MULTIPLE STRESS CREEP RECOVERY (MSCR)

THE MSCR TEST IN PLAIN LANGUAGE

When bitumen started being used as a binder for asphalt pavements more than a hundred years ago, the first quality control test ever conducted was the "chew test". A piece of bitumen was chewed by an experienced tester over several minutes. Based on the expertise of the tester, a judgement was made about the stiffness and the consistency of the bitumen.

If we analyze the chew test from a rheological perspective it amounts to a repeated creep and recovery test, conducted under isothermal conditions at the temperature of the human body. It took us many decades and a variety of evolving specifications but with the development of the newer Multiple Stress Creep Recovery (MSCR) test, the circle is complete: we have arrived back to the chew test, only today it is conducted using a Dynamic Shear Rheometer (DSR) and fortunately does not endanger the health and safety of the tester.

The development and adoption of the PG Grading specification was part of the Strategic Highway Research Program (SHRP) during the early 90's and represented without doubt a major step forward in asphalt specifications. The specification was developed after extensive research was conducted into the behaviour of all major asphalt cement sources and types available in North America, and was designed to be as all-encompassing and as blind to any modification as possible. Needless to say, the traditional modification techniques up to then were mainly air blowing and fluxing. However, it so happened that during the same timeframe elastomeric modification of asphalt binders was becoming mainstream. SB and SBS type modification processes were quickly adopted by agencies and asphalt suppliers. Because traffic loadings increased continuously, premium performing binders were needed.

It soon became clear that the newly adopted PG Specification was not designed to capture the specific performance delivered by elastomeric polymers. As a result, agencies adopted extra tests specifically to quantify or specify such polymers. Tests like Elastic Recovery, Toughness & Tenacity, maximum DSR phase angles, etc. were soon adopted on top of the new PG requirements. The era of the so-called PG Plus specifications started. Quebec is an example of an agency that recognized the benefit of elastomeric modification, adopted an Elastic Recovery test and mandated minimum elasticity levels for bitumens of higher grades.

NCHRP 9-10 was a research project commissioned in the mid 90's to continue aspects not addressed during SHRP. The project had the purpose of capturing polymer modification behaviour in bitumens into performance-related tests, and eventually specifications. One of the tests developed during this project was the Repeated Creep Test, designed to better capture rutting resistance provided by Polymer Modified Asphalts (PMA). This test is one of the precursors of the current MSCR test, currently standardized under the AASHTO T350 protocol.

The MSCR test is a DSR test where the bitumen sample is loaded for one second with a constant stress (creep) and then immediately allowed to relax for 9 seconds. This loading pattern happens multiple times and at two different stress levels: one low (0.1 kPa) and one high (3.2 kPa). The instrument measures the deformation of the sample throughout the whole testing period, both during stress and during the relaxation and recovery periods and calculates a number of parameters for each cycle: peak, recovered and non-recovered strains. Figure 1 shows and example of a creep and recovery cycle and the strain measurements shown above. Based on these values, the calculated parameters of interest are:

- The non-recoverable creep compliance J_{nr}, at 0.1 and 3.2 kPa
- The percent recovery R, at 0.1 and 3.2 kPa

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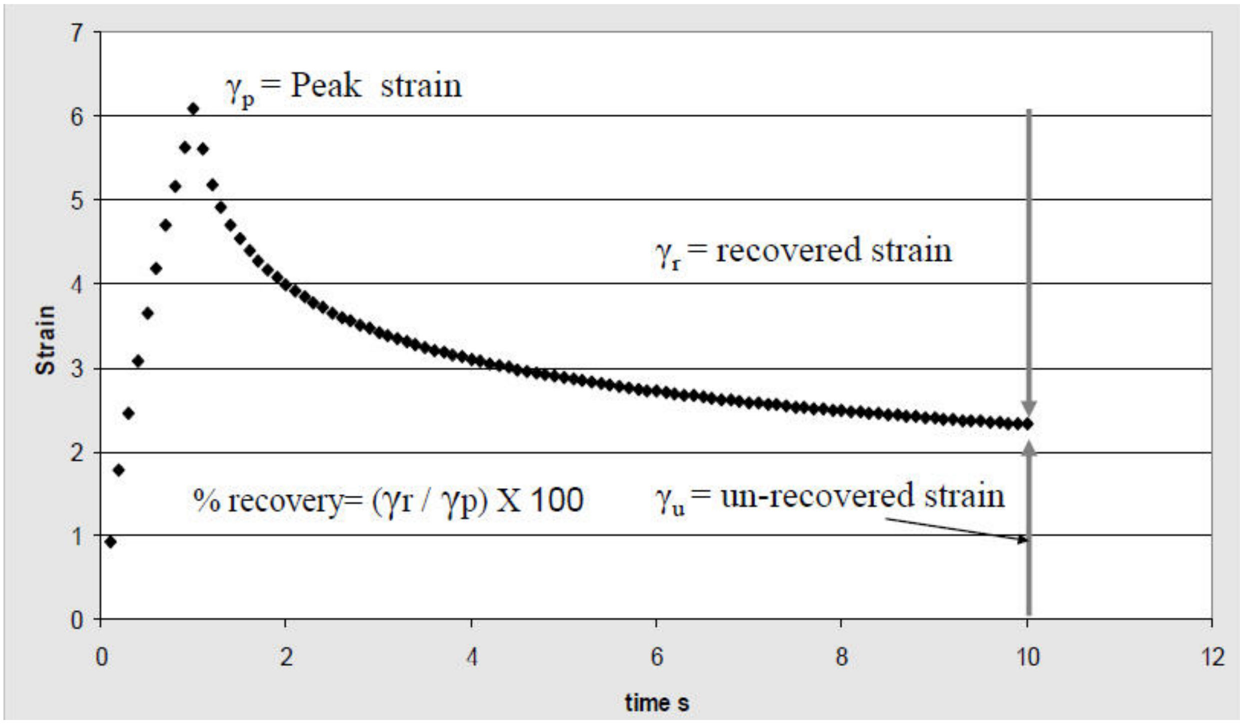

J_{nr} is the parameter that best correlates with rutting resistance in the field, as it quantifies only the non-recovered portion of deformation. It is a compliance (the invert of a modulus), meaning a lower value means a stiffer material. It is also measured at both low and high stresses, and the higher stress level is chosen so the material is purposely no longer in its linear viscoelastic region. This is a first in bitumen specifications, but a correct direction to take: when trying to predict failure it is necessary to take the material in a non-linear response environment, because that's where failure happens.

The recovery parameter R is reported in % and it is a measure of the elastic response of the bitumen. It has several advantages over a classic Elastic Recovery test by use of the ductilometer. Firstly, it is done at the environmental high temperature, which is the right way of quantifying the elastic response of a polymer. Pavements don't rut at 10 or at 25°C, they rut in the middle of a hot summer day. Secondly, pavements also rut under heavy traffic, and therefore the Recovery is also measured at high stresses (3.2 kPa). This is another big advantage over a classic ER test: ER measures elastic response, but not under load. Depending on the modification type and polymer, some bitumens can be elastic under low stresses but can lose their elasticity under high loads. MSCR Recovery can detect weak and shear susceptible polymer networks that the classic ER test cannot. Thirdly, the minimum recovery for a bitumen to be considered elastic is adjusted as a function of its stiffness (or compliance), by the following relationship:

$$R \geq 29.371.J_{nr}^{-0.263}$$

This approach allows a clear quantification of the contribution of the elastic polymer network to the elasticity of the PMA, independently of the stiffness and elastic component of the bitumen matrix.

Shear susceptibility of certain PMA's was also the reason why another parameter was proposed with the introduction of the MSCR test: a maximum allowable J_{nr} drop of 75% between the lower and the higher testing stress levels. While this is theoretically a sound approach, the requirement is currently under review because it can give artificially high results for binders with very low J_{nr} values.

The MCSR test has been developed and field validated over the last 10 years or so. It is currently in different implementation stages in various jurisdictions across Canada and the US. There are two different ways that this test is adopted today:

- As a "plus" test beside a PG specification
- As part of the newly developed MSCR Specification, standardized as AASHTO M332

Several provinces and states have recognized the merit and the simplicity of the MSCR test but decided they are not yet ready for AASHTO M332 implementation. Instead, they are using the MSCR Recovery as a better way of specifying elastomeric modification of asphalts for certain grades. Ontario and Alberta are examples of the approach described.

By contrast, other provinces and US states are transitioning to a full adoption of the AASHTO M332 specification. Quebec has announced a proposed transition to the above specification, making them a leader in Canada, should the transition be completed as planned. The majority of US states either have, or are in process of adopting the MSCR specification.

What is different in AASHTO M332? The general framework of this specification is similar with the M320 (classic PG specification). The most significant difference is in how the top end is graded. PG grading was designed for neat asphalts and these generally show thermorheologically simple behaviour, meaning (among other) that the time-temperature superposition principle is valid. As a result, grade bumping was conveniently expressed by bumping the PG high temperature, to account for heavy or very heavy traffic. Example: a PG 58-28 is the base climatic grade for southern Quebec or southern Ontario. It becomes a PG 64-28 for heavy traffic roads or PG 70-28 for very heavy traffic arteries. The climate never justifies a PG 70 in Ontario or Quebec but heavy traffic does. Therefore, stiffer bitumens are expressed through higher temperature PG.

PMA's are usually more complex materials and many are not thermorheologically simple. The way the MSCR specification is grading binders is without using grade bumping by altering the PG high temperature. This is done by always testing the binder at the climatic high temperature and having different stiffness requirements for different traffic levels. The different grades are expressed through letters placed after the PG high temperature:

Traffic Designation	J_{nr} Requirement	Example MSCR Grade	Approx PG Grade
"S" Standard traffic	$J_{nr} < 4.5$	PG 58S-28	PG 58-28
"H" High traffic	$J_{nr} < 2$	PG 58H-28	PG 64-28
"V" Very High traffic	$J_{nr} < 1$	PG 58V-28	PG 64-28 (strong) PG 70-28
"E" Extremely High traffic	$J_{nr} < 0.5$	PG 58E-28	PG 70-28 (strong) PG 76-28

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Generally speaking, the Recovery as a specification requirement is not mandatory, unless an elastic behaviour is desired. In this case, the Recovery should be specified only for H, V and E grades. S bitumen grades are almost always non-modified grades.

The requirement for the MSCR to always be tested at environmental level can create confusions during transition times, especially for PG + MSCR type specifications. It is often seen that the MSCR is mistakenly tested at the same temperature as the RTFO DSR requirement. For a bumped PG grade, this is incorrect. Even if the PG grade is a 70-28, as an example, if the paving project is in a 58 zone, the MSCR should be tested at 58 and classified by the traffic designation letter. Modern DSR testing protocols have templates that allow for automatic dual temperature testing without the need for a second sample: RTFO DSR is tested at PG high temperature followed by MSCR test at the environmental temperature.

While the MSCR test was developed specifically to be a better rutting test compared to the old $G^*/\sin(\delta)$ parameter, it has indirect ramifications for other areas of pavement performance. One might argue that it has no bearing on the low temperature properties of bitumen, because it is a high temperature test. If properly specified, however, the MSCR can ensure that a strong and robust polymer network is present in the binder. This polymer network will directly improve the thermal strength of the bitumen at low temperature, therefore improving (lowering) the critical cracking temperature T_{cr} without any changes the stiffness and relaxation properties of the neat asphalt.

Adoption of the full MSCR specification is the logical direction for spec evolution from where we are today. Other new tests, like Delta T_{cr} and extended PAV will follow and will better describe asphalt cement aging and its behaviour at low temperatures. Like any change, these tests face opposition and fear, and their implementation takes time.

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