European round robin tests for the Multiple Stress Creep Recovery Test and contribution to the development of the European standard test method

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ABSTRACT

In 2011, the task group TG1 of CEN TC336/WG1 was assigned the task to produce a European standard test method for the Multiple Stress Creep Recovery (MSCR) Test. The MSCR test measures non-recoverable creep compliance and percent recovery using DSR and is used to evaluate the sensitivity to permanent deformation of bituminous binders. In 2012, upon completion of the first draft version of the document prEN 16659, TG1 decided to organize a European round robin test, with 4 different binders. This initiative was taken to evaluate and improve the test procedure, to allow laboratories to gain experience with the test method and to determine the precision. Based on the outcome of the statistical analysis and the feedback from the 25 participants, the draft version was revised and a second round robin test was conducted in 2014. The specific purposes of this second round robin test were to expand the precision data to a wider range of binders by testing 7 other binders and to explore alternative test conditions. This paper reports on the outcome of the round robin exercises and the findings, conclusions and recommendations of TG1 towards the implementation in the framework of European binder specifications.

Keywords: Comité Européen de Normalisation, Modified Binders, Performance based standards, Permanent Deformation, Testing

1. INTRODUCTION

In the present European specification framework for polymer modified bitumens (EN 14023), the so called "consistency of the binder at elevated service temperatures" is still characterized by the Ring & Ball softening point, while it is well known that this binder characteristic is only an adequate indicator for resistance to permanent deformation in case of non-modified paving grade bitumens.

There have been attempts to introduce new types of rheological tests to determine bitumen characteristics which are more closely related to the rutting resistance of asphalt. For example, the Equiviscous Temperature (EVT) based on Low Shear Viscosity (LSV) (CEN/TS 15324 [1]) was shown to correlate well with asphalt rutting, when compared to other rheological characteristics, and this for a wide range of bitumens including paving grade and polymer modified bitumens [2]. However, this test remains rarely used. The procedure is rather complicated and time consuming and there is a lack of experience and precision data. Moreover, the principle of the test method is debatable: an oscillation test at very low shear levels does not simulate the true stresses and strains that are experienced by bitumen within an asphalt pavement. When subjected to traffic, pavement stresses are not reversed but repeated, leading to very high accumulated strains. Especially for highly modified bitumens designed for high traffic roads, an oscillatory test at low shear levels is not very representative.

In the US, a new test method called "Multiple Stress Creep Recovery (MSCR) test" was introduced to improve the system of Performance Graded (PG) asphalt binder specifications [3, 4]. The test evaluates the deformation of a bitumen specimen when it is repeatedly loaded and allowed to recover. It is repeated at multiple stress levels, to assess the impact of stress amplitude on permanent deformation. This test is very interesting since the repeated loading/recovery and the high stress levels are more representative of in situ loading by traffic. Moreover, the test procedure [5, 6] is relatively easy and fast compared to many other rheological tests. However, the most important is the evidence of a good correlation with asphalt rutting, which has already been demonstrated by several researchers [3, 9, 10, 11].

Consequently, the task group TG1 of CEN TC 336/WG1 was assigned the task to develop a European standard for the MSCR test. In 2013, this resulted in the first draft of the test method prEN 16659: "Bitumen and Bituminous Binders - Multiple Stress Creep and Recovery Test (MSCRT)" which passed CEN Enquiry with 28 positive votes and 5 abstentions. The many comments received have subsequently been solved by TG1 and implemented in the revised version. In June 2015, CEN TC336/WG1 accepted to launch the Formal Vote procedure.

Besides writing the European standard, TG1 set itself the following goals:

- To evaluate and possibly improve the test method;
- To offer European laboratories the opportunity to gain know-how, improve their practices and contribute to the European standard;
- To determine the precision of the test results.

Precision data are already reported in the ASTM standard [5] based on the test results from eight laboratories for eight binders. Soenen et al [8] also reported precision data of test results from five laboratories for nine binders. However, the interpretation of these data still leaves questions and the values reported may not be representative for the MSCR test as it is described in the European standard prEN 16659 and the level of expertise as it exists today in European laboratories.

Therefore, TG1 invested a lot of effort in the organization of two large round robin tests, one in 2012 and the second in 2014. By involving a high number of laboratories from all over Europe, TG1 aimed to produce more accurate precision data and achieve at the same time the other goals mentioned above. This paper describes these round robin exercises conducted by TG1, the results, the lessons learned and the perspectives of the MSCR test in Europe.

2. THE MSCR TEST

2.1 Principle

The MSCR test is performed using a Dynamic Shear Rheometer (DSR), with parallel plates of 25 mm diameter and a gap of 1 mm. The binder specimen is subjected to series of ten creep/recovery cycles, with a 1 second creep period followed by a 9 seconds recovery period (see figure 1).

Figure 2 shows the first creep recovery/cycle (cycle 1) and the results derived from each individual creep/recovery cycle (cycle N):

- J_{nr}^{N}, the non-recoverable creep compliance, which is the ratio of the non-recovered strain to the applied stress;
- $\%R^{N}$, the percent recovery, which is the ratio in percent of the recovered strain at the end of the recovery period to the strain at the end of the creep period.

Both parameters are averaged over the ten cycles (N=1 to 10) to obtain the results 'J_{nr}' and '%R' at the applied stress level.

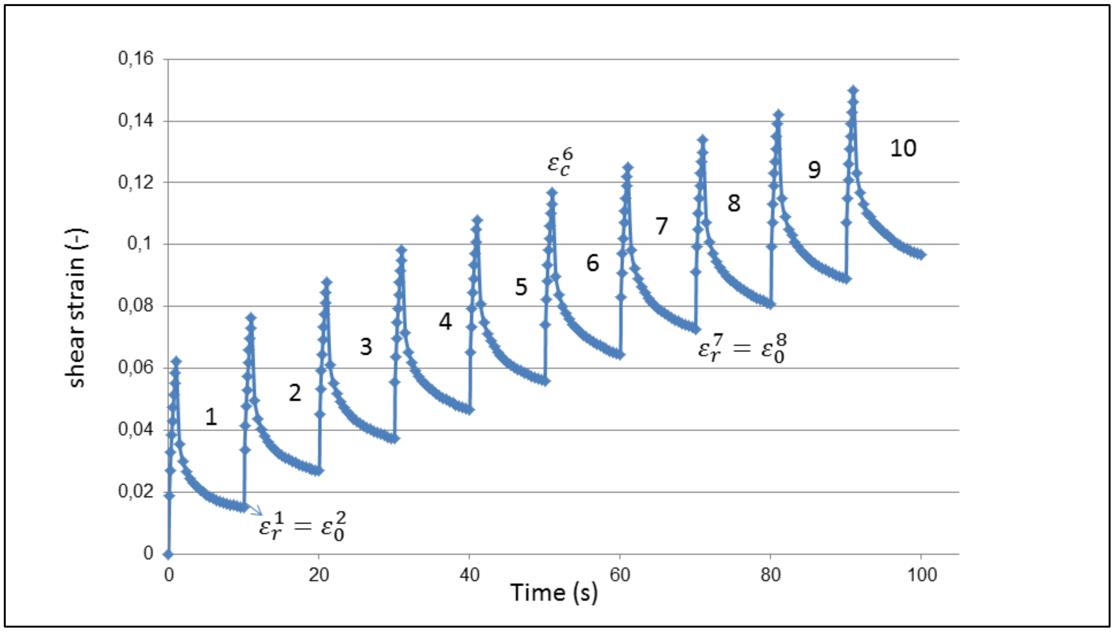


Figure 1: One series of ten creep-recovery cycles at constant stress level (from prEN 16659)

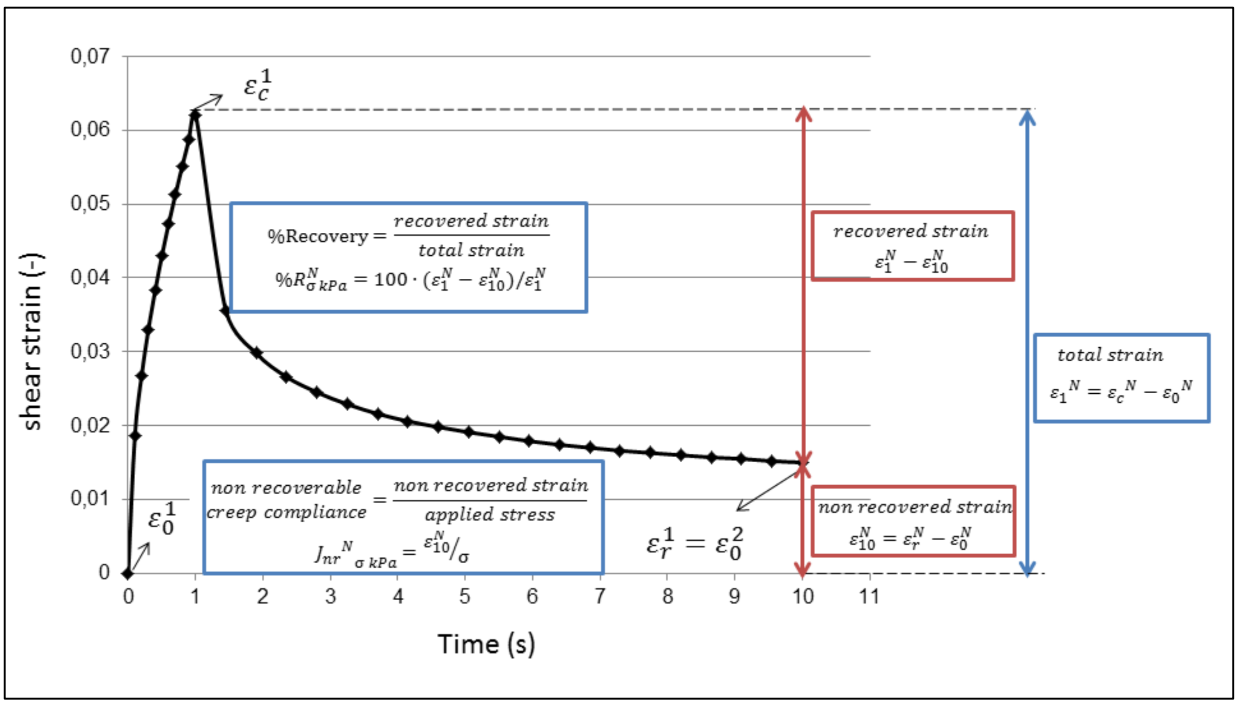


Figure 2: First creep/recovery cycle and the parameters derived for each cycle (N=1 to 10) (from prEN 16659)

The non-recoverable creep compliance 'J_{nr}' is an indicator for the sensitivity of bituminous binders to the permanent deformation under the repeated loading. It depends on the binder stiffness and on its capacity to recover from deformation. This capacity is characterized specifically by the percent recovery '%R'. The importance of the latter parameter is that it clearly discriminates binders with different degrees of polymer modification.

The series of ten cycles are applied at multiple stress levels in increasing order, without any rest period between the series. This forces the bitumens beyond their limits of linear behaviour, which is reflected by an increase of J_{nr} with stress level. This procedure allows to evaluate the stress sensitivity of the bitumen at the selected test temperature.

2.2 Test conditions

The principal test conditions of the MSCR test are the test temperature and the applied stress levels. The standard test method prEN 16659 recommends a test temperature of 50, 60, 70 or 80°C, but other temperatures may be used. The test is performed at a low stress level of 0.1 kPa, followed by a stress level of 3.2 kPa, but additional stress level may be applied, e.g. 6.4 kPa, 12.8 kPa, etc. Hence, the test method leaves the user a high degree of freedom in the selection of the test conditions. However, for specification purposes, the test conditions shall be fixed. A discussion on the selection of appropriate test conditions will follow in chapter 5.

3. ORGANIZATION OF THE ROUND ROBIN TESTS

The first round robin test was launched in 2012, with a set of four binders provided by different producers:

- paving grade bitumen 30/45
- polymer modified bitumen 25/55-55;
- polymer modified bitumen 45/80-75;
- paving grade bitumen 50/70 with 3 % wax.

All participants received 2 cans of each binder, one of which had to be subjected to RTFOT (EN 12607-1) before performing the MSCR test. In this way, each binder was tested in the fresh state and in the short term aged state. A total of 31 laboratories volunteered to participate, of which 26 laboratories representing 10 European countries returned test results. Each sample was tested three times under repeatability conditions using a new specimen for each repeated test.

The second round robin test was carried out in 2014, with a set of seven binders:

- paving grade bitumen 70/100;
- paving grade bitumen 15/25;
- polymer modified bitumen 25/55-60;
- polymer modified bitumen 45/80-75 (different from the PMB 45/80-75 used in the first round robin test);
- polymer modified bitumen 90/150-75;
- paving grade bitumen 70/100 with 3 % wax;
- EVA polymer modified bitumen.

The specific purposes of this second round robin exercise were to expand the precision data to a wider range of binders and to explore alternative test conditions. Two test temperatures were considered: 60 °C and 70 °C. Moreover, an additional stress level of 6.4 kPa, with no rest period between the previous series at 3.2 kPa, was used. This allowed to evaluate the impact of temperature and/or higher stress level on the precision of the test results. In the second round robin test, the binders were tested only in their fresh unaged state. One of the findings of the first round robin test was that the reproducibility was worse in case of the aged binders, probably because of the reproducibility of the short term ageing. Since the aim of TG1 was to determine the precision of the MSCR test as such, it was decided to omit RTFOT ageing in the second round robin test. Once again, a high number of 28 laboratories agreed to participate, of which 23 laboratories sent their results. Each sample was tested 3 times under repeatability conditions.

The participants received a template to calculate and report the test results: J_{nr} and %R at 0.1 kPa and 3.2 kPa (and additionally at 6.4 kPa in the second round robin test).

Each round robin test was accompanied by a survey, probing for the experience and practice of the users. The questionnaires contained questions related to the specific practices (e.g. the specimen preparation method), the clarity of the test protocol and the feasibility with regular laboratory equipment. The responses suggested several improvements which TG1 implemented in the revision of prEN16659.

4. ANALYSIS OF THE RESULTS

4.1. Statistical analysis

The statistical analysis was carried out with reference to the following standards: NBN ISO 5725-2:1996, ISO 13528:2005 (F) and ISO/CEI 17043:2010 (F).

The following statistical tests were applied:

- Dixon's test (for the number of tests < 30) and Grubbs' simple and double tests on the laboratory means;
- Cochran's and Grubbs' tests on the within laboratory variances.

The outliers detected with these tests were rejected to calculate the general means and the repeatability 'r' and reproducibility 'R'. Results may have been rejected due to an inconsistency of the laboratory means or due to a large within laboratory variance.

Tables 1 to 3 summarize the results of the statistical analysis for the paving grade bitumens, the polymer modified bitumens and the special bitumens respectively. For the+ binders tested in the first round robin test, there are no data at the test temperature of 70 °C and the 6.4 kPa stress level. Note that in table 2, there are two bitumens PMB 45/80-75 which were supplied by two different producers.

The definition of ‘r’ and ‘R’ is according to NBN ISO 5725-1:1996:

- ‘r’ is the value less than or equal to which the absolute difference between two test results obtained under repeatability conditions may be expected to be with a probability of 95 %.
- ‘R’ is the value less than or equal to which the absolute difference between two test results obtained under reproducibility conditions may be expected to be with a probability of 95 %.

Note that, when the number of laboratories is less than 30, the probability level associated to ‘r’ and ‘R’ may be different from 95 %. However, this has little impact on the practical usefulness of these values, which are used to evaluate whether a difference between two measurements could be due to the inherent precision of the test method or whether it should be considered as suspect.

Table 1: Repeatability ‘r’ and reproducibility ‘R’ of paving grade bitumens

	J_{nr} (kPa^{-1})						%R (%)					
Temperature (°C)	60			70			60			70		
Stress level (kPa)	0.1	3.2	6.4	0.1	3.2	6.4	0.1	3.2	6.4	0.1	3.2	6.4
	15/25											
MEAN	0.19	0.20	0.21	0.92	1.03	1.12	22.3	19. 9	15.5	10.0	4.4	2.2
r	0.01	0.01	0.01	0.05	0.06	0.06	1.3	0.7	1.0	1.1	0.4	0.4
R	0.05	0.05	0.04	0.43	0.43	0.46	5.0	6.6	6.4	3.8	4.4	2.8
	30/45											
MEAN	1.07	1.22					10.8	4.2				
r	0.04	0.05					1.0	0.5				
R	0.41	0.56					3.3	2.4				
	70/100											
MEAN	4.53	5.02	5.41	15.85	17.00	18.64	1.4	-0.2	-0.7	-2.3	-2.9	-2.9
r	0.31	0.43	0.41	0.79	0.93	1.03	0.9	0.2	0.2	0.8	0.3	0.2
R	0.84	1.25	2.78	4.78	6.17	5.61	2.8	1.7	1.8	6.8	6.5	7.4

Table 2: Repeatability 'r' and reproducibility 'R' of polymer modified bitumens

	J_{nr} (kPa^{-1})						%R (%)					
Temperature (°C)	60			70			60			70		
Stress level (kPa)	0.1	3.2	6.4	0.1	3.2	6.4	0.1	3.2	6.4	0.1	3.2	6.4
	PMB 25/55-55											
MEAN	0.68	0.85					40.5	30.6				
r	0.05	0.09					2.8	4.2				
R	0.32	0.45					13.7	15.8				
	PMB 25/55-60											
MEAN	0.18	0.19	0.19	0.74	0.81	1.37	66.9	65.5	61.6	52.3	44.9	39.6
r	0.01	0.01	0.01	0.06	0.04	0.29	0.6	0.7	1.1	1.5	0.9	1.0
R	0.05	0.06	0.06	0.26	0.27	5.8	6.4	5.9	15.2	9.2	12.8	14.6
	PMB 45/80-75 (1)											
MEAN	0.07	0.08					86.7	86.3				
r	0.01	0.01					1.2	1.7				
R	0.03	0.04					2.6	5.6				
	PMB 45/80-75 (2)											
MEAN	0.02	0.03	0.04	0.09	0.19	0.40	91.6	91.0	89.0	85.6	73.6	58.6
r	0.01	0.01	0.01	0.02	0.05	0.08	1.4	1.9	2.2	2.4	3.3	4.6
R	0.03	0.05	0.07	0.11	0.18	0.43	7.9	9.7	14.9	11.0	24.7	43.9
	PMB 90/150-75											
MEAN	0.05	0.12	0.19	0.11	4.23	7.80	96.7	93.0	67.5	96.9	54.6	38.5
r	0.04	0.09	0.21	0.06	0.99	1.63	2.2	3.5	5.3	1.1	9.6	3.3
R	0.21	0.35	0.42	0.31	15.56	20.05	10.6	14.4	103.1	6.6	103.9	122.9

Table 3: Repeatability 'r' and reproducibility 'R' of special binders

	J_{nr} (kPa^{-1})						%R (%)					
Temperature (°C)	60			70			60			70		
Stress level (kPa)	0.1	3.2	6.4	0.1	3.2	6.4	0.1	3.2	6.4	0.1	3.2	6.4
	EVA											
MEAN	0.18	0.75	1.62	3.81	6.92	7.88	59.0	37.9	11.2	9.9	0.2	-1.2
r	0.05	0.17	0.31	0.42	0.19	0.32	6.2	7.5	2.9	2.6	0.5	0.3
R	0.19	1.76	2.61	1.65	1.91	1.95	78.7	69.2	23.4	7.2	3.7	5.5
	50/70 + 3 % wax											
MEAN	0.11	1.42					75.1	8.2				
r	0.1	0.22					9.9	2.2				
R	0.37	1.35					61.3	14.3				
	70/100 + 3 % wax											
MEAN	0.21	1.95	3.2	0.91	11.07	14.9	45.2	3.4	-0.1	40.9	-1.6	-2.7
r	0.07	0.28	0.4	0.54	0.74	1.01	7.0	1.0	0.3	11.2	0.3	0.3
R	0.5	3.04	2.83	2.13	11.57	12.39	83.6	9.5	4.0	86.2	5.6	7.3

The range of mean J_{nr} values for the polymer modified bitumens in table 2 is significantly smaller than for the paving grade bitumens in table 1. Polymer modified bitumens are thus, as expected, clearly superior in this test related to the resistance to rutting.
The results of the special binders in table 3 are more difficult to explain. They show a high stress dependency and precision is poor, especially reproducibility. This can be explained by differences in preparation between the various laboratories. It has been shown that the rheology of EVA and wax modified binders depends strongly on the thermal history experienced by the sample before testing [12]. The poor reproducibility can thus be attributed largely to the preparation of the samples, rather than to the MSCR test method. Therefore, the results of these special binders will not be considered for the estimation of the precision of the MSCR test in the following section.
In the case of the softest paving grade bitumen (70/100) and some of the special bitumens, there are negative values for %R. Although the absolute values are rather small, the negative values for %R are physically impossible because this would indicate that the deformation continues to increase in the recovery phase where the stress is supposed to be zero. An explanation for the occurrence of these negative values is given in chapter 5.
To evaluate the impact of the test conditions, a graphical representation of the evolution of the mean J_{nr} and mean %R as function of stress level and test temperature is shown in figures 3 and 4, for the paving grade and the polymer modified bitumens respectively. The following observations are made:

- Figure 3 shows a logical ranking of the paving grade bitumens according to the paving grade and the test temperature. There is a small increase of J_{nr} and a decrease of %R with increasing stress, but stress dependency remains relatively small.
- For the polymer modified bitumens represented in figure 4, there is a strong impact of the degree of modification on %R and this is also reflected in a smaller J_{nr}. Some polymer modified binders exhibit a strong stress dependency, especially the very soft but highly modified PMB 90/150-75.

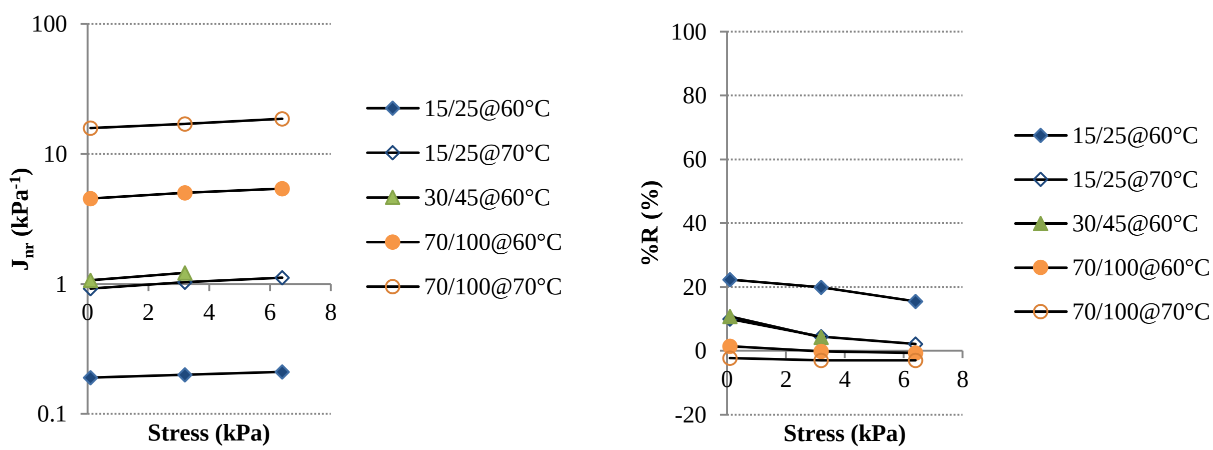


Figure 3: J_{nr} (left) and %R (right) of the paving grade bitumens

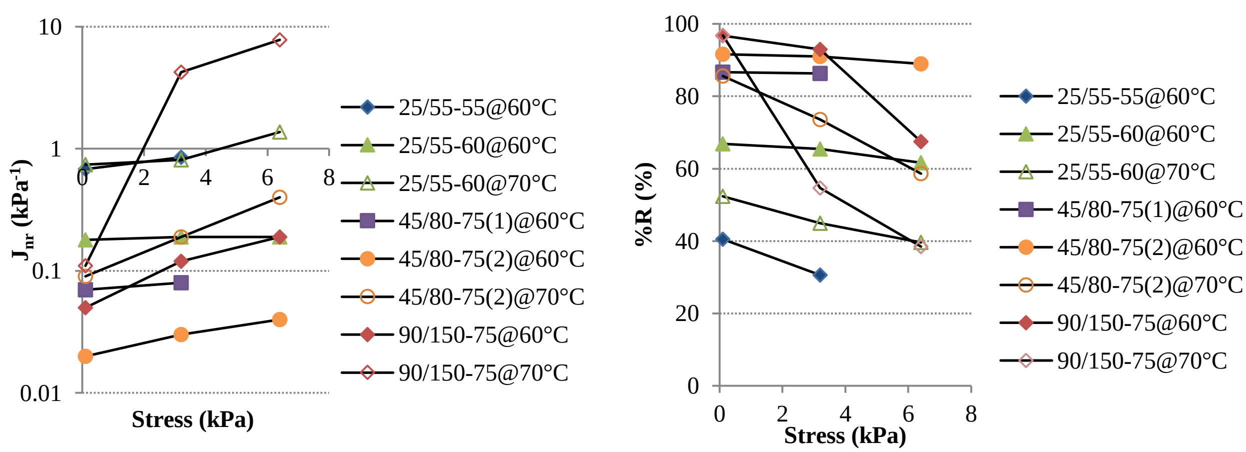


Figure 4: J_{nr} (left) and %R (right) of the polymer modified bitumens

4.2 Precision of MSCR test results

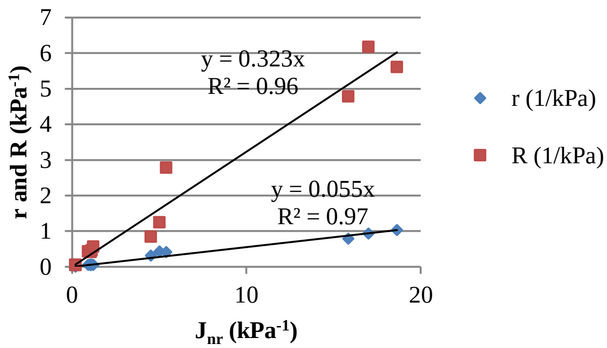
Tables 1 to 3 show clear differences in repeatability and reproducibility values for the three groups of binders. Hence it is not accurate to make an estimation of the precision irrespective of the binder type. Following analysis was therefore conducted for the paving grade bitumens and the polymer modified bitumens separately. As already explained in the previous section, the special binders are not considered in the further analysis.

Figure 5 on the left hand side shows the repeatability and reproducibility values determined for the paving grade bitumens plotted against the mean values of J_{nr}. Since table 1 does not show any systematic dependence of repeatability and reproducibility on either test temperature or stress level, all data are gathered in this plot, irrespective of test temperature and stress level. The plot shows that repeatability and reproducibility are both proportional to the value of J_{nr}. The linear fit of the data allows to make an estimation of the precision as a percentage of the measured value:

- r/J_{nr} (in %) = 5.5 %
- R/J_{nr} (in %) = 32.3 %

The same exercise was done for %R on the right hand side of figure 5. Note that the negative values of %R were set to zero. The data points don't show a very clear dependence on the value of %R. The average values of the repeatability and reproducibility of %R are given by:

- r = 0.6 %
- R = 4.4 %



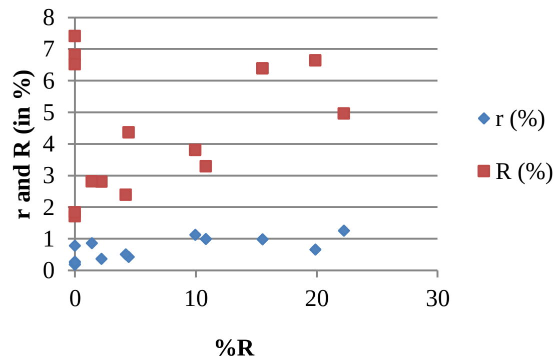


Figure 5: Precision data as function of the amplitude of the test results for the paving grade bitumens (left: for J_{nr}; right: for %R)

Figure 6 includes all repeatability and reproducibility values determined on the polymer modified bitumens in the two round robin tests, at the test temperatures of 60 °C and 70 °C and stress levels of 0.1, 3.2 and 6.4 kPa, with the exception of the following data:

- Some results obtained at 70 °C and 6.4 kPa, which showed very high 'r' and 'R' values;
- Results for the very soft polymer modified bitumen PMB90/150-75, which showed excessively high 'r' and 'R' compared to the other polymer modified bitumens.

For the precision of J_{nr}, a linear trend is again observed, but the correlation is less than in the case of the paving grade bitumens. The slopes of the regression lines are higher, hence repeatability and reproducibility limits, as expressed in % of the amplitude of J_{nr} are larger for the polymer modified bitumen:

- r/J_{nr} (in %) = 8.1 %
- R/J_{nr} (in %) = 43.0 %

The plot of repeatability and reproducibility of %R versus %R again shows no dependence on the amplitude of the test result. The average values of repeatability and reproducibility of %R are given by:

- r = 2 %
- R = 12 %

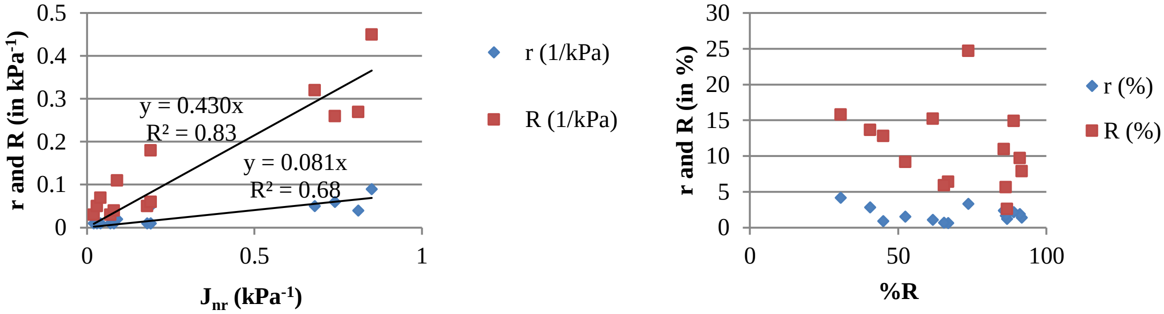


Figure 6: Precision data as function of the amplitude of the test results for the polymer modified bitumens (left: for J_{nr}; right: for %R)

4.3 Summary and comparison of precision data

Based on the analysis of the precision data as described in the previous sections, TG1 made a proposal of precision data for the prEN 16659 (see table 4). This allows to estimate the precision of the test results, depending on the type of bitumen. As for all test methods, these precision data will evolve in time when more data from other round robin tests will be available. Precision is expected to improve, since the expertise of the laboratories increases, test equipment is constantly improved, etc.

Table 4: Repeatability 'r' and reproducibility 'R' of the MSCR test

		J_{nr} (in % of J_{nr})	%R (in %)
Paving grade bitumens	r	6 %	1 %
	R	33 %	5 %
Polymer modified bitumens	r	9 %	2 %
	R	43 %	12 %

An effort was made to compare these precision data to available results from previously conducted interlaboratory campaigns. Soenen [8] reported results of MSCR tests from five laboratories on nine binders. The results showed the same trend: repeatability and reproducibility of J_{nr} increasing with the value of J_{nr} and repeatability and reproducibility of %R independent of the value of %R. An overall estimation of the precision of the test method for any binder is not made in this paper. Repeatability and reproducibility are only reported for each binder individually. The ASTM standard [5] reports values of repeatability and reproducibility, for different ranges of J_{nr}. For %R, the values of repeatability and reproducibility are independent of %R. This confirms once again the independence of the precision of %R on the value of %R. The estimations in the ASTM standard are based on the test results from eight laboratories for eight binders, but there is no distinction made between polymer modified and non-modified bitumens. However, when comparing only the "worst case" precision data for the polymer modified bitumens in table 4 to the precision data reported in the ASTM standard, it is observed that the repeatability and reproducibility values obtained in the European Round Robin test are at least equal or smaller.

5. PROBLEMS IDENTIFIED AND LESSONS LEARNED

A few laboratories obtained negative values for %R. This phenomenon has been reported previously in literature [8] and was explained by the fact that the dynamic shear rheometer in question was unable to apply the block stress signal in the short creep period without a significant delay. When there is a delay between the theoretical end of the creep period and the actual time the stress has returned to zero, the strain will still increase for a short time beyond the theoretical creep period. In that case, the strain at the end of the recovery phase may be higher than the strain recorded at the end of the theoretical creep period, resulting in the negative value of %R. It was noticed in the returned questionnaires that the laboratories who reported significant negative values all used the same older type of rheometer. This justified the elimination of the results of the laboratories that used that type of rheometer. Note that in table 1 and in table 3, there are still a few negative values for % recovery. This occurs only for bitumens with no or negligible capacity to recover. The values are very near to zero and can be considered as zero within the reproducibility limits.
The special binders considered in these round robin tests were the only binders of which the precision results, particularly the reproducibility, were unsatisfactory. The impact of thermal history, which depends on the sample

preparation procedure and is therefore likely to differ between laboratories, is held responsible for the poor reproducibility.
With respect to the selection of the test conditions, the following lessons were learned:
In the second round robin test, two test temperatures were used: 60 °C and 70 °C. The conclusion is that 60° C seems the most appropriate for the complete range of binders, while 70 °C is too high for the softer binders and has a negative effect on precision. Moreover, the temperature of 60 °C is generally seen as representative for the temperature range in which rutting occurs. This is why many countries in central and southern Europe use 60 °C for the standard wheel tracking tests according to EN 12697-22. Although not considered in this study, 50 °C may also be a good option since some European countries have chosen 50 °C as the standard test temperature for wheel tracking tests.
Increasing the stress level from 3.2 kPa to 6.4 kPa changes the ranking of the test results in only a few cases. This is observed in figure 4 for the case of the very soft polymer modified bitumen. However, for this particular bitumen, repeatability and especially reproducibility is excessively high at the higher stress level, which means that the results at 6.4 kPa are less reliable. Therefore, it may not be a good option to use higher stress levels to determine J_{nr} and % R for specification purposes and the maximum stress level of 3.2 kPa seems to be more appropriate.
The test can be performed on fresh binder as well as on short term aged binder, as in the AASHTO specification MP 19-10 [7]. The second option seems more realistic from the point of view that pavement rutting occurs in asphalt with bitumen aged during production. However, the important drawback is that repeatability and especially reproducibility are not as good when the test is preceded by RTFOT ageing.

6. PERSPECTIVES

The MSCR test is seen as a good test to characterize the resistance to permanent deformation at elevated service temperatures of both paving grade bitumens and polymer modified bitumens (although the test is intended specifically for the polymer modified binders). The European standard prEN 16659 is in the final phase of Formal Vote, most European laboratories have acquired the expertise to perform the test and the precision of the test is satisfactory. The next step will be the selection of the test conditions used to measure the characteristics that will be subjected to specifications and the final step will be the definition of the specifications.
In the US PG system, the same two stress levels of 0.1 kPa and 3.2 kPa are used. The test temperature is the high temperature grade, determined on the fresh binder by the $G^*/\sin\delta$ criterion. The MSCR test is performed on the RTFOT short term aged binder and specifications are imposed on J_{nr} at 3.2 kPa, depending on the type of traffic (‘Standard’, ‘Heavy’, ‘Very heavy’ or ‘Extremely heavy’). Moreover, the difference in J_{nr} between 3.2 kPa and 0.1 kPa is used to eliminate binders which are highly stress sensitive [4].
In view of the definition of future European specifications, the following considerations are important to take into account:
The test temperature of 50 °C or 60 °C has the advantage that the results can be correlated more closely with the wheel tracking test which is also performed at 50°C or 60°C in most European countries. The round robin test showed that reproducibility becomes low at 70 °C for soft binders, so 70 °C seems to be too high as a standard test temperature for all binders.
The selection of the optimal stress level is still controversial. Some studies claim that higher stress levels improve the correlation with asphalt rutting tests [9,10], while other studies show satisfactory correlations with a stress level of 3.2 kPa [11]. The round robin tests showed that precision is lower at 6.4 kPa than at 3.2 kPa. Before selecting a higher stress level for specification purposes, it is necessary to verify that repeatability and reproducibility are still acceptable.
The first round robin test showed that, if each laboratory performs RTFOT prior to the MSCR test, the precision of the test results is low. Therefore, provided that short term ageing will not alter the ranking of binders - and there is no indication or evidence that this should be the case – it is recommended to define specifications on the results measured on fresh samples.

7. CONCLUSIONS

The MSCR test has been adapted to European practice with the aim of improving the performance related specifications for polymer modified bitumens. The new project European norm (prEN 16659) is at the moment of writing this paper ready to be launched for Formal Vote by CEN TC336.
The outcome of the round robin tests described in this paper shows that the MSCR test is promising and presents many advantages:

- The principle of the test aims at accurately simulating the real loading conditions leading to rutting.
- The two parameters identified are relevant and their interpretation is straightforward:

- J_{nr} shows the sensitivity to rutting;
- %R clearly distinguishes polymer modified bitumens from non-modified bitumens and also distinguishes between polymer modified bitumens with different levels of modification.

- The test method is relatively fast and simple and only a few grams of binder are needed.
- A lot of European laboratories have now acquired practical experience and are capable of performing the test.
- Precision data have been established for both paving grade bitumens and polymer modified bitumens.

Although the test was developed specifically for polymer modified bitumens to fill the need for performance related specifications, the test can also be performed on paving grade binders and these are distinguished in a logical way.
The next step towards performance related specifications is the selection of the standard test conditions and the definition of classes based on the test results.

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