Multiple Stress Creep-Recovery Analysis of Asphalt Material

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Abstract

Asphalt is one of the major construction materials used in road pavement. There are a number of AASHTO and ASTM standard tests that have been developed for asphalt analysis. In this paper, we introduced the use of the TA Instruments AR series rheometers for performing the asphalt analysis required in the newly developed ASTM standard, Multiple Stress Creep Recovery Test (MSCR). We also introduced the use of a special asphalt analysis feature, Navigator scripts, on TA Instruments AR series rheometers.

Introduction

One of the main challenges in asphalt technology is how to use rheological principles to characterize the viscoelastic properties of asphalt that are related to pavement performance. The testing systems required to measure these properties and the methods by which we can use these properties to improve pavement performance are still under development.

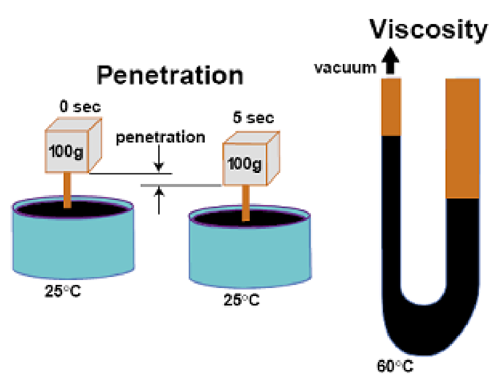


Figure 1 Empirical asphalt binder grading tests: penetration and viscosity

Historically, asphalt cements have been graded by two empirical tests: penetration and viscosity (Figure 1). These tests were developed in an era of less traffic and significantly lower pavement loadings. Trucks of yesteryear were limited to 72,000 lbs. and rode on bias-ply tires with tire pressure of 75 psi. Today, truck weights exceed 80,000 lbs. and radial tires are inflated to 125 psi. This results in a 40% increase in stresses applied to the pavement. It has become obvious that our previous empirical specifications do not relate directly to asphalt binder performance in our pavements.

Therefore, the Strategic Highway Research Program (SHRP) sponsored $50 million of research funding on asphalt binders to relate the specifications to actual pavement performance. The new Performance Grade (PG) asphalt binder specifications provide better viscoelastic measurements throughout a broad temperature range (Figure 2). Numbers of AASHTO and ASTM standards (e.g. AASHTO T315, TP5, M320; and ASTM D7175, D6521, D6373 etc.) have been published regarding evaluations of asphalt performance. More specifications to better mimic the real road traffic situations are still under investigation.

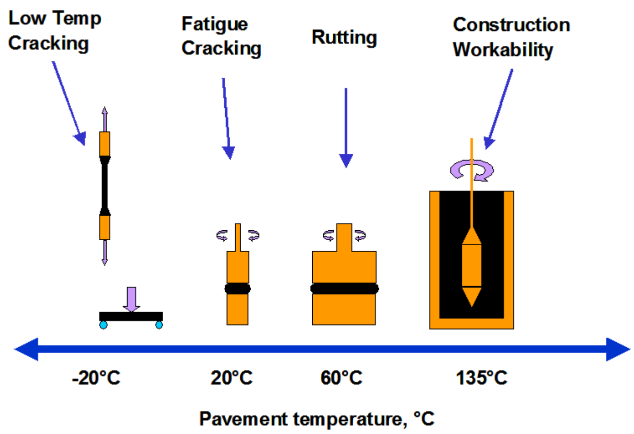


Figure 2 Asphalt PG grading tests

Multiple Stress Creep and Recovery Test (MSCR)

Rutting is one of the major causes of premature failure of asphalt concrete. A recently proposed/published repeated creep test can be used to identify asphalt binder that is susceptible to rutting. This test method is used to determine the presence of an elastic response in an asphalt binder under shear creep and recovery at two stress levels at a specified temperature. For performance grade (PG) binders, the specified temperature will typically be the PG grade upper temperature as determined in specification D6373. Ten creep and recovery cycles are run at 100 Pa stress and 3200 Pa stress consecutively. Each cycle includes 1 s creep and 9 s recovery. After the measurement the test results are calculated as follows:

- For each of the ten cycles at a creep stress of 100 Pa, calculate the percent recovery, $\varepsilon_r(100, N)$, for N = 1 to 10:

$$\varepsilon_r(100, N) = \frac{(\varepsilon_1 - \varepsilon_{10}) \cdot 100}{\varepsilon_1}$$

where ε_1 is the strain at the end of the creep step, and ε_{10} is the strain at the end of the recovery step.

- For each of the ten cycles at a creep stress of 3200 Pa, calculate the percent recovery, εr(3200, N), for N = 1 to 10:

$$\varepsilon_r(3200, N) = \frac{(\varepsilon_1 - \varepsilon_{10}) \cdot 100}{\varepsilon_1}$$

- Calculate average percent recovery at 100 Pa:

$$R100 = SUM(\varepsilon_r(100,N))/10 \quad \text{for } N = 1 \text{ to } 10$$

- Calculate average percent recovery at 3200 Pa:

$$R3200 = SUM(\varepsilon_r(3200,N))/10 \quad \text{for } N = 1 \text{ to } 10$$

- Calculate percent difference in recovery between 100 Pa and 3200 Pa:

$$Rdiff = ((R100 - R3200)*100) / (R100)$$

- For each of the ten cycles at a creep stress of 100 Pa calculate the non-recoverable creep compliance, $J_{nr}(100, N)$, for N = 1 to 10:

$$J_{nr}(100, N) = \frac{\varepsilon_{10}}{100}$$

- For each of the ten cycles at a creep stress of 3200 Pa calculate the non-recoverable creep compliance, Jnr(3200, N), for N = 1 to 10:

$$J_{nr}(3200, N) = \frac{\varepsilon_{10}}{3200}$$

- Calculate the average non-recoverable creep compliance at 100 Pa:

$$J_{nr}100 = SUM(J_{nr}(100,N))/10 \quad \text{for } N = 1 \text{ to } 10$$

- Calculate the average non-recoverable creep compliance at 3200 Pa:

$$J_{nr}3200 = SUM(J_{nr}(3200,N))/10 \quad \text{for } N = 1 \text{ to } 10$$

- Calculate the percent difference in non-recoverable creep compliance between 100 Pa and 3200 Pa:

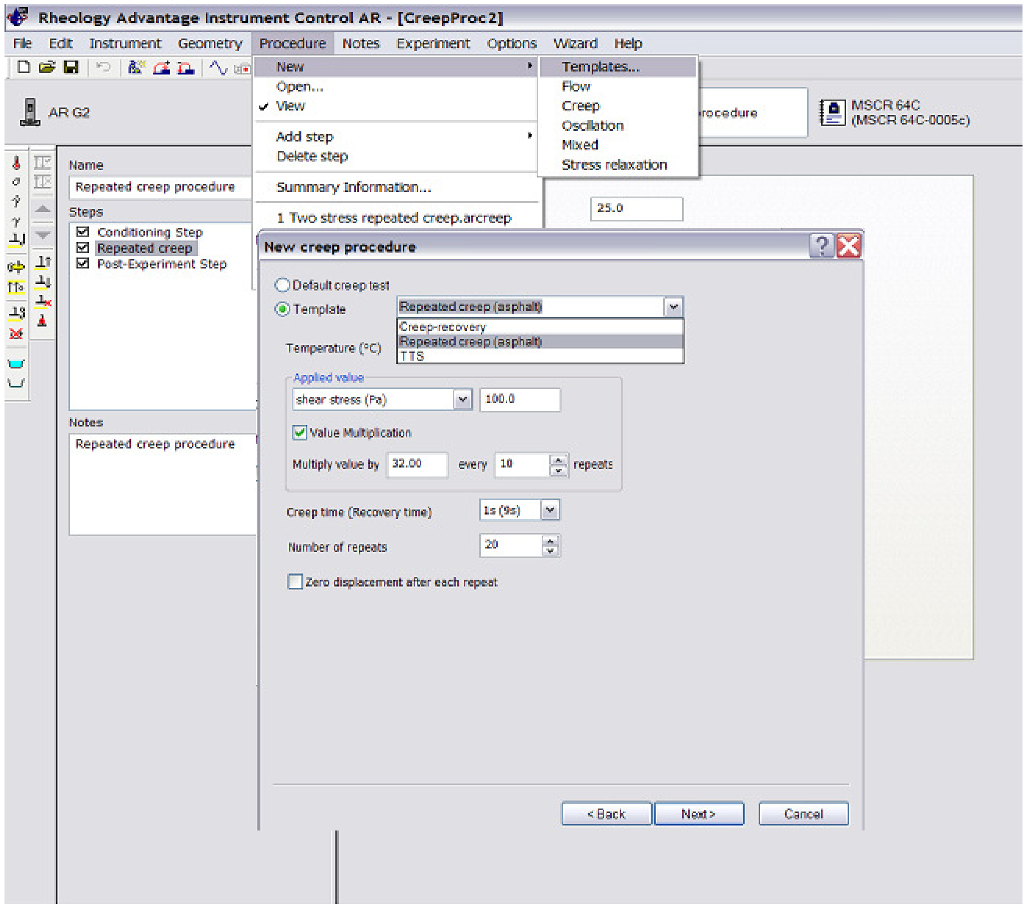
$$J_{nr}\text{-diff} = ((J_{nr}3200 - J_{nr}100)*100) / (J_{nr}3200)$$

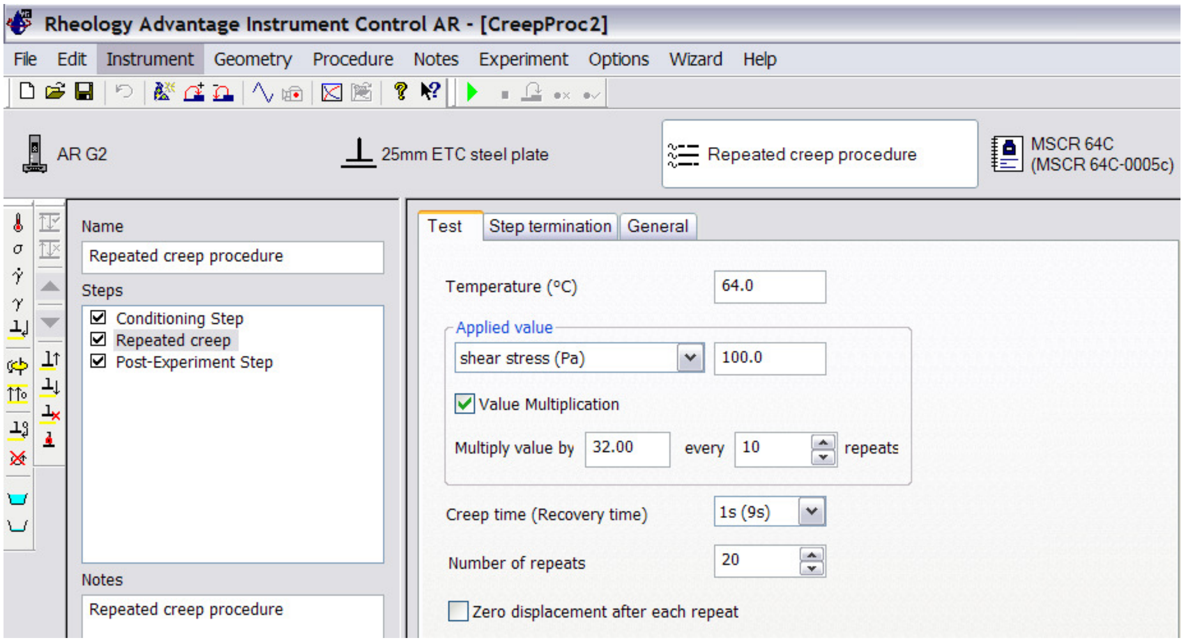
The non-recoverable creep compliance is used as an indicator of the resistance of an asphalt binder to permanent deformation under repeated load.

Perform MSCR test using a AR rheometer

TA Instruments AR series rheometers (AR-G2, AR2000ex, AR1500ex) are powerful Dynamic Shear Rheometers (DSRs) for all typical asphalt analysis. They are equipped with a variety of temperature control systems including submersion cell, Peltier, environmental test chamber (ETC), Peltier with upper heated plate, electrically heated plate (EHP), and have all the required geometries for asphalt analysis (e.g. 25 mm plate, 8 mm plate and torsion geometry).

Regarding the MSCR testing, one can choose to perform the test manually or through running the Navigator script. The instrument control software has a built-in template to accommodate this particular test. To manually program this experiment, one should open the AR Instrument Control software, go to "procedure – new – template - creep", then, enter the experimental temperature and creep stresses as shown in the two screen shots below. After the experiment, the test result is shown in figure 3.





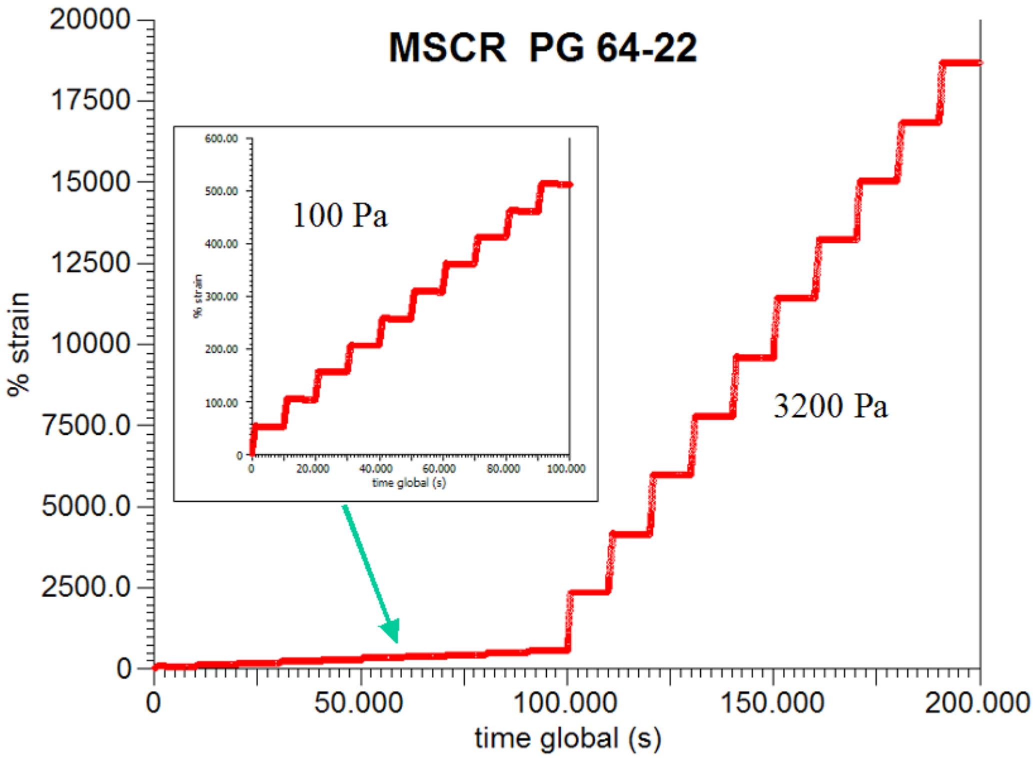
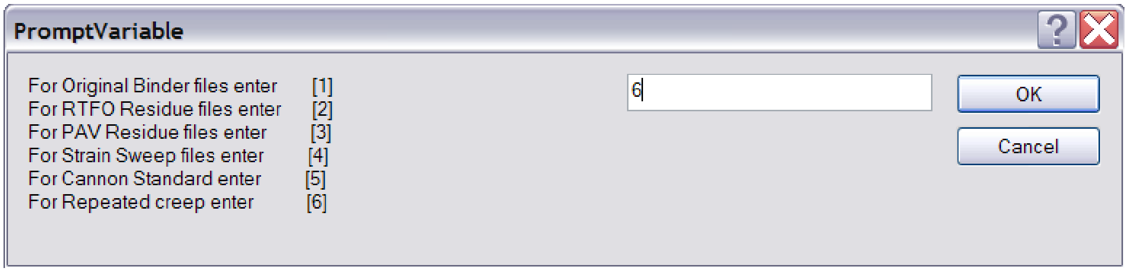


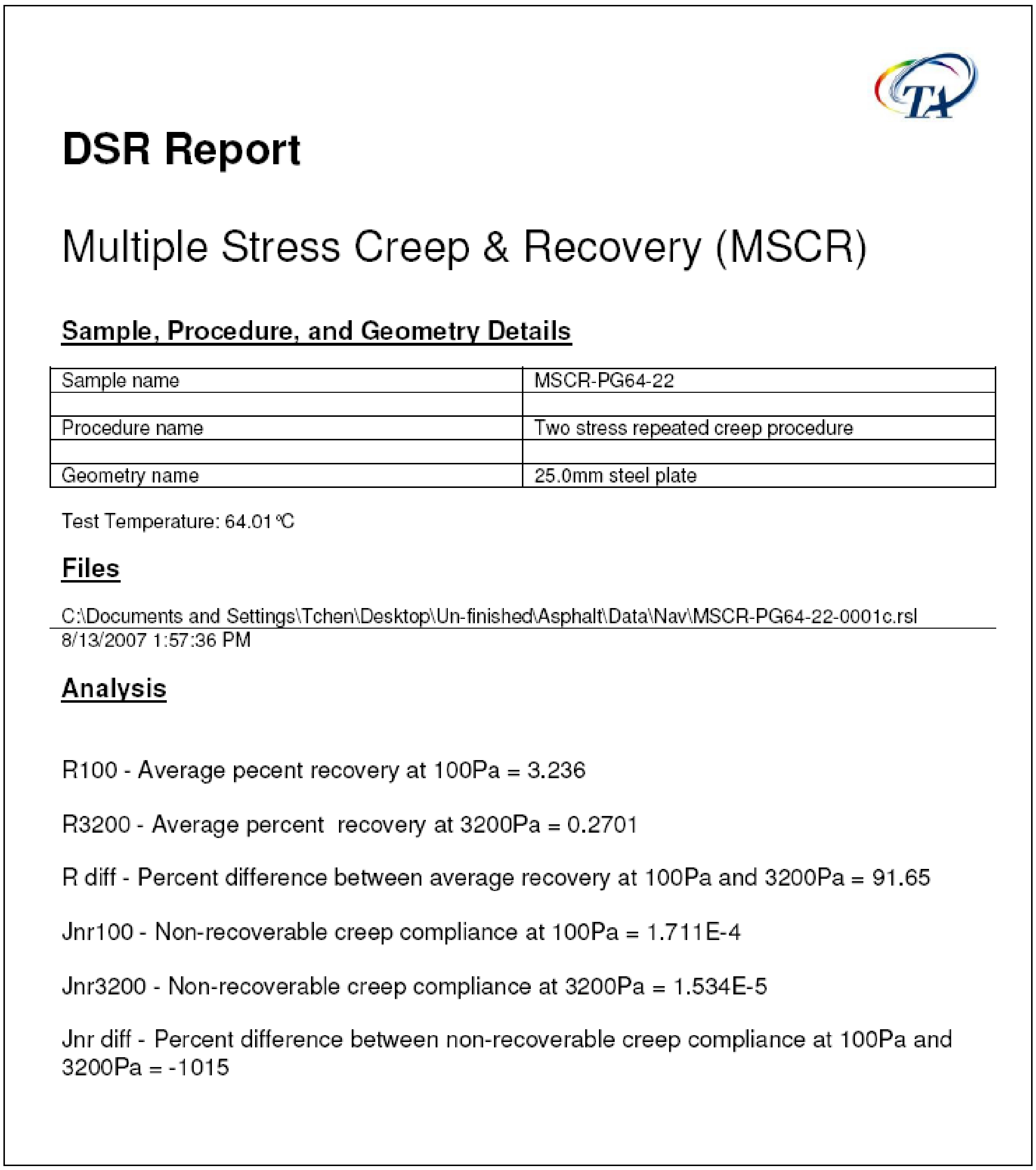
Figure 3 multiple stress creep recovery test result

As can be seen from the MSCR specification, the result analysis is quite tedious and time consuming. TA Instruments provides a data analysis script, which makes the data analysis easy and quick. To use the data analysis script, TA Rheology Navigator needs to be installed. After installing the software, go to the following directory from your computer, open, and run the file "Old file printout.nvs".

C:\Documents and Settings\All Users\Documents\TA\Rheology\Scripts\Utility Scripts

Choose "6" for repeated creep analysis, then find the data file you want to analyze. The final analysis report will be automatically printed out or saved as PDF file shown in Figure 4.





DSR Report

Multiple Stress Creep & Recovery (MSCR)

Sample, Procedure, and Geometry Details

Sample name	MSCR-PG64-22
Procedure name	Two stress repeated creep procedure
Geometry name	25.0mm steel plate

Test Temperature: 64.01 °C

Files

C:\Documents and Settings\Tchen\Desktop\Un-finished\Asphalt\Data\Nav\MSCR-PG64-22-0001c.rsl
8/13/2007 1:57:36 PM

Analysis

R100 - Average pecent recovery at 100Pa = 3.236

R3200 - Average percent recovery at 3200Pa = 0.2701

R diff - Percent difference between average recovery at 100Pa and 3200Pa = 91.65

Jnr100 - Non-recoverable creep compliance at 100Pa = 1.711E-4

Jnr3200 - Non-recoverable creep compliance at 3200Pa = 1.534E-5

Jnr diff - Percent difference between non-recoverable creep compliance at 100Pa and 3200Pa = -1015

Figure 4 Report templates for a multiple stress creep recovery test

The repeated creep analysis can also be used for testing solid asphalt mix. Figure 5 shows the picture of testing an asphalt mix sample on an AR2000 rheometer using torsion geometry. Also, to better mimic the real traffic situation on the road, one can program a repeated creep analysis with more than 2 stresses. An example is shown in figure 6.

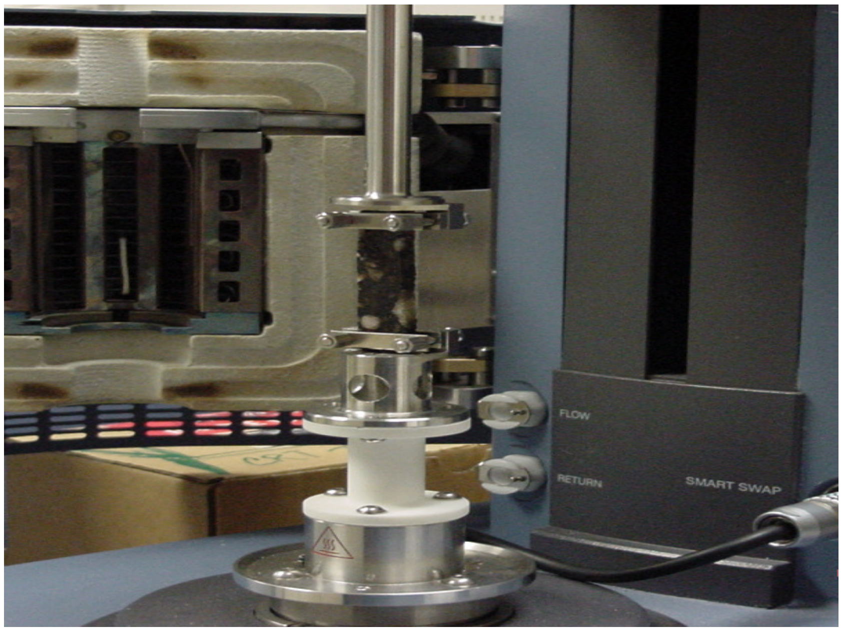


Figure 5 Testing solid asphalt mix on an AR2000 rheometer

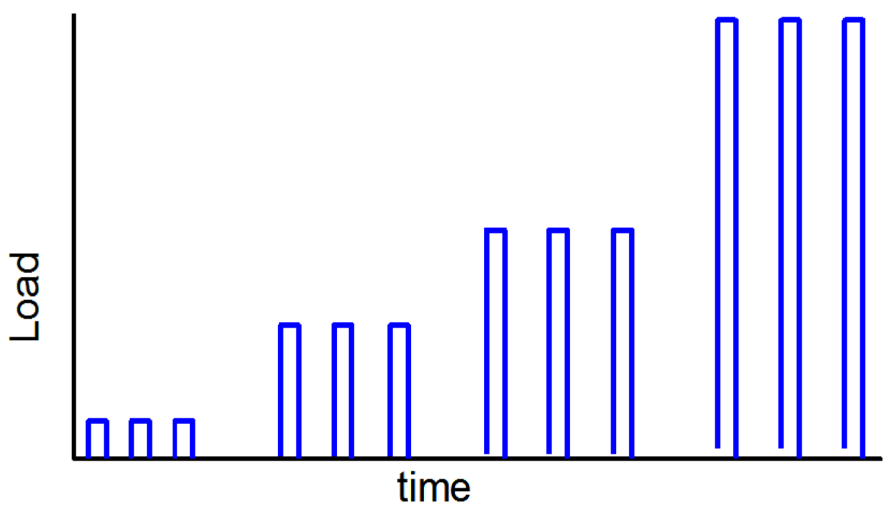


Figure 6a

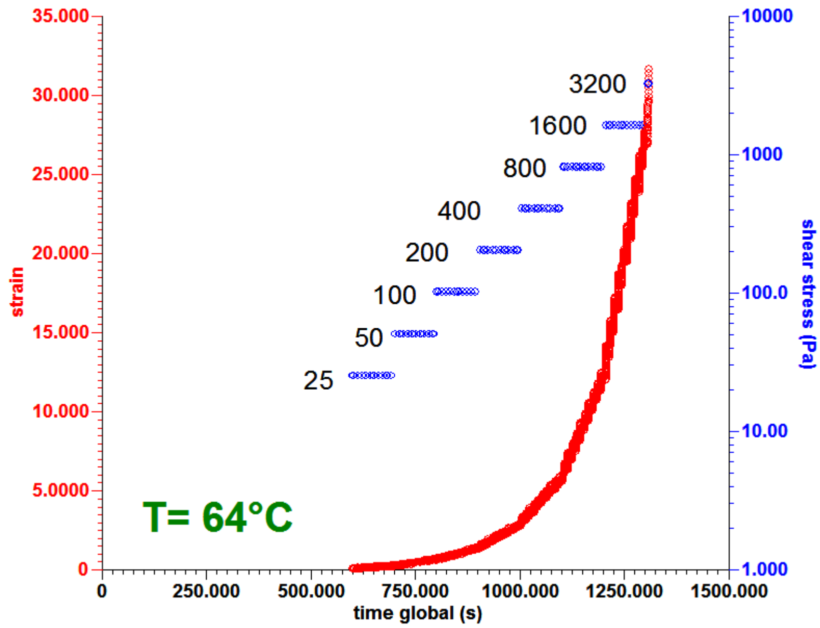


Figure 6b
Figure 6 Repeated creep analysis with multiple stress loads

Perform MSCR test using AR rheometer with Navigator Script

TA Rheology Navigator is a programming tool. People can write their own script to control the instrument and the data analysis software. After installing the rheology navigator, one can also find some existing scripts that are provided by TA Instruments for certain specific asphalt analysis. All the available asphalt-testing scripts are listed in figure 7. The newly published MSCR test is included in the list.

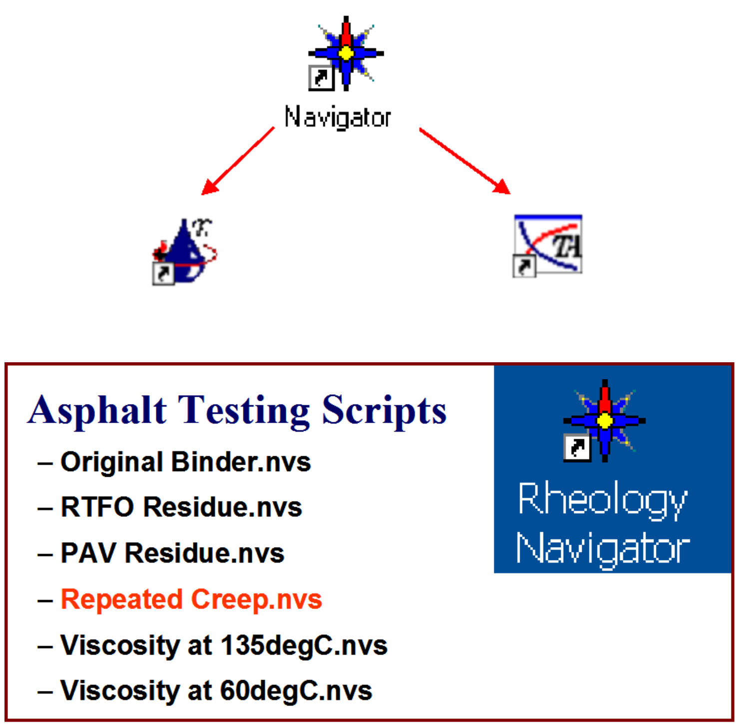


Figure 7 Available asphalt-testing scripts in Rheology Navigator

One benefit of using the Rheology Navigator script for asphalt analysis is that the operator does not have to be experienced in rheology. One can just choose the right test script, and then simply follow the command shown on the computer screen. The script will control the instrument so that it performs the test using the published standard conditions, and will also control the data analysis software for the results analysis. At the end of the test, the results can be automatically saved or printed out for documentation (e.g. figure 4).

References

[1] ASTM standards:

D6373 Specification for performance graded asphalt binder

D7175 Standard test method for determining the rheological properties of asphalt binder using a dynamic shear rheometer

D6521 Standard practice for accelerated aging of asphalt binder using a pressurized aging vessel (PAV)

[2] AASHTO standards:

T315 Standard test method for determining the rheological properties of asphalt binder using a dynamic shear rheometer

M320 Standard specification for performance-graded asphalt binder