MSCRT: PERFORMANCE RELATED TEST METHOD FOR RUTTING PREDICTION OF ASPHALT MIXTURES FROM BINDER RHEOLOGICAL CHARACTERISTICS

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ABSTRACT

Rutting is one of the main damages of pavement particularly in view of the constant increase in traffic intensity and loadings. For this key issue the bituminous binder of the asphalt mix plays an important role. So that the demand for a binder characteristic that would allow predicting the mixture behavior has received considerable attention in the recent past.
The current binder rheological characteristics G and δ are measured in the linear range. But the rutting is the plastic deformation of an asphalt mix caused by heavy traffic loads under low speed. This is a high strain failure in the pavement and leads to a non-linear response. So multiple stress testing is needed to describe the binder properties in the non-linear range.*
Following the development in the USA the standardized multiple stress creep recovery test (MSCRT) is claimed to better capture the prediction of rutting.
This paper presents a study on the rutting resistance of several mixtures and the corresponding binders. Relations between the behavior of mixtures and binders are discussed through the use of the different analysis methods of penetration, softening point, DSR (G, δ), MSCRT and the French wheel-tracking test for the mixtures.*
The MSCRT appears as a good candidate to predict the rutting of asphalt mixes in measuring high temperature properties of binders, in particularly for modified binders.

Keywords: rutting, bitumen, mixtures, rheology, MSCRT

1. INTRODUCTION

Rutting is one of the main damages of a pavement particularly in view of the constant increase in traffic intensity and loadings. This key issue to long term pavement performance has long been admitted to depend on the asphalt mix design of the surface layer, particularly the aggregate skeleton. However the bituminous binder used to stick the aggregates together is also of prime importance.
The wish for a binder property that would allow predicting the mixture behavior, all other asphalt parameters constant, has received considerable attention in the recent past. Following the Strategic Highway Research Program in the USA in the 90's, several rheological parameters were proposed as predictors of binder rutting potential, from simple measurements of binder modulus and phase lag, to complex concepts like low or zero shear viscosities [1, 2]. Most of these standardized indicators have in common to be assessed in the linear range.
Although, recent studies [3] displayed good correlations between binder low shear viscosity related parameters with asphalt mixture rutting data, others [4] showed how difficult this parameter determination is in case of PmB's. Moreover, limitations of these rheological criteria measured in the linear range were identified [5]. They fail to accurately predict the rutting behavior of modified mixtures from binder lab characterization due to the fact that rutting is caused by an accumulation of irreversible deformation or permanent deformation in the pavement layers under repeated traffic load [6].
Hence, rutting is the plastic deformation of an asphalt mix caused by heavy traffic loads under low speed at high service temperature. This is a high strain failure in the pavement, leading to a non-linear response of the binder used in the surface course asphalt mix. Whereas for simple materials like pure bitumens the test response is only slightly influenced by the type of stress polymer modified binders responses are very much stress or strain dependant. US developments [7, 8] have considered multiple stresses testing to describe binder properties in the non-linear range, by using the multiple stress creep recovery test (MSCRT). This test is based on repeated creep and recovery sequences, conducted at different stress levels measured in a dynamic shear rheometer. Claimed to better capture the benefit of binder modification, the non recoverable compliance measured by MSCRT at the upper pavement temperature was proposed lately as a potential specification criterion [9, 10] to replace the parameter $G^*/\sin\delta$.

This paper relates two studies about abilities of different tests to assess for permanent deformation resistance. The first one compares binder characteristics expected to relate to rutting and the actual rutting resistance of several mixtures made out of the corresponding binders from a wide variety of origins. Indeed, it confirms the potential of MSCRT to correlate with wheel-tracking mixture tests (WTT). Influences of binder nature, grade, and polymer modification are addressed, clearly showing the benefit in terms of rutting resistance of some modified binders, crosslinked ones particularly, and some special binders. Some of this study was presented elsewhere [11]. The second one deals specifically with MSCRT and softening point. It warns the reader about the pernicious effect of looking for binders with always higher softening points.

2. EXPERIMENTAL

2.2. Testing procedures

Binder properties including penetration at 25°C (EN 1426), ring and ball softening point (EN 1427), and $G^*/\sin\delta$, the rheological stiffness parameter used in the Superpave binder specifications, measured at 60°C (EN 14770) after RTFOT (EN 12607-1) aging were analyzed.

MSCRT was carried out in a dynamic shear rheometer using 25 mm parallel plate geometry with a 1 mm gap. AASHTO standard [12] was followed with some variations regarding stress levels and temperature. Temperature was different for the 2 studies but stress were the same, using a constant stress creep of 1 s followed by a zero stress recovery of 9 s, repeated ten times, at 11 stress levels ranging from 25 to 25600 Pa, instead of only 100 and 3200 Pa. High stress levels were chosen to evaluate the behavior of the bituminous binders due to the fixed temperature of 60 °C. The measurement must be done in linear and non-linear range for soft and hard grade bitumen at this given temperature. At each stress level, the ten cycles were applied with no rest period. Out of the various MSCRT parameters, this paper focuses on the non-recoverable compliance Jnr, the non-recovered strain at the end of the recovery part of the test divided by the initial stress applied during the creep. Jnr value is calculated by equation (1):

$$Jnr = \gamma_u/\tau \qquad (1)$$

Where γ_u is the average non-recovered strain and τ the stress applied during creep (Figure 1).

The higher the Jnr, the lower the resistance to deformation induced by MSCRT at different stress levels; therefore low Jnr means high resistance to permanent deformation.

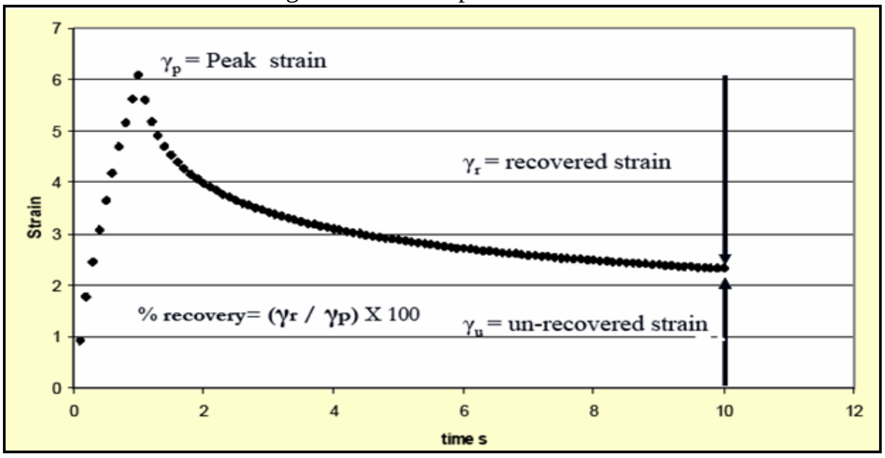


Figure 1: Principle of the binder creep and recovery response

Asphalt mixes were made using a diorite type aggregate from the French quarry “La Noubleau” to design standardized asphalt concrete EB 10 for wearing course (EN 13108-1). Optimized for rutting resistance, they fit in the third class with a rut depth less than 5% after 30000 cycles at 60°C in the French wheel tracking rutting test. Asphalt concretes were laboratory mixed (EN 12697-35), and then compacted using the French roller compactor (EN 12697-33) to produce 500x180x100 mm slabs with 7.2% air void content and 5.7 w/w% binder content.

Wheel tracking tests were run using the French LCPC rut tester according to EN 12697-22 (large size device). The tests were performed at 60 °C temperature, 1 sec^{-1} frequency and a 500 daN rubber tire load. Rut depth profiles expressed in %, were measured from 100 to 30000 passes.

3. FORMER STUDY @ 60°C: CORRELATION BETWEEN JNR AND FRENCH RUTTING

3.1 Materials

Seven polymer modified, one special and eight neat bitumens were used in this study to cover the main binder types used in European markets for paving applications.

The used neat binders include 1 bitumen 70/100, 4 different 35/50 grades, 2 bitumens 20/30 and 1 hard grade 10/20. The PmB’s are commercial grades industrially produced according to the Styrelf® dynamic crosslinking process, as presented in multiple patents. Their elastomer content ranges from 2 to 5 %. Following EN 14023 grading, the used PmB’s noted A through G were PmB 25-55/55 (A), PmB 45-80/55 (B), PmB 25-55/65 (C and D), PmB 10-40/70 (F), PmB 10-40/65 (E and G). The special grade bitumen is a 40 pen Multigrade produced by blending different refining bases, according to the Ornital® proprietary formulation from Total designed for anti-rutting characteristics.

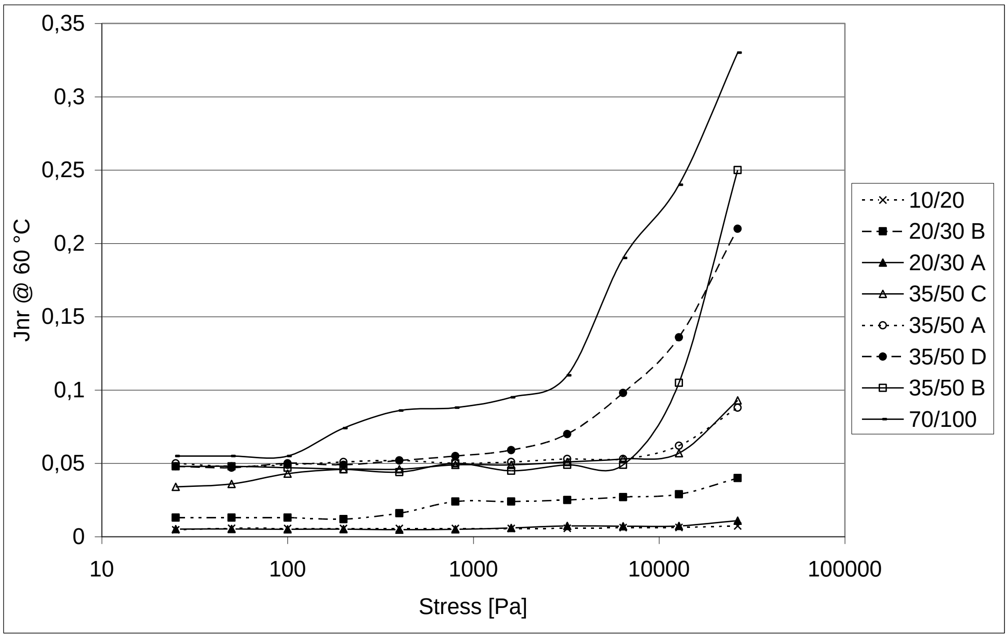
MSCRT was carried out on RTFOT aged binders in a dynamic shear rheometer using 25 mm parallel plate geometry with a 1 mm gap. AASHTO standard [12] was followed with some variations regarding stress levels and temperature. Thus, the test was run at 60°C, the WTT temperature, instead of the PG grade upper limit. The binders were short term aged to mimic the oxidation effect during mixing in the asphalt plant.

3.1 Binder results

MSCR test shows the binder stress dependence as in Figure 2a and b. The binder compliance remains fairly constant at low stress level whereas at high stress level, above around 3200 Pa the binder resistance to deformation starts to decrease as the non recoverable compliance sharply raises; the higher the stress level, the more stress sensitive the binder. Differences in binder responses depend on binder grade, origin and production process.

In case of polymer modified binders (Figure 2b), Jnr values are generally very low (below 0.1) and their sensitivity to stress starts at higher stress level, above 6400 Pa.

This stress dependency is somewhat different than presented earlier [9] because of the lower testing temperature inhere inducing higher creep deformation resistance to the binders.



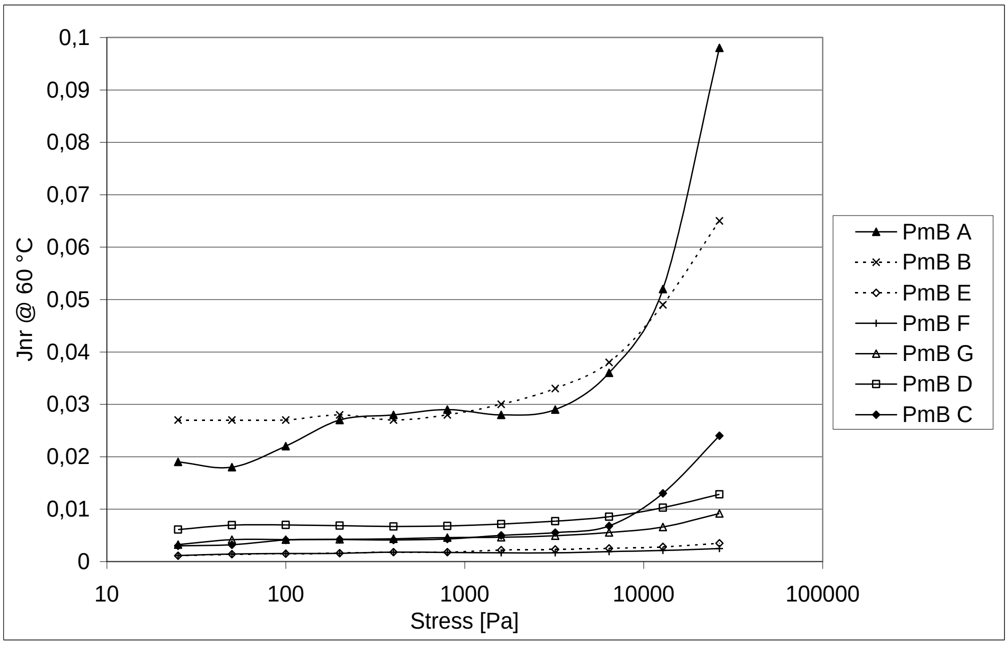


Figure 2: Jnr values at several stress levels for pure binders (2a) and PmB's (2b)

As presented elsewhere [11] binders with the same penetration grade but different compositions and production routes behave differently. Thus the special grade behaves similarly to PmB C and D until 6400 Pa stress. As the applied stress continues to grow, the PmB becomes somewhat less stress susceptible. Contrarily, the unmodified binder 35/50 A always remains at a higher Jnr level, clearly differentiated from the other binders. MSCRT does show the benefit of PmB's and multigrade bitumen resistance to plastic deformation. Overall Jnr better differentiates binder properties.

Looking more systematically at the comparison between the classical properties and Jnr at several stress levels for all binders as in Table 1, one can find no correlation even with the characteristics measured at the same 60°C temperature like the modulus G* and the phase angle δ. Trends slightly improve at higher stress.

Table 1: Correlation coefficients R^2 of binder parameters with Jnr values at various stresses

Jnr at stress	Softening point	Penetration	G*/sinδ	G*	δ
25600	0,7459	0,4645	0,4511	0,5242	0,5698
12800	0,7824	0,5722	0,5508	0,6309	0,5717
6400	0,7727	0,5801	0,5801	0,6564	0,6005
3200	0,7722	0,5433	0,5919	0,6814	0,3756
800	0,4756	0,4501	0,5388	0,6350	0,1341
100	0,3444	0,3015	0,3804	0,4600	0,0853

3.2 Asphalt rutting results

Binder properties after RTFOT aging were compared to the rutting performances of an asphalt mix. Correlations coefficients (R^2) between classical binder parameters and the rut depth at 30000 cycles from the French wheel tracking test were calculated.
In case of classical properties, R^2 coefficients were very low respectively 0.158 and 0.599 for penetration and softening point. Either the Superpave stiffness parameter G*/sin δ at 60°C with a low 0.272 confirms that this parameter does not work for polymer modified binders.
From a European perspective this study confirms the better softening point prediction power compared to penetration, to eliminate binders susceptible to permanent deformation. However, the low R^2 value indicates the correlation is only a trend.

On the other hand in Table 2, the Jnr values of neat and polymer modified binders at the stress level of 25600 Pa appears to linearly correlate far better to WTT than G*/sin δ and the softening point. The correlation coefficients are stress level related, with trends starting to show up at 3200 Pa. Correlations are more evident at higher stress values above 6400 Pa, when the binders start deviating from their linear behavior (R^2 going as high as 0.90 in a coupe of cases). The dependence on the number of passes is somehow blurred by the fact that the soft binder 70/100 failed in the rut tester before 30000 cycles, other asphalt mixes featuring a good resistance against rutting, below 5 mm rut depth at 30000 cycles. One should not forget also the uncertainties linked to the rut depth determination itself.

Table 2: Correlation coefficients of Jnr values at several stress levels and WTT rut tester

Jnr [Pa-1]	Cycles of French Rutting tester at 60 °C			
	1000	3000	10000	30000
100	0,2186	0,1857	0,1074	0,3604
1600	0,3441	0,3468	0,2925	0,3028
3200	0,6350	0,6374	0,4916	0,4453
6400	0,8498	0,9025	0,8483	0,5674
12800	0,8787	0,9008	0,8050	0,7149
25600	0,8475	0,8059	0,6410	0,7711

4. TEMPERATURE AND STRESS EFFECT

In the previous study, the best correlation with French WTT rut was found to be Jnr-values at 12800 Pa. That particular stress should be representative of the state of stress of the binder during the test. One can see that that particular stress would be higher for a porous asphalt or a lower binder content. However that value will be kept as the reference in the rest of the article.
Also, in the previous study, MSCRT was conducted at 60°C which is the temperature for the French WTT. In the USA, AASHTO MP19 [13] advocates for a different use of the MSCRT. Measurement should be made at 100 and 3200Pa at the actual high pavement temperature with no grade bumping (average 7-day maximum pavement design temperature). A Jnr(@3200Pa) value below 4kPa-1 (resp 2kPa-1 and 1kPa-1) is suitable for standard (resp heavy and very heavy) loading. Also the difference in Jnr values between 100Pa and 3200Pa shear stress should not exceed a ratio of 0.75.
Considering the results of our previous study and the AASHTO MP19, several bitumen were tested at 58, 70 and 82°C. Tests were conducted on binders before any ageing treatment in order to maximize the quantity of tested

references. Since softening point is measured on untreated binder, it is assumed to have no impact on the validity of the conclusions of that study. Jnr-values at 100, 3200 and 12800 Pa are retained to characterize the permanent deformation susceptibility of binders.

At 58°C, data were collected over a panel of 5 pure binders 35/50 and 50/70, 6 crosslinked polymer modified binders and one special binder. Penetrations and softening points are showed in table 3. Two types of modification were used for the PmBs. PMB-1 to PMB-3 have an increasing content of the first polymer modification and PMB-4 to PMB-6 have an increasing content of the second polymer modification. PMB-1 to PMB-3 are specially designed to present high softening points.

Table 3: Penetration and softening point of binders tested at 58°C.

.	35/50				50/70	PMB						Special
	1	2	3	4		1	2	3	4	5	6	
Penetration (dmm)	39	42	41	36	51	41	38	46	36	32	33	31
Softening point (°C)	52	52,2	51,4	53,2	49	62,8	74,6	90	61,4	62,6	67,2	63,6

Considering Jnr-curves in figure 3, 3 categories appear: 50/70 with very high values, PMB and Special with very low values and 35/50 with intermediate values. PMB-4 to PMB-6 present a logical ranking that is the higher the polymer content, the lower the Jnr-value. The same remark can be done for PMB-1 to PMB-3. However, PMB-1 to PMB-3 exhibit discontinuous behaviors regarding stress. Above a critical stress, Jnr-values increase dramatically as if the polymer network was disrupted.

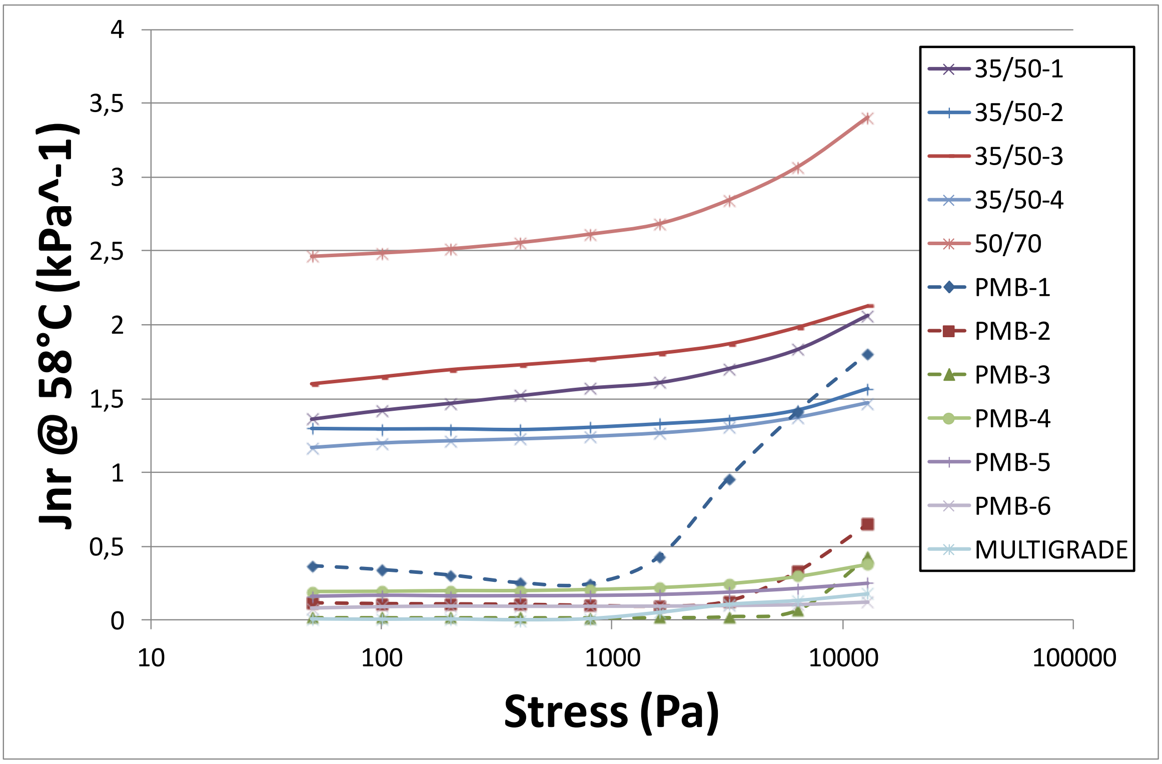


Figure 3: Jnr values at several stress levels for binders tested at 58°C

Plotted in a softening point-Jnr graph represented figure 4, that special behavior leads to a fairly good correlation at 100 and 3200 Pa but not at 12800 Pa, stress at which Jnr correlates the best with the French WTT rut as seen before. PMB-1 to PMB-3 have good resistance to permanent deformation but their high softening points do not provide them extra resistance.

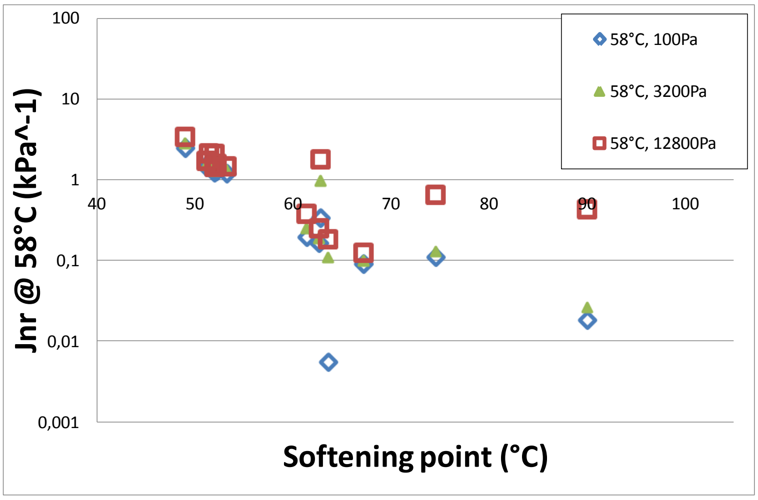


Figure 4: Correlation of softening point with Jnr values at several stress levels for binders tested at 58°C

Since AASHTO MP19 recommends changing temperature depending on road pavement actual temperature, a large panel of bitumen was tested at 70 and 82°C, covering pure, special, polymer/acid/wax modified binder, commercial and lab produced binders. Some of the binder tested at 58 and 70°C could not be tested at 82°C because they were too liquid. Correlation between Jnr- values and softening point are illustrated by figure 5. It seems fairly good for binders with softening point below 70°C at 100, 3200 or 12800Pa. However, binders with high softening point exhibit a marked stress-dependent behavior. Although they resist the best at low stress, they may undergo higher deformation than binder with intermediate softening points at higher stress.

From that test panel, softening point seems to be more correlated to Jnr-values at low stress. This result is different from what was found in paragraph 3.2 because binder type was taken from a wider ranger. It might be interesting to evaluate actual stress undergone by the binder during a softening point test, a rutting test and in the pavement.

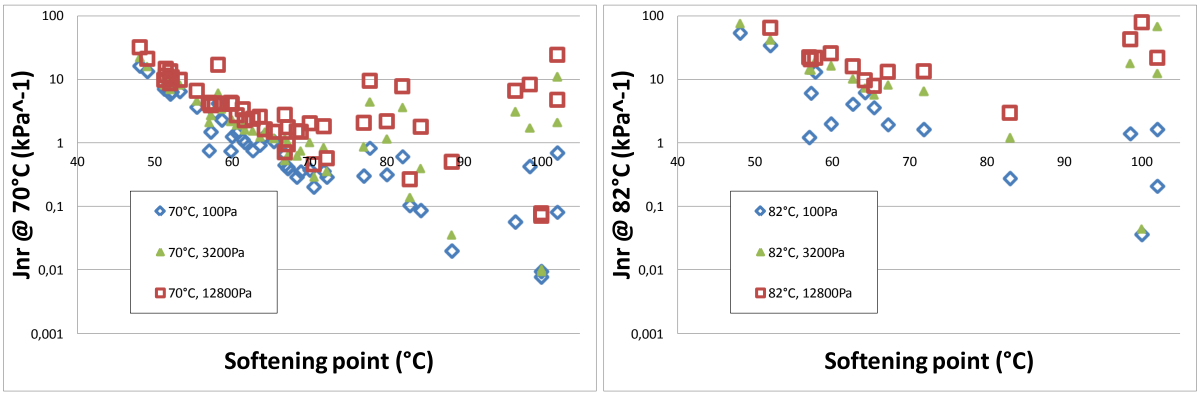


Figure 5: Correlation of softening point with Jnr values at several stress levels for binders tested at 70 and 82°C

5. CONCLUSIONS

Multiple Stress Creep and Recovery Test newly developed in the USA to predict the impact of PmB's on rutting resistance was evaluated in this paper.

The results show that the binder parameter Jnr, the non-recoverable creep compliance determined through MSCRT could be a better alternative than the Superpave G*/sin δ and/or the R&B softening point used in Europe. It better correlates to mix rutting performances evaluated using the French rutting test, even considering mixes showing good rutting performances. On the other hand, no correlation was found between Jnr and usual binder properties. Jnr values clearly differentiate binders, even those having either penetrations, softening points or G*/sin δ in the same range. This criterion characterizing modified as well as neat binders could be used blind with respect to the binder composition.

Carrying out MSCRT at various stress levels showed binder stress dependencies. Rut resistant binders are less stress sensitive, and remain in the linear domain over higher stress levels. It is noteworthy that many of the high softening point binder tested here exhibited high stress dependency. One should be aware that the demand for binders with always higher softening point may lead to the contrary of the desired effect if MSCRT assessment is not performed

Whereas Eurobitume recently stated in its data collection position paper that “simple tests can and should be used for simple binders” and that “for PMB there is a need to measure high temperature properties in a better way than traditional tests allows”, MSCRT appears as a very good candidate to fill up the gap.

Future research would involve testing wider ranges of binders and mixes at various temperatures, looking for optimized parameters, and evaluating MSCRT precision. For instance the stress at which the binder changes from linear to non-linear response at a given temperature could be a good indicator for binder stress sensitivity.

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