difference in recovery was calculated by (6) between three stress levels as:

$\Delta\overline{\gamma}_{rec}'$ – percent difference recovery at 0.1 kPa and 3.2 kPa stress levels,

$\Delta\overline{\gamma}_{rec}''$ – percent difference recovery at 0.1 kPa and 6.4 kPa stress levels,

$\Delta\overline{\gamma}_{rec}'''$ – percent difference recovery at 3.2 kPa and 6.4 kPa stress levels (Table 1).

Table 2 and *Table 3* summarize the percent differences in recoveries and the non-recoverable compliances for different stress levels.

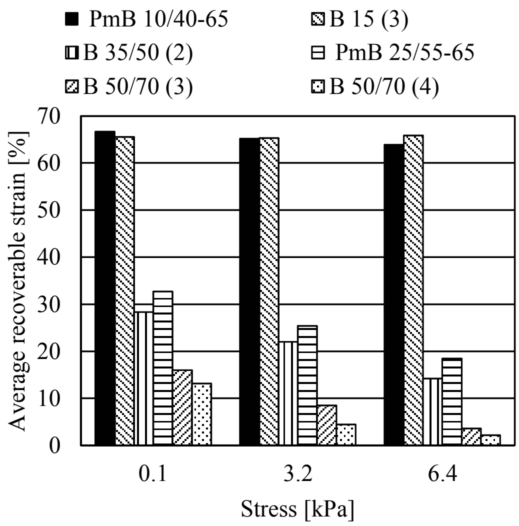

Figure 4: Average recoverable strains of different binders depending on stress levels

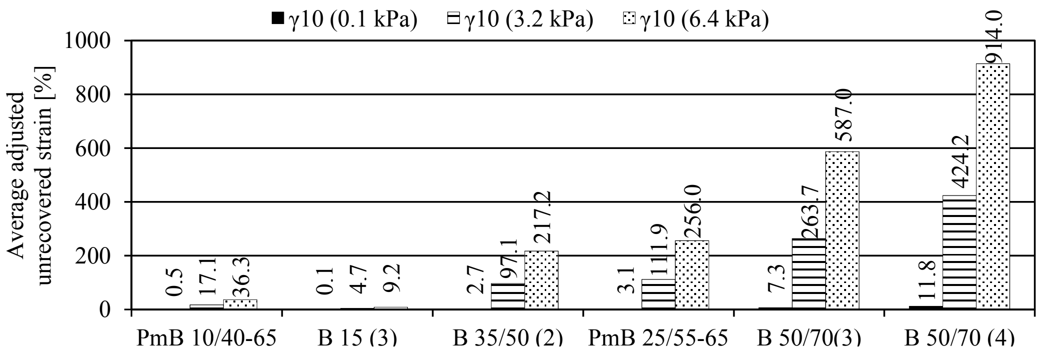

Figure 5: Adjusted average unrecovered strains at 0.1-3.2-6.4 kPa stress levels of different binders

The non-recoverable compliance depicted on *Fig. 6* shows very well the sensitivity of binders to permanent deformation under repeated loads.

The diagram on Fig. 6 illustrates that binders with lower penetration (B 15 (3), PmB 10/40-65) have lower values of non-recoverable compliance irrespectively of being polymer modified or not.

Low values of differences in recoveries of PmB 25/55-65 and B 15 (3) indicate the low stress sensitivity of these binders having lower penetration *(Fig. 7).* The PmB 25/55-65 shows almost the same parameter values as paving grade B 35/50 (2) bitumen.

Percents difference in non-recoverable compliance illustrated on *Fig. 8*. The calculated differences with stress combinations τ_1=0.1 kPa and τ_2=3.2 kPa or τ_1=3.2 kPa and τ_2=6.4 kPa don't show significant deviation between hard bitumen and modified bitumens. Percent difference of hard bitumen B 15 (3) presented negative values which needs further investigation.

Table 2: Percent difference in recovery and non-recoverable compliance [1/kPa] of hard bitumen and modified binders

Sample	PmB 10/40-65	B 15 (3)	PmB 25/55-65
$\Delta\gamma_{rec}'$	2.22	0.37	22.36
$\Delta\gamma_{rec}''$	4.23	-0.46	43.53
$\Delta\gamma_{rec}'''$	2.05	-0.83	27.27
$J_{nr}(0.1)$	0.051	0.015	0.306
$J_{nr}(3.2)$	0.053	0.015	0.350
$J_{nr}(6.4)$	0.057	0.014	0.400

Table 3: Percent difference in recovery and non-recoverable compliance [1/kPa] of paving grade binders

Sample	B 35/50 (2)	B 50/70 (3)	B 50/70 (4)
$\Delta\gamma_{rec}'$	22.38	46.99	65.97
$\Delta\gamma_{rec}''$	49.90	77.46	83.42
$\Delta\gamma_{rec}'''$	35.45	57.48	51.29
$J_{nr}(0.1)$	0.274	0.730	1.180
$J_{nr}(3.2)$	0.303	0.824	1.326
$J_{nr}(6.4)$	0.339	0.917	1.428

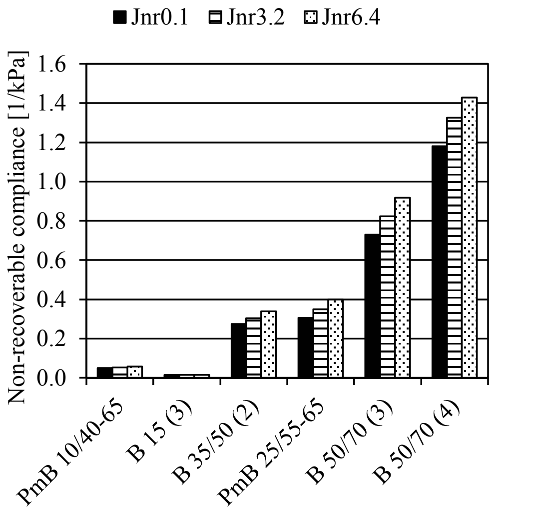

Figure 6: Diagram of non-recoverable compliance for different binders depending on stress levels

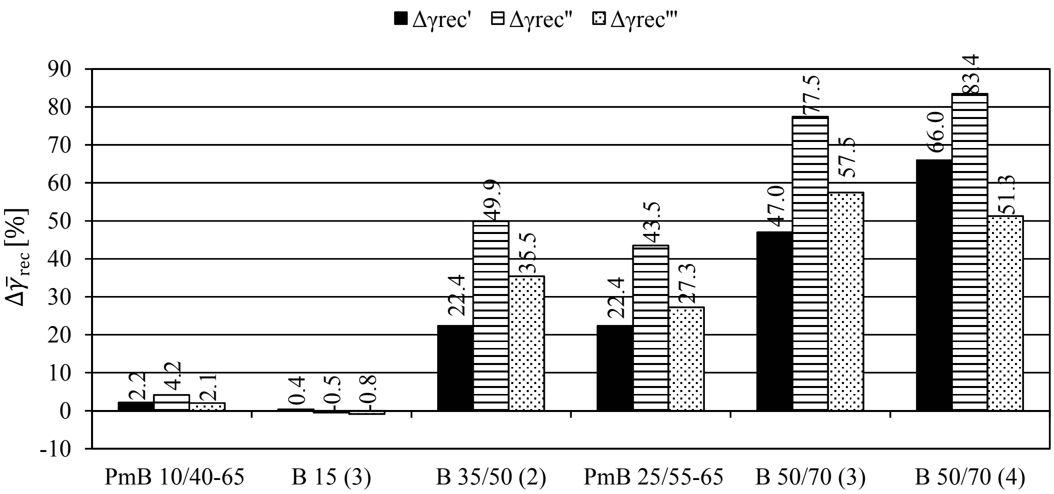

Figure 7: Percent difference in recoveries of different binders depending on stress levels

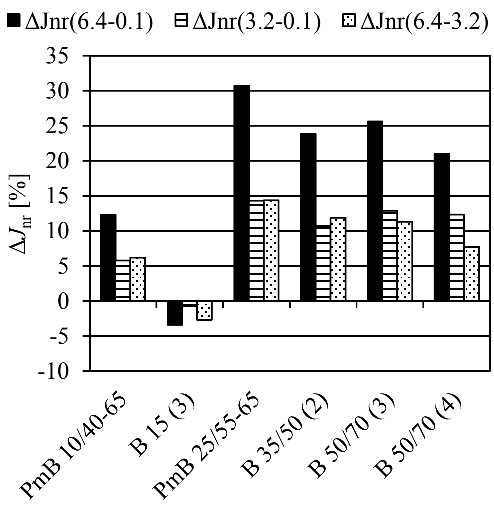

Figure 8: Percent difference in non-recoverable compliance of different binders depending on stress level

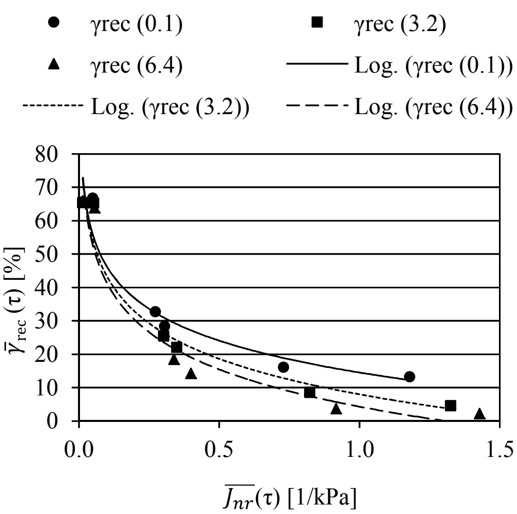

Figure 9: Average recoverable strains versus average non-recoverable compliance for different binders

Fig. 9 shows the close relationship between average recoverable strain and average non-recoverable compliance for three stress levels of 0.1 kPa, 3.2 kPa and 6.4 kPa. The regression equations with good correlation coefficients for stress level of 0.1 kPa (R^2=0.934) are as the following:

$$\bar{\gamma}_{rec} = 14.524 - 13.776 \cdot ln(\overline{J_{nr0.1}}), \quad (9)$$

for stress level of 3.2 kPa (R^2=0.941):

$$\bar{\gamma}_{rec} = 7.985 - 15.371 \cdot ln(\overline{J_{nr3.2}}), \quad (10)$$

for stress level of 6.4 kPa (R^2=0.935):

$$\bar{\gamma}_{rec} = 4.301 - 16.102 \cdot ln(\overline{J_{nr6.4}}). \quad (11)$$

Comparison with AASHTO Standard Specification

The performance of binders is evaluated in this section obtained with MSCR test data. In AASHTO (American Association of State Highway and Transportation Officials) "Standard Specification for Performance – Graded Asphalt Binder M 320-09" the non-recoverable compliance and percent difference in compliance are specified as performance parameters. The comparison was made for very heavy traffic level. The stress sensitivity parameter was determined as:

$$\Delta\overline{J_{nr}}\%(3.2-0.1) = 100 \cdot [\overline{J_{nr}}(3.2) - \overline{J_{nr}}(0.1)] / \overline{J_{nr}}(0.1). \quad (12)$$

Table 4: Conformity of different binders for heavy traffic with AASHTO M320-09 Specification

Traffic level	Very heavy
Specified J_{nr} (3.2)	<1.0
Specified percent difference ΔJ_{nr}(3.2-0.1), %	75
Type of binder	J_{nr}(3.2) at 60°C
50/70 (3)	0.303
50/70 (4)	0.824
PmB 25/55-65	0.35
PmB 10/40-65	0.053
B 35/50	0.303
B 15(3)	0.015
Type of binder	ΔJ_{nr}(3.2-0.1) at 60°C
50/70 (3)	11.4
50/70 (4)	11.0
PmB 25/55-65	12.5
PmB 10/40-65	5.5
B 35/50	9.66
B 15(3)	-0.72

If this ratio is greater than 75% then the bitumen is considered stress sensitive and doesn't satisfy the requirement. The non-recoverable compliance J_{nr}(3.2), shall be below 1.0 [1/kPa]. Table 4 contains the specified values and the derived parameters of binders from MSCR test. The cited specified values were taken for PG 64 grade bitumen. However the tests were performed at +60°C because this temperature is specified for wheel tracking test of hot asphalt mixes in Hungary. Being aware of this difference it can be regarded that the tested binders meet the specification requirements.

Conclusions

The MSCR test is appropriate for evaluation of elastic and unrecoverable response of paving grade and polymer modified binders. Six different binders were selected in penetration range 10–70 and the MSCR test was performed on RTFOT residues using dynamic shear rheometer at +60 °C. The MSCR test can reveal distinction between same penetration grade binders coming from different producers.

Among six tested binders the B15 (3) hard bitumen has the best MSCR performance.

Percent difference of non-recoverable compliance for stress combinations (3.2-0.1) kPa and (6.4-3.2) kPa show no significant deviation for hard bitumen and polymer modified bitumens. There is a significant deviation between non-recoverable compliance differences at different stress combinations for 50/70 paving grade binders.

Close regression relationship has been found between average recoverable strain and non-recoverable compliance with good correlation coefficients R^2=0.934–0.941.

The tested binder parameters meet the AASHTO M320-09 specification requirements for PG 64 grade binder.

REFERENCES

1. Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR), AASHTO Designation: TP 70-07
2. J. D'Angelo, R. Kluttz, R. Dongré, K. Stephens, L. Zanzotto: Revision of the Superpave High Temperature Binder Specification: The Multiple Stress Creep Recovery Test. Journal of AAPT 76, (2007), 123–162
3. Standard Specification for Performance-Graded Asphalt Binder, AASHTO designation: M320-09